ENERGY IN ICELAND

HISTORICAL PERSPECTIVE, PRESENT STATUS, FUTURE OUTLOOK

Second edition

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Cover photo: Oddur Sigurdsson, Snowdrifts in the outwash plain at the Kverkjokull outlet glacier.
Back page photo: Oddur Sigurdsson, Iron oxide precipitate from a mineral spring in the Canyon of Markarfljot.
Printing: Gudjon O
Second edition, September 2006
First published in February 2004
ISBN: 9979-68-198-5

UMHVERFISMERKI
141 381
Prentað efni

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National Energy Authority and Ministries of Industry and Commerce
September 2006

FOREWORD BY THE MINISTER OF INDUSTRY AND COMMERCE

During the last century, Iceland proceeded from being one of the poorest nations in the western world to enjoying one of the highest living standards in the world. There are of course, many reasons for this development, but our renewable energy resources – used in a sustainable manner – have played an important role. As a result electricity generation in Iceland is entirely from domestic energy resources, and nearly all buildings are heated with domestic energy, mainly geothermal heat.

Today, approximately 71% of the country's total primary energy is renewable energy, which is unique in the world. Nevertheless, the aim is to improve on this figure with the long-term goal of Iceland becoming self-sufficient for all its energy needs, using its own renewable resources.

Three years ago, the Ministries of Industry and Commerce and the National Energy Authority (Orkustofnun) first published the booklet *Energy in Iceland*. The booklet immediately proved to be a valuable reference on Iceland's energy resources.

In the foreword to the first publication, my predecessor expressed the intention of presenting similar reviews at two to three-year intervals. Due to the keen interest from abroad in energy affairs in Iceland, as well as the warm welcome this information booklet has received, it was obvious that the second edition was due.

This edition is similar to the previous one. It contains a historical summary of energy affairs in Iceland, as well as sections on the country's energy resources, energy use, regulatory structure, energy efficiency and prospects for the future.

I hope you will find *Energy in Iceland* both informative and enjoyable to read.

Jón Sigurðsson
Minister of Industry and Commerce

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1 INTRODUCTION

Oddur Sigurðsson

A geothermal area near Hrafntinnusker in mid-Iceland.

During the past century, Iceland transformed itself from an impoverished nation to a land of plenty. Harnessing domestic energy and the availability of energy resources for industrial and public consumption played a major role in this development. It was, in fact, a precondition for economic development.

There were a number of stages along the way to prosperity, most notably the mechanization of fisheries, and later agriculture, and the development of a communications infrastructure. These advancements were followed by the development of general utilities, electrification of towns and rural areas, and the creation of geothermal district heating services. Thanks to the latter, most Icelanders enjoy inexpensive heat from geothermal sources.

Around the middle of the 20th century, efforts to utilize the country's energy resources for power intensive industry began. The largest single effort was the construction of the Alusuisse aluminum plant, ISAL, (owned by Alcan since 2000) in Straumsvik, just south of Reykjavik, in 1969. The hydroelectric power was harnessed from a glacial river in the Burfell power station. As the end of the 20th century approached, a new era dawned with the growth of Iceland's power intensive industry. That growth continues today. Electricity production was 8.7 TWh in 2005 and is expected to increase to approximately 14.6 TWh in 2008, a 70% rise. This increased production is mainly due to the needs of the aluminum industry. The annual aluminum production was 275 kilotons in 2005 but is estimated to increase to 726 kilotons in 2008.

While the importation and distribution of fossil fuels in Iceland have always been in the hands of private enterprises, power production and the distribution of electricity and geothermal energy have almost completely remained in the public domain, or been carried out by publicly owned corporations. The entire organization and legal framework surrounding energy use was, until recently, built around this structure. In 2003, a new electricity act was adopted, introducing competition to the generation and sale of electricity. Furthermore, a new act regulating district heating is planned 2007.

This booklet concentrates primarily on a general overview of Icelandic energy affairs, generation of energy and its utilization, commencing with a brief historical overview.

2 HISTORICAL OVERVIEW OF ENERGY AFFAIRS

National Museum of Iceland

The first car came to Iceland in 1904. Until then the Icelandic horse had been the only mode of land transport for people and goods.

The beginning of energy use

Due to the scarcity of wood, the most widely used fuels in Iceland until the mid-20th century were peat and dried sheep-dung, used for cooking and heating. Horses provided transport, and natural hot springs were sometimes used for bathing and washing. Energy utilization in the modern sense, however, only started with the industrial revolution and the advent of mechanical power. Here, as in so many other areas, Icelanders were latecomers to the scene. The age of mechanization did not start in Iceland until the turn of the 20th century with the arrival of steam trawlers, motor-powered fishing boats and later automobiles. At that time the first hydropower generators were being built and people experimented with piping, through which geothermal steam flowed to heat their houses.

All this took place without much intervention of public authorities. During electrification, and the subsequent construction of district heating installations, however, the state and local communities played a major role. The first government initiative concerning energy appeared in the form of legislation on various aspects of energy affairs in the early 20th century. In particular, the Inland Waters Act, adopted in 1923, is still in force to a large extent. It was regarded as both a necessary and natural step for the government to take the initiative in the utilization of domestic resources, both by carrying out exploration for potential energy resources, and through direct participation in developing energy production and distribution facilities.

The utilization of hydropower and later geothermal power increased steadily in the past century, to more than 70% of the primary energy use in Iceland, while fossil fuels must be imported.

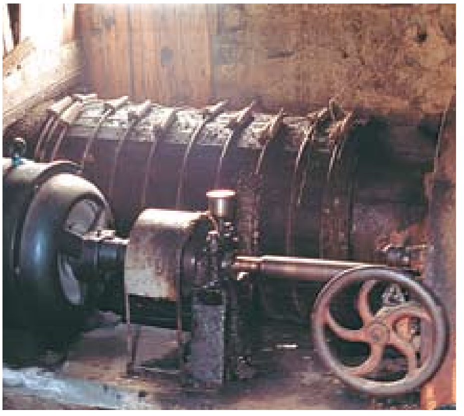
The days of peat are long gone; peat has not been produced in Iceland since the early 1960s. Now, Icelanders keep warm with geothermal heat, run utilities on hydroelectric power and geothermal steam, and drive cars fueled by imported petroleum.

Electricity production and the first power stations

Electric power was produced for the first time in Iceland in 1899, but the first hydropower turbine began operation in 1904. The 9 kW generator was located in Hafnarfjordur (near Reykjavik) and served the innovator's workshop – he was a carpenter – his household and a few additional houses, in effect being Iceland's first rudimentary power distribution network. In the following years, many small plants were built and by 1934 there were 38 power stations with an installed capacity of about 5 MW total. The majority of these were hydropower stations, but a few of them were kerosene fuelled stations.

During the following decades increased electrification, and development of the distribution system took place in the urban areas. The Electricity Act of 1946 provided for the establishment of the State Electricity Authority (Raforkumalaskrifstofan), which was established in 1947. Among the responsibilities of the State Electricity Authority was to electrify the rural areas of the country and be responsible for hydrological surveys. The development of the State Fertilizer Plant (Aburdarverksmidjan) in 1953 kicked off the power intensive industry, which has had a strong impact on the development of electric power. In this period, the only other power intensive industry was the State Cement Plant (Sementsverksmidja rikisins), which commenced operations in 1958. Around 1960, an effort was made to research for potential hydropower stations to boost the power intensive industry. In 1956 an assessment of the possibilities of hydro power plants in two Icelandic rivers was made. As a result of that survey, the construction of the Burfell hydroelectric plant began in 1965, and by 1972 the first glacial river power plant in Iceland was fully operational.

The majority of the power was sold to the ISAL aluminum plant, the first of its kind in Iceland. Meanwhile, local development continued and an effort was made in the mid-seventies to connect Iceland's individual distribution systems. By 1984, all major power stations were connected to a central grid. By then every region had access to hydroelectric power, and diesel power stations, for the most part, became reserve



Oddur Sigurðsson

A hydropower station in South Iceland. The station was rebuilt in the 1940s and is still in use!

units. Today, existing diesel power stations are almost exclusively used for backup power in cases of breakdowns at other power stations or in the distribution system.

Iceland began experimenting with generating electricity using geothermal steam in 1944 at Reykjakot, a farm north of the small village of Hveragerdi. A small turbine was employed but the electricity generation was on a very small scale. In 1969, the first commercial geothermal steam turbine was connected to a high temperature geothermal well in Bjarnarflag, North Iceland, and by 2005 geothermal power stations produced 19% of the total electricity generated in Iceland.

Geothermal utilization

The first settlers of Iceland utilized hot springs, both for bathing and washing. However, modern use of geothermal energy didn't start until in the early twentieth century. Today, Iceland's geothermal resources account for over half of the country's primary energy needs.

In the late 19th century, experiments with utilizing geothermal energy in market gardening were initiated; and in the early 20th century geothermal resources were first used to heat greenhouses. At about that time, Icelanders began to utilize geothermal energy to heat swimming pools and buildings. Today, space heating is the largest component of geothermal energy use.

The utilization of geothermal energy for space heating on a large scale began with the laying of hot water pipes from the hot springs of Laugardalur in Reykjavik, in the 1930s. These pipes carried hot water to two primary schools, a swimming pool, the main hospital and 60 family homes. The formal operations of Reykjavik District Heating, now part of Reykjavik Energy, started in 1943. Following the oil price hikes of the 1970s, the government took the initiative by promoting the expansion of district heating utilities, and as a result the share of geothermal energy used for space heating increased from 43% in 1970 to 83% in 1984 and 89% by 2005. This development is illustrated in Figure 1.

Fuel production and use

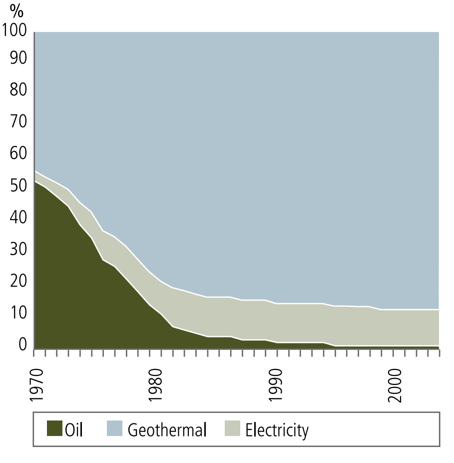
Imported fuels are a major component in Iceland´s energy budget. According to trade statistics, coal was first imported early in the 17th century, but there is no mention of petroleum imports until 1867. Neither of these energy sources was, however, imported to a significant extent until the past century. The harnessing of natural energy sources and Iceland's electrification took place decades later than in neighbouring countries, although Iceland was ahead in the utilization of geothermal energy.

Peat production ceased during the early 1960s and was replaced by coal and oil, imported for space heating purposes. Since the mid-20th century and until methane refining was implemented at a city waste yard in 2000, no fuel was produced in Iceland. In 2003 a hydrogen fuel station was constructed as a part of an international demonstration project. Methane and hydrogen production are small scale. Methane production in Iceland has the potential capacity to power about 4,000 small cars, or 20 buses, but so far refined methane has mostly been used to produce electricity. Methane used thus far for fuel has powered approximately 50 cars and 2 buses. Meanwhile, the hydrogen fuel station has been used to service and produce hydrogen for 3 buses.


Helga Barðadóttir

Construction at Karahnjukar power plant.

Figure 1. **Space heating by source 1970–2005.**



Recent developments in production

Electricity production has been mostly constant from 2000 to 2005, although it is increasing slightly. Currently, the country's largest hydropower plant is being constructed and two more geothermal power plants will soon be added. Together with the expansion of an existing geothermal power plant (in 2005), the electricity production in Iceland is expected to increase by 70% from 2005 to 2007.

3 ENERGY RESOURCES


Oddur Sigurðsson

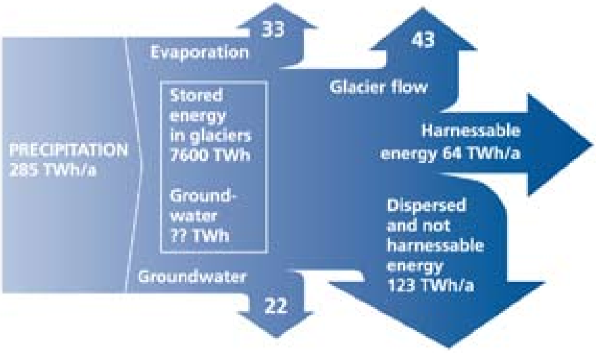
A mudpool.

Energy reserves

Iceland has abundant renewable energy resources, both geothermal and hydro. Despite the fact that Iceland possesses extensive unexploited renewable energy resources, they are not unlimited. Only rough estimates are available on the size of Iceland's energy reserves. Therefore, there is considerable uncertainty involved in assessing to what extent they can be harnessed with regards to what is technically feasible, cost-efficient, and environmentally desirable. The estimated figures generally proposed for hydropower are 30 TWh annually. For electricity production from geothermal resources the figure is 20 TWh annually, giving a total of 50 TWh per year. These estimates do not include resources that are unlikely to be developed for environmental reasons or due to prohibitive cost. The estimate, however, does include resources that are currently being utilized.

It should, however, be noted that environmental desirability estimates are subjective, and the 30 TWh figure quoted above for hydropower might be an overstatement. On the other hand, with technological advances in the harnessing of geothermal power for the production of electricity, it is likely that the 20 TWh figure is understated. The net result, 50 TWh per year, can therefore be considered a reasonable estimate. One of the objectives of the so-called Framework Programme for utilization of Hydro and Geothermal Energy Resources, discussed further in chapter 5, is to evaluate these resources in more detail.

Figure 2. **Hydropower derived from precipitation in Iceland.**



Hydropower

Iceland's precipitation has an enormous energy potential. Much of it is stored in ice caps and groundwater, and dissipated by evaporation, groundwater flow and glacier flow. In addition, about one-half of the total rainfall is widely distributed, not precipitating in one area, and therefore does not end up as a useful energy source. However, almost one-quarter remains, from which it is considered technically possible to produce 64 TWh annually. As previously mentioned, it is generally estimated that less than one-half of this energy can be utilized in a cost-effective and environmentally friendly manner, taking into account the experience of other countries in recent decades. Figure 2 shows the primary hydropower resources in Iceland.

The hydropower plants in Iceland have been mainly concentrated in the most densely populated southwestern part of the country. The two aluminum plants, ISAL and Century Aluminum (Nordural), are situated near the capital. The Karahnjukar power plant, currently being constructed in the eastern part of the country, is 690 MW and will add substantially to the country's electricity production, see Figure 3. It will serve the aluminum plant Alcoa Fjardaal, situated in Reydarfjordur.

Geothermal power

The geothermal resources in Iceland are closely associated with the country's volcanism, and its location on the Mid-Atlantic Ridge.

The high-temperature resources are located within Iceland's active volcanic zone, running from the southwest to the northeast of the country, while the low-temperature resources are mainly located in areas flanking the active zone. There are over 600

Figure 3. **Installed capacity of the main hydropower plants.**

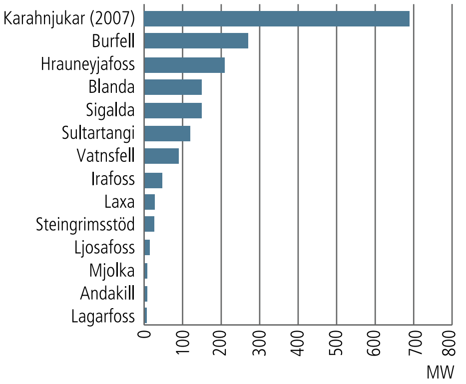
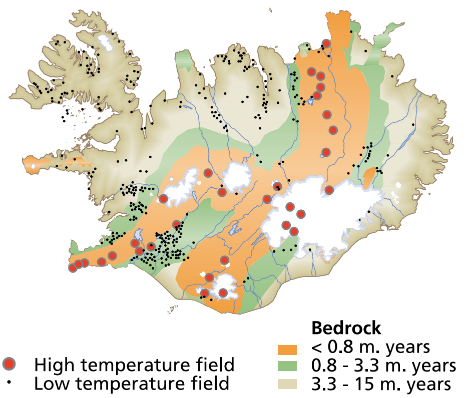


Figure 4. **High and low temperature geothermal areas.**



hot water springs in 250 low-temperature fields, and 32 active high-temperature fields have been identified.

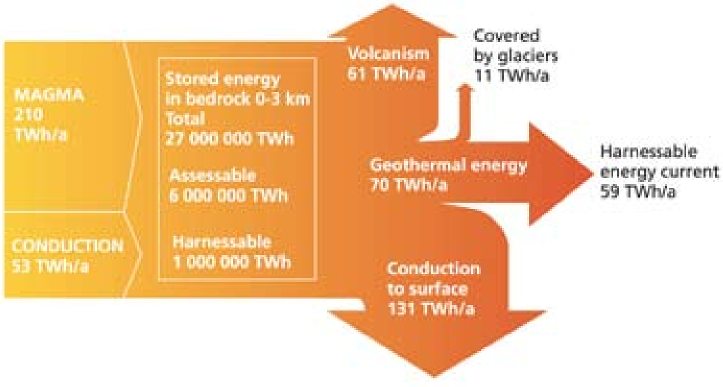
Geothermal energy is generally classified as a renewable resource. This is based on the fact that geothermal sources are steadily renewed, although this renewal takes place at a varying rate depending upon the nature of the geothermal reservoir. Energy production from hot dry rock, which is not practiced in Iceland, is solely dependent on the energy source, i.e. the heat current from the earth which is so slow that compared to the time scale of human activity it cannot be considered as a renewable energy source. All other geothermal production is dependent on the energy carrier, i.e. hot water or steam, and sustainable production can be maintained with proper management. Figure 5 shows the estimated source of Iceland's primary geothermal power.

The utilization of geothermal resources takes place across the country. Over the years, drilling projects in so-called cold areas have successfully increased the number of municipalities that are able to receive hot water for house heating. Geothermal utilization has greatly increased in recent years, not least due to the increased capacity for generating electrical power. Figure 6 shows the installed capacity of geothermal power plants combined with plants under construction.

High and low temperature

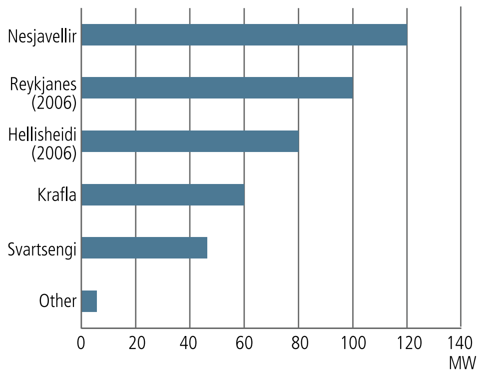
In low temperature geothermal systems, temperatures in the uppermost 1,000 m may reach up to 150°C. In the high temperature fields, on the other hand, temperatures reach over 200°C at 1,000 m depth. High temperature geothermal areas are found within the active volcanic zone of Iceland, see Figure 4.

Figure 5. **Terrestrial energy current through the crust of Iceland.**



In 2005, geothermal plants generated 19% of the total 8.7 TWh electricity produced. In 2009, the total production is predicted to be about 14.6 TWh, 20% of which is expected to be generated by geothermal plants.

Figure 6. **Installed capacity of Iceland's primary geothermal power plants.**



Fossil resources

In Iceland, fossil resources are scarce. There are large areas of peat land, covering about 3% of total land area. This resource, however, has not been utilized since the early 1960s. Iceland also has resources of lignite. The seams are thin and ash content is generally high because of the frequent eruptions during the period of lignite formation. The lignite is therefore classified as second grade and has not been utilized since the late 1950s. Iceland has no known resources of crude oil, oil shale, bitumen, natural gas or uranium. Iceland has not cultivated trees or other biomass for energy purposes but in earlier centuries charcoal was produced in many farms and fuel wood was prepared from driftwood in some parts of the country.

Cold areas

Areas in Iceland, where no sign of geothermal heat is found on the surface, are called cold areas.

It has been speculated that oil might be found inside Iceland's economic zone. An Act was passed in 2001 on prospecting, exploration and production of hydrocarbons.

4 ENERGY USE

Primary energy use in international context

By international comparison, the energy use in Iceland is in a class by itself. Per capita energy consumption is among the highest known and the proportion of this, provided by renewable energy sources, is greater than in other countries. Nowhere else does geothermal energy play a greater role in a nation's energy supply, as Iceland is among those nations with the highest relative utilization of this energy resource. In addition to geothermal energy, Iceland's energy supply is based on hydro power and imported fossil fuels. The share of domestic renewable energy sources has grown significantly in recent decades and in 2005 amounted to over 71% of total energy consumption. Table 1 shows the consumption of primary energy in Iceland 2005.

In 2005, primary energy consumption amounted to about 500 GJ per capita, which ranks among the highest in the world. There are a number of reasons for this, in particular, the high proportion of electricity used in Iceland's power intensive industry, and substantial energy consumption for fishing and transportation. In addition, more energy is required for space heating than in most other countries due to the cold climate.

Calculating primary energy

According to standard calculating methods, primary energy consumed in producing electricity from geothermal energy is ten times the electricity produced, which means that the efficiency of the generation process is 10% if no heat is returned to the geothermal reservoir by injection of the effluent water. When electricity is generated by hydropower, however, primary energy is calculated as equal to the electricity generated. This shows that primary energy does not necessarily give an accurate picture of how much energy is generated by power plants. When geothermal energy is utilized directly for heating, as for instance in district heating utilities, there are no international standard methods for calculating primary energy. In Iceland, primary energy has been calculated as the energy extracted by cooling the water to 15°C.

Almost 29% of primary energy in Iceland is imported and a little over 71% is domestic, renewable energy. Figure 7 shows the development of energy use in Iceland since 1940. The impact of rising oil prices in the 1970s can clearly be seen. The price hikes served to accelerate the development of geothermal heating systems in Iceland. Coal is used in the ferrosilicon and cement industry, but the major share of imported petroleum products is used for fishing and transportation. It has not been technically feasible to utilize domestic energy in these sectors of the economy. This, however, may change in the future, with increased use of hybrid cars, plug in hybrids and if hydrogen used as an energy carrier becomes a reality.

In Figures 8 and 9, the primary energy use in Iceland is compared to that in the rest of the world. The unique position of Iceland, in terms of renewable energy, is evident.

Geothermal energy use

The utilization of geothermal energy has been important since Iceland's settlement, but in modern times geothermal energy has played an increasingly important role in Icelandic energy affairs. From space heating to swimming pools, snow melting and electricity production, geothermal energy is now an indispensable part of every Icelander's life.

Figure 10 gives a breakdown of the utilization of geothermal energy in 2005. The figure shows net energy utilized rather than primary energy. Estimated total supply of geothermal primary energy is around 85 PJ.

Space heating

Geothermal energy is used mainly for space heating in Iceland. Geothermal space heating is the most common in Icelandic build-

Table 1. **Consumption of primary energy in Iceland, 2005.**

	PJ	ktoe	%
Hydro	25.2	603	16.3
Geothermal	85.0	2,030	54.9
Petroleum products	40.1	958	25.9
Coal	4.6	109	3.0
Total	154.9	3,700	100

PJ: petajoule, 10^{15} Joule
ktoe: kilotons of oil equivalent
1 ktoe = 0.041868 PJ = 11.63 GWh

Figure 7. **Primary energy consumption in Iceland, 1940–2005.**

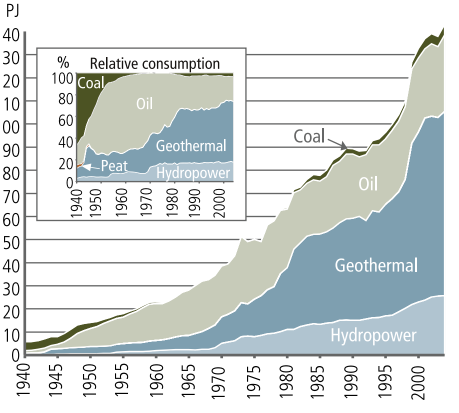
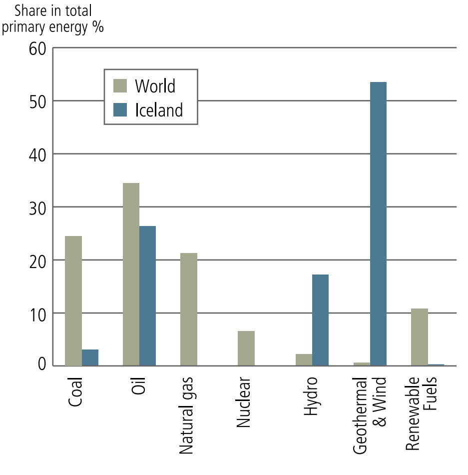
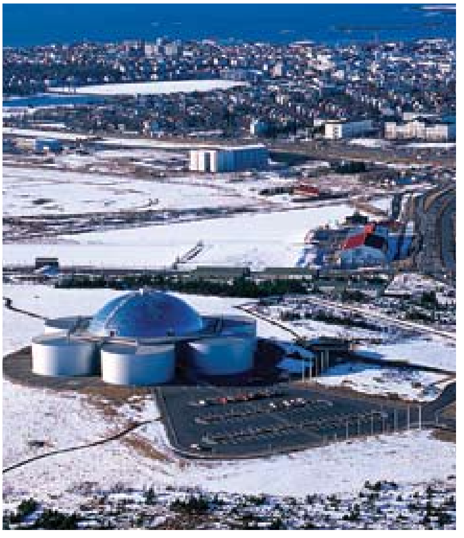


Figure 8. **World primary energy supply compared to Icelandic primary energy supply in 2003.**





Oddur Sigurðsson

Heated parking space at Perlan, Reykjavik.

ings; in 2005 it accounted for 89%. The remainder of the buildings is heated by electricity, 10%, and oil, 1%. The evolution of the space heating market is shown in Figure 1.

In recent years, the increased utilization of geothermal energy for space heating is a result of the population increase in the capital area. Existing heating utilities have been expanding and taking over small utilities. In addition, a number of small heating utilities have been established in rural areas. A major heating utility located in Eskifjordur, East Iceland, will be completed in 2006.

There are some 200 small, rural utilities in Iceland. As a result of changing settlement patterns, and the continuing search for geothermal sources in the so-called cold areas of Iceland, the share of geothermal energy in space heating can be expected to exceed 90% in the near future.

Snow melting

During the past two decades, geothermal energy has been increasingly used to melt snow from streets and pavements in the urban areas. In 2005, the total area of snow melting systems installed in Iceland is estimated to be around 835,000 m^2, and the systems' annual energy consumption is approximately 360 GWh. Over half of this energy is retour water from space heating systems.

During the winter months in Iceland, it is not uncommon to see pavement and walkways outside public or private buildings clear of snow. This is due to the snow melting systems installed underneath the sidewalks.

UNU Geothermal Training Programme

In 1978, the United Nations University Geothermal Training Programme was established with Iceland's National Energy Authority as the host institution. The purpose of the programme is to help developing countries with considerable geothermal potential to build groups of specialists on geothermal exploration and sustainable development. The programme annually offers specialized training in various fields of geothermal studies. In 2005, 338 scientists and engineers from 39 countries had completed training in the six month specialized courses that are offered. UNU-GTP graduates are, in many countries, among the leading specialists in geothermal research and development.

Electricity production

The demand for electricity in Iceland has increased considerably due to a large expansion within the power intensive industry. This demand has partially been met through increased electricity produced geothermally, as is shown in Figure 11. Of the total electricity generation of 8,680 GWh in 2005, 1,658 GWh, or 19.1%, were produced from geothermal energy.

The first geothermal power plant with 3 MW installed power started operations in 1969, in Bjarnarflag, North Iceland. The plant is still operating.

The Krafla power plant in North Iceland has been operating since 1977. For the first 20 years its installed power was 30 MW. In the early stages, volcanic activity caused a delay in the completion of the plant originally planned to its capacity. However, the capacity was increased to 60 MW in 1997. As a result of drilling exploration projects over the years, the area's estimated potential capacity has increased, so a further increase of 40 MW is under consideration.

The Svartsengi co-generation power plant has been producing both hot water and electricity since it started operations in 1977. It is located on the Reykjanes peninsula, 40 km from Reykjavik, and serves about 16,000 people.

The installed capacity for electricity production in Svartsengi is 47 MW, and an expansion of 30 MW is planned. Furthermore, a 100 MW power plant at Reykjanes is under construction by Hitaveita Sudurnesja.

At the Nesjavellir high-temperature field, Reykjavik Energy is operating a co-generation plant. The plant started operations in 1990 with the production of hot water for

Figure 9. **Primary energy use in Iceland compared to that in the rest of the world, calculated in ktoe, 2003.**

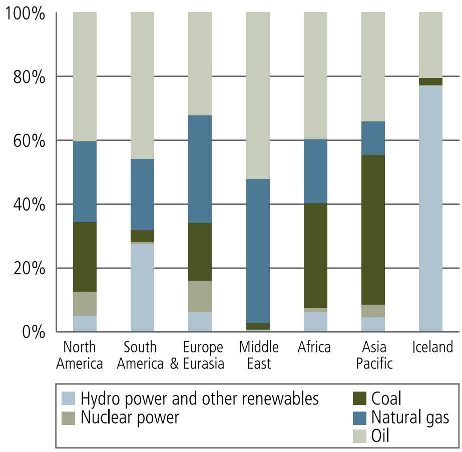
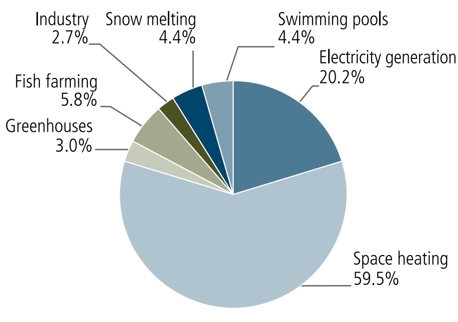


Figure 10. **Utilization of geothermal energy in Iceland, 2005.**



The silica rich geothermal seawater in the Blue Lagoon comes from the Svartsengi geothermal power plant.

the Reykjavik area, 27 km away. At the end of 1998, the power plant started generating electricity, with 60 MW installed capacity. An expansion of the plant to 90 MW was completed in 2001 and another to 120 MW in 2005. The company also has a geothermal power plant under construction at Hellisheidi in South Iceland. The installed capacity will be 80 MW in 2006, but is expected to be gradually expanded to 190 MW in 2008.

A 690 MW hydropower plant is under construction in Karahnjukar, Northeast Iceland. The plant will start operations in 2007.

At Husavik, in Northeast Iceland, a low-temperature geothermal field began generating electricity in 2000, when one of the first Kalina binary-fluid 2 MW generators in the world was put into service. This generator utilizes hot water which is cooled from 120°C to 80°C. The electricity generated is sufficient to satisfy more than half the electricity demand of the town. The 80°C water from the power plant is subsequently used for district heating. The total installed capacity of hydro and geothermal power plants is shown in Figure 12.

Industry

The seaweed product manufacturer Thorverk, at Reykholar in West Iceland, uses geothermal heat directly for its production. The plant produces 2,000–4,000 tons of rockweed and kelp meal annually, using 28 l/s of 107°C hot water for its production.

Search for geothermal areas

The state subsidizes space heating in areas where geothermal resources have not been identified. Since 1998 the Ministry of Industry has been running a program to encourage geothermal exploration for domestic heating in cold areas. Geothermal exploration can be expensive and somewhat risky, but a new exploration technique, drilling 50–100 m deep thermal gradient exploration wells, has proven successful. As a result of this program, more than 10 local heating utilities were planned, and many were already commissioned by 2006. Each heating utility serves from 4 to 1,000 people, totaling over 3,000 people.

Since 1986, a facility at Haedarendi in Grimsnes, South Iceland, has produced carbon dioxide (CO_2) from geothermal fluid. The plant uses approx. 6 l/s of fluid and produces some 2,000 tons of CO_2 annually. The product is used in greenhouses, for manufacturing carbonated beverages and in other food industries.

Geothermal heat is also used to dry fish in many areas in Iceland.

Fish farming

In recent years, geothermal energy has been used to a considerable extent in aquaculture. Despite a reduction in the number of fish farming operations, total production has increased, and is estimated to have been around 8,800 tons of round fish in 2005. Geothermal energy is a primary source of energy in smolt farming.

Greenhouses

Apart from space heating, one of the earliest uses of geothermal energy in Iceland was for heating greenhouses. In 2005, there was a total of 175,000 m² of greenhouse area. Of this area, almost half is used for the production of flowers and plants, and the remainder for vegetables. The increased use of electric lighting within the industry in recent years has extended the growing season and improved greenhouse utilization.

Swimming pools

There are about 160 swimming pools in Iceland, in 130 of which geothermal heat is used. While most of these pools are public, this figure also includes pools belonging to schools and other institutions. About 89% of all pools are heated by geothermal sources, 7% by electricity, and 4% by burning oil. Outdoor swimming pools account for about 76% of all pools.

Figure 11. **Installed capacity of geothermal power plants 1969–2006.**

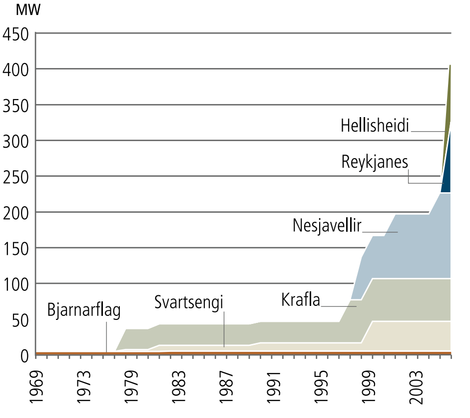


Figure 12. **Total installed capacity of hydro and geothermal power plants in Iceland.**

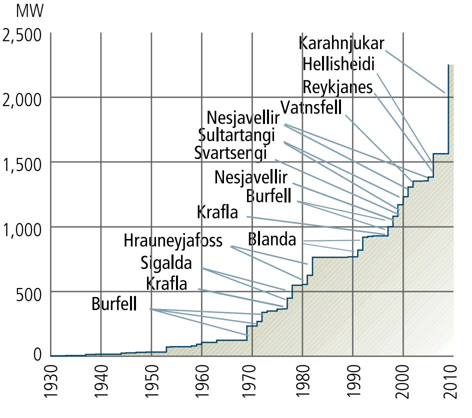
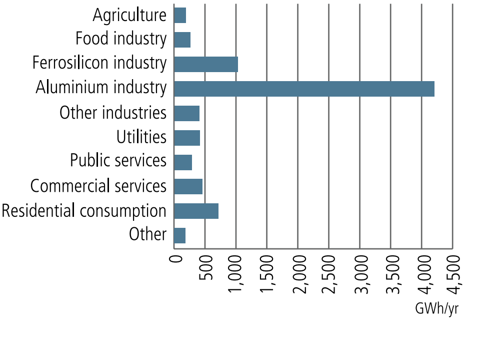


Figure 13. **Electricity consumption in 2005.**



Oddur Sigurðsson

During the Christmas holiday season, many people in Iceland decorate their houses lavishly.

Swimming pool attendance has increased in recent years. In 2005, it was estimated that on average each Icelander went to a swimming pool 16 times per year.

A new, average-sized swimming pool uses the same amount of hot water as is needed to heat 80–100 single-family dwellings.

Electricity

Figure 13 shows 2005 electricity consumptions divided into the major fields of usage. The figure clearly indicates that the use of electricity for aluminum production exceeds all other uses. This will increase dramatically in the near future.

In 2005, power intensive industry consumed approximately 62% of all electricity produced in Iceland. With the construction of a new aluminum plant planned to go online in 2007, it is predicted that by 2009 power intensive industry will consume 80% of the electricity produced in Iceland.

Other uses of electricity account for about 38% of all electricity consumed. This figure has increased by 2.8% per year over the last five years.

General domestic use of electricity, excluding electrical heating, has increased beyond expectations, according to electricity statistics from the Icelandic Energy Forecast Committee (Orkuspárnefnd), published in 2005.

Over the last decade, general domestic use has increased from 3.5 MWh/home to 4.4 MWh/home per year. General home usage is expected to increase by 2% annually over the next decade.

The main reasons for the added increase over the last few years are that the number of electrical appliances, such as TVs and computers, has increased substantially. Another reason is that the relative importance of electricity in household budgets has decreased, so there has been little incentive to save energy.

In industry, other than power intensive industry, the use of electricity has for the most part increased in service areas such as retail stores, but in the public sector, the need to power schools and gym halls has also caused an increase in the use of electricity.

Power intensive industry

The development of energy resources for use in power intensive industry got off to a relatively late start in Iceland. While major rivers in the Nordic countries and continental Europe were harnessed as an energy resource, rivers and geothermal regions in Iceland remained untouched, with the exception of a few small hydroelectric generating plants, which local authorities built to provide electricity to the general public through local distribution grids.

The power industry's pioneering venture was the construction of Aburdarverksmidjan, the State Fertilizer Plant at Gufunes in Reykjavik, which started operations in 1953. The plant is now out of commission. At the beginning of the 1960s, an extensive discussion took place on the need to diversify exports and to utilize the country's energy resources. At this time, exports were almost exclusively based on fishing and fish processing. Under these circumstances, it was only natural to look to other natural resources, the country's untapped energy potential.

The aluminum industry, which was growing rapidly at the time, was an attractive option. Following a number of investigations and discussions with several foreign aluminum producers, the Icelandic government signed an agreement with the Swiss company Alusuisse in 1966 for the construction of an aluminum plant (ISAL) with an annual production capacity of 60,000 tons. Iceland would construct a hydropower plant to provide power for the production. Following this agreement's conclusion, the first stage of the Burfell power plant, with a capacity of 110 MW, was put into service in 1969. Today the installed capacity is 270 MW, after several upgrades.

Figure 14. **Consumption of petroleum in Iceland, both domestic and transportation to and from the country, 1982–2004.**

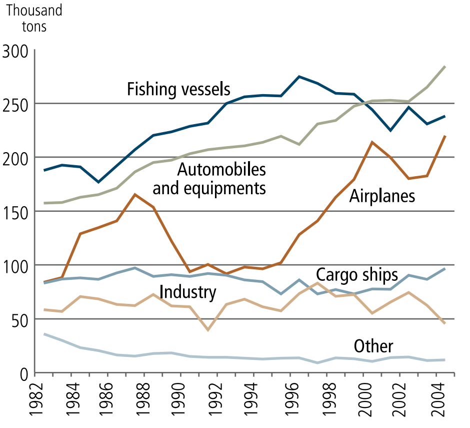


Figure 15. **Relative share of CO_2 equivalent emissions in Iceland, 2003.**

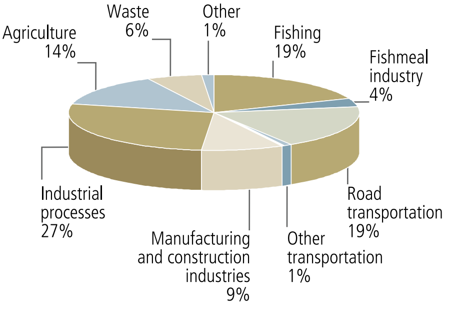


Table 2. **Imported fuel in 2005.**

	kilotons
Coal products	**150**
Hard coal	117
Coal coke	33
Petroleum products	**985**
Gasoline	164
Kerosene	139
Gasoil	418
Fuel oil	63
Liquefied petroleum gas	2
Petroleum coke	147
Other petroleum prods.	51

In 1970, the first year that the ISAL plant was operating at full capacity, Iceland's power intensive industry consumed almost half of all electricity produced. That same year, the diatomite plant Kisilidjan hf. was established to process diatomite from the lakebed of Lake Myvatn. Access to a steady supply of geothermal energy made the plant internationally competitive. In 1975, the Icelandic government, in cooperation with some other governments, established Icelandic Alloys Ltd. (Islenska jarnblendifelagid), a ferrosilicon plant. In 1999 the plant was expanded, and annual production increased from 70,000 to 115,000 tons.

Efforts to increase the power intensive industry during the 1980s were unsuccessful, especially due to a depressed aluminum market. It was not until 1995 that the market began to improve, and move in the direction of developing further energy-intensive industrial projects. Since 1995, this development has been rapid.

Construction of the Nordic Aluminum plant (Nordural) at Grundartangi, West Iceland, started in 1997, and the plant went online in 1998. The plant was commissioned by Columbia Ventures Corporation but Century Aluminum bought Nordic Aluminum in 2004. Initially, the plant produced 60,000 tons annually. In a second phase, which became operational in 2001, the plant was expanded and its annual production capacity increased to 90,000 tons. Further expansion in 2006 will increase the annual production capacity to 220,000 tons. In 1997, an expansion of the ISAL plant in Straumsvik was also completed, and the annual production capacity of that plant brought to 162,000 tons.

Demand for electricity needed to support power intensive industry has grown substantially, and decisions have been made to greatly increase aluminum production in Iceland during the first decade of the 21st century. This includes the construction of an aluminum plant in Reydarfjordur with an annual production capacity of approximately 322,000 tons, as well as the expansion of Nordic Aluminum at Grundartangi to produce as much as 300,000 tons. Further expansion of the Alcan plant to produce 200,000 tons annually is also under consideration.

House heating subsidies

Electricity for residential heating has been subsidized by the state and energy enterprises since 1982. The purpose is to equalize the cost of residential space heating throughout Iceland. The main requirement to receive a subsidy is when a building is considered a residential dwelling and if utilization of geothermal energy is either impossible or uneconomical.

Fuels

Traditional fuels

Table 2 shows imported fuel in 2005 by fuel categories and Figure 14 shows the development of Icelanders' oil usage from 1982. The usage is divided into five main categories: vehicles, aeroplanes, fishing vessels, transportation vessels, and industry. The numbers include domestic usage as well as that for international transport, and the fuel purchased abroad by Icelandair, the country's major airline. This amounts to about 60% of the entire fuel consumption. Since 1982, the increase in oil consumption has been 1.7% per year. About 90% of the oil consumption in 2004 was by transportation and fishing. Of the total oil consumption, which in 2004 was 909 kilotons, domestic consumption was 604 kilotons and international transport consumption for Icelandic companies was 306 kilotons. Most of the oil categorized as other in Figure 14 was used for heating.

Coal consumption amounted to 150 kilotons in 2005. By far the largest consumer was the ferrosilicon plant in Grundartangi, which uses about 90% of Iceland's coal imports. The second largest user is Iceland Cement Ltd.

The use of liquid gas is negligible compared to the rest of the fuels, or about 2 kilotons in 2005. Nonetheless, gas usage has increased in recent years, primarily due to power intensive industry where 35% of the country's total gas is consumed. Other usage can be divided as follows: home usage, 35%, services, 21% and 9% are used in light industry.

Due to the probable impact of greenhouse gases on climate, the nations of the world have signed agreements to restrict emissions

Figure 16. **Comparison of electricity prices for households (3,500 kWh/year) in Iceland and Western Europe, January 2006.**

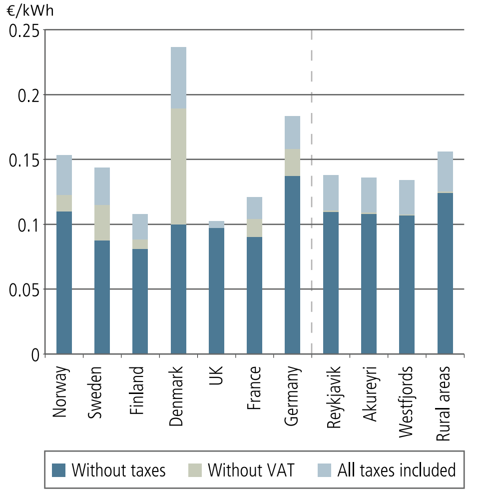
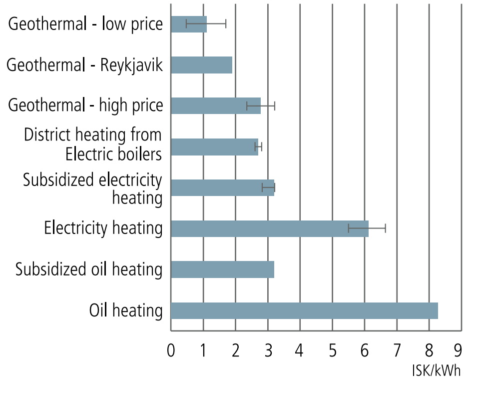


Figure 17. **Price per kWh for district heating in January 2006.**



Iceland New Energy

A hydrogen bus from the ECTOS project.

of these gases, such as the Kyoto protocol. About 71% of greenhouse gas emissions in Iceland are carbon dioxide (CO_2). By far the greatest share thereof, about 70%, is due to the burning of fossil fuels. This shows the significance of fossil fuel consumption in relation to greenhouse gas emissions. During the period 1990–2003, Iceland's total annual greenhouse gas emissions decreased from 3.3 million tons to 3.1 million tons of CO_2 equivalents annually, or by 6%. These figures do not include emissions from the international transport of goods and passengers, in accordance with international rules, nor do they include figures falling under the so-called Icelandic clause in the Kyoto protocol, see Figure 15. The figure shows the relative share of CO_2 equivalent emissions in Iceland in 2003.

Alternative fuels

The collection of methane from a waste yard started in 1997. In 2000, the production of vehicle fuel from refining of the methane started. The methane collected is mostly used to generate electricity, which in 2005 reached 4.2 GWh. The fuel produced amounted to 55,000 m^3 in 2005, and was used to power 46 small flexible fuel vehicles plus 2 heavy-duty vehicles. In 2005, two public buses were added, and in 2006 it is estimated that the amount of methane used as fuel for vehicles will increase 5 or 6 fold with the addition of at least 10 small vehicles, and 2 heavy-duty vehicles.

Three hydrogen buses have constituted a part of the public transport system for some years, and hydrogen has been produced in one filling station. The international demonstration project, ECTOS, led by Icelandic New Energy, was renewed in 2006, so the buses will run until 2007.

Iceland's production of alternative fuels is expected to increase over the long term. Iceland is self-sufficient regarding electricity and heating, and becoming self-sufficient regarding fuel is economically as well as environmentally desirable.

Energy prices

Electricity prices

Electricity prices in Iceland are similar to those in other Scandinavian countries, and Western Europe. The price for power is generally lower in Iceland, but the distribution and transmission costs are higher. Figure 16 compares electricity prices of four of Iceland's major electric companies to prices in various European countries, at the beginning of 2006.

Prices for space heating

Real prices for hot water and space heating vary significantly, depending on the energy source. Utilization of geothermal energy is in general the cheapest, but becomes more expensive with deeper boreholes, and longer pipelines. Other sources of space heating are electricity and fuel. Fuel is used in a few regions where there is no access to electricity other than that which is generated from diesel oil. The price difference can be seen in Figure 17.

Fuel prices

As all fossil fuel in Iceland is imported, pretax prices tend to be higher than in OECD. This may at least partially be explained by the small amount imported, combined with long transportation routes. Prices for gasoline and diesel oil have been rising and becoming increasingly volatile as international market prices have soared. Figure 18 compares the price of gasoline in Iceland to that of other countries.

By the end of 2005, taxes constituted about 59% of the gas price in Iceland, of which VAT was about 20%, see Figure 19.

Figure 18. **Prices of gasoline at end of 2005. Unleaded premium (95 RON) for Europe; regular unleaded for Canada, Japan and the United States.**

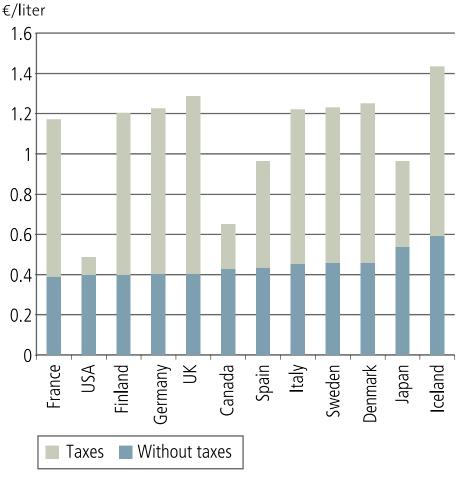
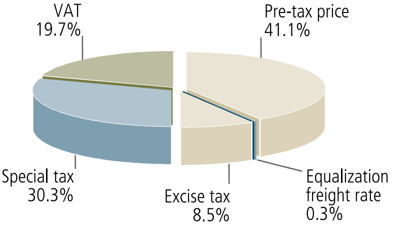


Figure 19. **Composition of gasoline price at the end of year 2005.**



5 REGULATORY STRUCTURE

Oddur Sigurðsson

Yellow roses in a greenhouse. Many greenhouses use geothermal heat and artificial lighting to extend the growing season.

Legislation on electrical energy

The Electricity Act, No. 65/2003, based on EU Directive No. 96/92 was enacted in mid-2003. The Act includes aspects of the Inland Waters Act, No. 15/1923; the Energy Act, No. 58/1967; the Act on Electric Generating Stations, No. 60/1981; and Acts on individual energy enterprises. The objective of the Electricity Act is to encourage an economical electricity system, thereby strengthening Icelandic industry and regional development. In addition, the Act is intended to create a competitive environment for the generation and sale of electricity, foster efficiency and cost-effective transmission and distribution of electricity, ensure the security of the electricity system and the interests of its consumers, and promote utilization of renewable energy sources.

In accordance with the Electricity Act, Landsnet, a limited liability company, was established to provide the electrical transmission and system operation services. The com-

The Electricity Act of 2003

The 2003 Electricity Act creates a competitive environment for the generation and sale of electricity. The transmission and distribution of the electricity is on a non-competitive basis.

pany commenced operation in early 2005, and is responsible for the transmission and system operation services of its predecessor, National Power Company (Landsvirkjun), which is the biggest shareholder with 70%. Other owners of Landsnet include the Icelandic State Electricity (Rafmagnsveitur rikisins), 24%, and the Westfjords Power Company (Orkubu Vestfjarda), 6%. The aforementioned companies released their transmission system lines and equipment to Landsnet as equity. This amalgamation enlarged the previous transmission system by approximately 43%, resulting in greater equalization in transmission cost for many customers, especially those residing in remote areas of the country. Landsnet may operate an electricity market if it maintains separate accounts.

The National Energy Authority (Orkustofnun) is responsible for supervising the transmission and distribution enterprises, and the establishment of income caps for the enterprises' tariffs.

The National Energy Authority is to supervise concession activities, i.e. the transmission and distribution of electricity, while the generation and sale of electricity is under the surveillance of the competition authorities, just like any other competitive activity.

A special Appeals Committee on Electricity is to examine any disputes arising from the National Energy Authority's administrative decisions.

The Energy Act contains other general provisions on how licenses are granted, other procedures, tariffs, and miscellaneous provisions relating to how accounts must be kept separate.

Fossil fuels in Icelandic territory

In 2001 the Icelandic parliament adopted an Act on the exploration for and production of fossil fuels in Icelandic territory. Based on the general laws, the Icelandic government has decided that a more detailed set of rules on licensing the search for and exploitation of oil shall be prepared and completed in 2007. On behalf of the Ministry of Industry, the National Energy Authority is entrusted with the supervision of matters concerning fossil fuels.

Framework Programme for Utilization of Hydro and Geothermal Energy Resources

In 1999, the government took the initiative to reassess Iceland's potential for electricity development, and created a Framework Programme for Utilization of Hydro and Geothermal Energy Resources. The objective of the Framework Programme is to

Oddur Sigurðsson

The Ferrosilicon plant and aluminum plant at Grundartangi.

evaluate and compare various power development proposals, and discuss their respective impacts on: the environment, natural and cultural heritage, other resources, and regional development.

First, preliminary assessment can help the authorities to plan the utilization of the resources. It will also reveal project locations where the protection value is high and legislative protection is desirable. Thirdly, an early assessment is helpful to land-use planners. This assessment will not replace the detailed assessment required by legislation for environmental impact assessment.

Technically feasible hydroelectric power plants are estimated to number about 70 and technically feasible geothermal power plants between 30 and 40. The conclusions for phase one, which includes 19 hydropower projects and 24 geothermal plants in 10 geothermal areas were submitted in the fall of 2003. The National Association for the Protection of the Icelandic Environment (Landvernd), was entrusted with consulting power companies, associations, and the public, and disseminating information through public meetings and a website for the Framework Programme.

A second project evaluation phase was initiated in 2004 with the goal of presenting a new comparative list of projects by early 2009. These would be new projects in previously unexplored areas, as well as revised projects in areas considered during the first phase. The emphasis in this phase is on projects that require developing high temperature fields, as well as on improvements in the precipitation run-off map that facilitate decisions on the development of small hydro power projects.

Advisory groups are working on improvements in the methodology applied to evaluating energy potential and the landscape and wilderness at stake in the development of high temperature fields. A progress report on this work will be presented in early 2007 (see www.os.is/page/english).

The Framework Programme

The objective of the Framework Programme is to evaluate and compare various power development proposals and to discuss their potential impact on the environment, natural and cultural heritage, and regional development. The conclusions of the first phase were submitted in the fall of 2003. A second phase was initiated in 2004, the results of which are expected in 2009.

6 ENERGY EFFICIENCY

General usage


Oddur Sigurðsson

High-voltage transmission line.

Iceland is rich in clean, renewable energy sources, and the primary focus has been on how to increase their efficient utilization. To obtain energy efficiency the aim is to reduce energy consumption through the use of more efficient appliances and equipment.

Icelandic households use a considerable amount of energy, and there is ample potentiality to lower the energy bill for most consumers. Low-priced energy, especially geothermal heating, has led to a lack of awareness about rational use of energy among households. About 10% of households in Iceland use electricity for space heating, which is subsidized by the authorities. Prices are subsidized to make the cost similar to that of geothermal heating. Increased energy efficiency in these areas decreases the cost for both the state and the consumers.

The energy consumption in the fisheries and transport is high, and almost primarily dependent on imported fossil fuels. Energy saving is the most immediate and cost-effective manner to reduce greenhouse gas emissions in these sectors. The National Energy Authority has promoted several projects to analyze the energy use and potential for increased efficiency in households and industry.

Energy agency

A step towards bringing attention to energy efficiency was taken at the end of 2005, when the first energy agency in Iceland was established, located in Akureyri, North Iceland. The agency is supported by EU and is fully autonomous and run by a management board.

The primary objectives of the agency are to provide consumers and public authorities with information in the field of energy efficiency and promote rational use of energy for space heating, putting emphasis on areas where geothermal energy is limited. In addition, the agency assists in creating and promoting educational material for schools and consumers, as well as small and medium sized companies. The agency helps facilitate energy efficiency strategies for municipalities, and helps promote fossil fuel reduction in the transport section.

Heat pumps

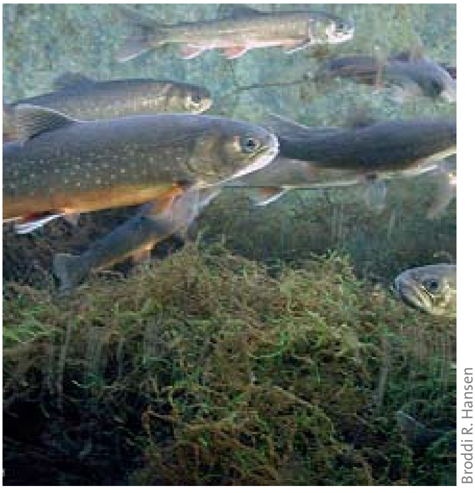
Heat pumps, which use renewable heat sources, offer the most energy-efficient way to provide heating and cooling in a variety of situations. In some cases useful heat is obtained from sources that are normally considered cold, such as cool air, earth and water. Heat pumps are increasingly being used, especially in the Nordic countries, where space heating is necessary for most of the year.

Heat pumps could be economic for places that have access to geothermal heat sources, which are not hot enough for direct use in space heating. In some of these cases, a heat pump could raise the temperature of the medium to the necessary level, thus making heat pumps an interesting alternative in cold areas.

Akureyri District Heating, now Nordurorka, used two large heat pumps from 1984 to 2004. In 2004 new boreholes made the heat pumps redundant.

The National Energy Authority commissioned a survey on the feasibility of heat pumps in Iceland, and a report was published in late 2005. The results of the survey showed that heat pumps are a strong option for space heating in places where no heating utilities exist (but e.a. lukewarm geothermal springs).

Pilot project in fish farming



Arctic char.

The use of energy in land-based aquaculture is substantial and can comprise between 5 and 10 percent of production costs due to the electrical power use for pumping, and the geothermal energy necessary for heating fish farming water. The overall electricity use is around 37 GWh/year, and the use per kilo of fish produced is roughly 7.1 kWh/kg.

Better water and energy management can reduce this cost, and the National Energy Authority supports a project to design and test a RAS (Recirculating Aquacultural System) for the production of Arctic char. The two phases of the project are system design and construction of a pilot plant. The plant, which produces 500 MTons/year, is designed to utilize available natural resources.

The objective of this project is to design the most cost-effective culture system for Arctic char, and to verify the design by a pilot scale run.

7 LOOKING TO THE FUTURE

Jónas Erlendsson

A swimming pool in Vik, South Iceland.

Policy objectives

The government's policy is to harness Iceland's clean and renewable energy reserves, geothermal and hydropower, for sustainable development, and to further improve the living standards in the country. Use of clean energy sources contributes to the reduction of carbon dioxide emissions.

The option of exporting power via a submarine cable has been studied on and off since the early 1950s. This type of export is now considered technically feasible, but still remains on the margin of becoming economically feasible. The cost of electricity would double if it is transported from Iceland to the continent of Europe. This fact favours the policy of producing power intensive products domestically for export.

Production of alternative fuels has also been studied for decades. Studies in the early 1990s indicated that the production and use of alternative fuels was not economically viable.

The situation may be somewhat different today, mainly due to progress in fuel cell technology, but many innovations and improvements are needed before hydrogen or other alternative fuels can replace oil in the energy system. During the past few years the discussion on alternative fuels in Iceland has mainly focussed on hydrogen as an energy carrier. In 1999, VistOrka, an Icelandic private company, together with DaimlerChrysler, Norsk Hydro and Shell International, signed a joint venture agreement on co-operation in this area. These companies are the owners of the resultant company, Icelandic New Energy (Islensk NyOrka). Even though the government is not a party to the agreement it made the following statement on that occasion:

> It is the government's policy to promote increased utilization of renewable energy resources in harmony with the environment. One possible approach towards this goal is production of environmentally friendly fuels for powering vehicles and fishing vessels. Liquid hydrogen is an example of such a fuel. The establishment of a company owned by Icelandic parties and several international corporate leaders in the field of hydrogen fuel technology could open up new opportunities in this field.
>
> The government of Iceland welcomes the establishment of this company by these parties and considers that the choice of location for this project is an acknowledgement of Iceland's distinctive status and long-term potential. The initiative taken by the parties involved in this project deserves to be applauded and respected.

Deep drilling

In 2000, the Iceland Deep Drilling Project (IDDP), an Icelandic energy consortium, was established. The IDDP is run by three energy companies along with the National Energy Authority and Iceland Geosurvey (Islenskar Orkurannsoknir). The purpose of the IDDP project is to study the economic feasibility of extracting energy and chemicals from hydrothermal systems at supercritical conditions. An advanced drilling technology is needed to study the supercritical hydrous fluid, as well as a novel fluid handling and evaluation system.

One of the IDDP's aims is the drilling into a high-temperature hydrothermal system, of a 4–5 km deep drill-hole, which is currently being prepared. Located at a rifted plate margin on a mid-ocean ridge, the drill-hole is expected to reach a 400–600°C hot supercritical hydrous fluid.

The IDDP is not considered as an alternative solution to meet short-term, future energy demands, but is rather seen as a long-term research and development project, which will take at least a decade to conclude. Among the potential benefits of this project are an increased power output per well, development of an environmentally benign energy source beneath currently producing geothermal fields, and an extended lifetime of the exploited geothermal reservoirs.

A Forum on Alternative Fuels

At the beginning of 2004, the government initiated a project named A Forum on Alternative Fuels, based at the National Energy Authority. The purpose of the forum is to encourage and advance more efficient energy use in areas where fossil fuels are currently being used, and increase the use of environmentally friendly energy carriers where possible. The forum is expected to coordinate the government's aims and responses in this category. Furthermore, delivering information, both to the government and the public, is an important function of the forum.

A panel made up of representatives from six ministries head the forum. The ministries involved are: Ministry of Industry, Ministry of Finance, Ministry for Foreign Affairs, Ministry of Communications, Ministry for the Environment and Ministry of Fisheries. The representative from the Ministry of Industry leads the panel.

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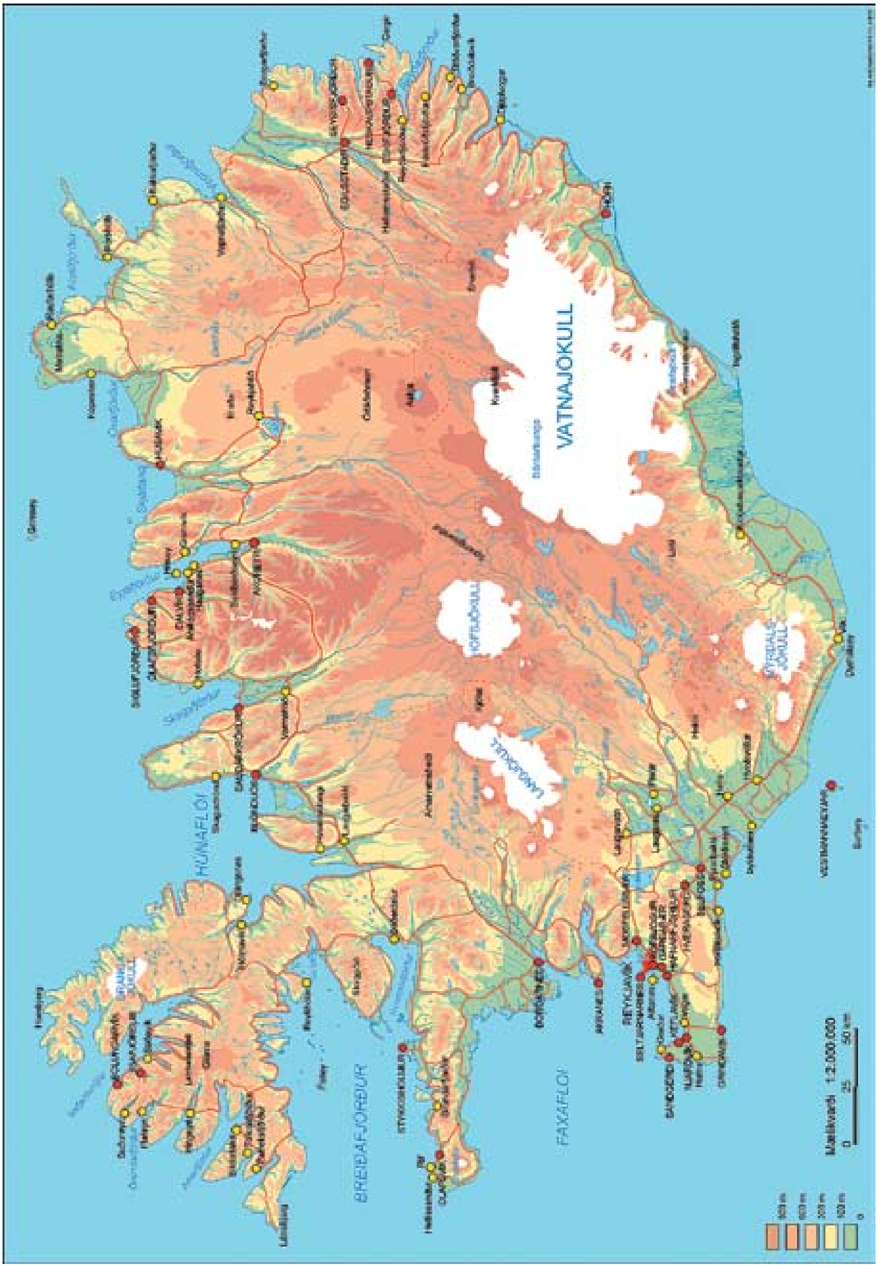
Figure 20. **Map of Iceland.**



MINISTRIES OF
INDUSTRY AND COMMERCE

ORKUSTOFNUN
National Energy Authority

September 2006