# GEOTHERMAL ENERGY IN ICELAND

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## INTRODUCTION

The annual primary energy supply in Iceland, which has a population of 268,000, is 98,000 TJ (T = $10^{12}$) or 366 GJ per capita, which is among the highest in the world. Geothermal energy provides about 48.8% of the total, hydropower 17.2%, oil 31.5% and coal 2.5%. The main use of geothermal energy is for space heating. About 85% of all houses are heated with geothermal energy; the rest are heated mainly by electricity. So far, geothermal resources have only, to a limited extent, been used for electric power generation, because of the availability of relatively cheap hydropower resources. Of the total electricity production of 5,000 GWh in 1995, only 288 GWh or 5.8% came from geothermal energy, 94% from hydro and 0.2% from fuels.

Figure 1 shows the annual primary energy supply in the period 1940-1995, classified by energy sources. Direct uses of geothermal energy (Table 1) are calculated as used energy based on an estimated temperature drop for each utilization sector.

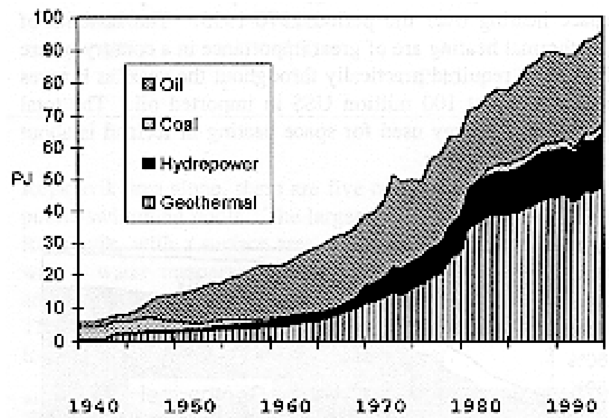


**Figure 1. Primary energy supply in Iceland 1940-1995, classified by energy sources (excluding aircraft and ship refueling outside Iceland).**

**Table 1. Summary Table of Geothermal Direct Heat Uses**

| | Installed Thermal Power $MW_t$ | Energy Use TJ/yr |
|---|---|---|
| Space Heating | 1,150 | 16,300 |
| Bathing and Swimming | 60 | 1,000 |
| Greenhouses | 45 | 830 |
| Fish and Other Animal Farming | 25 | 630 |
| Industrial Process Heat | 105 | 2,000 |
| Snow Melting | 55 | 380 |
| Subtotal | 1,440 | 21,140 |
| Heat Pumps | 3 | 18 |
| Total | 1,443 | 21,158 |

## SPACE HEATING

The main use of geothermal energy in Iceland is for space heating. In 1970 about 50% of the population was served by geothermal district heating systems. After the oil crisis in the 1970s, replacing imported oil with indigenous energy sources (geothermal and hydro) received high priority. Today about 85% of the space heating is by geothermal energy, the rest is by electricity (12%) and oil (3%). Figure 2 shows how geothermal energy has replaced imported oil for space heating over the period 1970-1995. The benefits of geothermal heating are of great importance in a country where heating is required practically throughout the year, as it saves annually about 100 million US$ in imported oil. The total geothermal energy used for space heating in Iceland is about 16,300 TJ per year.

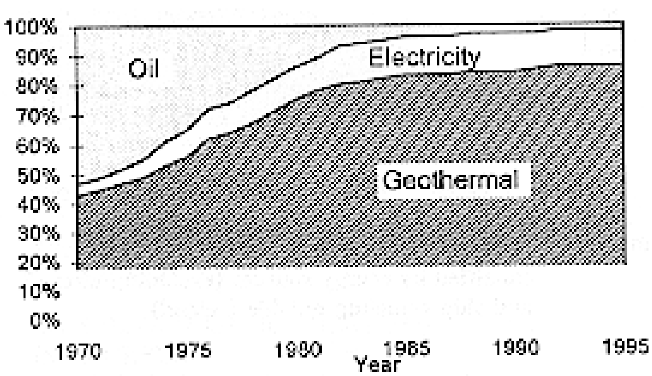


**Figure 2. Space heating market by sources 1970-1995.**

There are now 27 municipally-owned geothermal district heating services in Iceland. By far, the largest one is the Reykjavik Municipal District Heating (Hitaveita Reykjavikur) which had it's beginning in 1930. Today, it serves about 150,000 people, or 99.8% of the population in Reykjavik and five neighboring communities (see Table 2).

**Table 2. Reykjavik Municipal District Heating Service 1995**

| | |
|---|---|
| Number of people served | 147,740 |
| Volume of houses served | 39,478,000 $m^3$ |
| Water temperature at user end | 75°C |
| Number of wells in use | 57 |
| Installed capacity | 640 $MW_t$ |
| Total pipe length | 1,179 km |
| Water delivered | 59,650,000 $m^3$/year |

The only Icelandic district heating system using heat pumps is in Akureyri. Two heat pumps, 1.3 MWth each, were installed in 1984. They extract heat from part of the return water from the district heating system at 35°C and boost another part of the return water to 80°. They provide about 5% of the total energy production. The 10-year experience with the heat pump units has shown them to be satisfactory, both from technical and economical points of view.

Over the last decade, many district heating systems have been built in rural areas with low-population densities. These single-pipe systems typically serve 10 to 20 farms that can be one to three kilometers apart. These systems serve about 4,000 inhabitants and the total pipe length is about 900 km, or 225 m per person, compared to 12 m in towns. In most cases, plastic pipes are used. They are made in Iceland of polypropylene or polybutylene and have diameters ranging from 25 to 110 mm. The insulation consists of 4-m long sections of polyurethane "sandwiches," which are strapped to the pipe in the field after unrolling the pipe. The installation of these pipelines is simple and is often performed by the farmers themselves. Each farmer receives a certain maximum flow, typically 15 liters per minute, that he can freely use throughout the year.

Experience in Iceland to date shows that plastic pipes can be used for moderate pressure water at temperatures up to at least 85°C. At higher temperatures, the risk of pipe damage increases considerably. It is important to keep the water pressure low, due to temperature and pressure limitations of the plastic, and to keep the pipe wall, and thereby material costs, as thin as possible. Compared to the traditional pre-insulated steel pipes, the main advantages of plastic pipes are the relatively low piping costs, easy installations and no corrosion effects on plastic pipes. The main disadvantages are the low limits on water pressure and temperature, rapid increase in pipe cost with increased pressure and pipe diameter, corrosion of radiators because of oxygen diffusing through the plastic pipe walls and high heat loss, especially during wet weather.

Two systems for selling the geothermal water are in general use, by water meter or by subscription. Most commonly, the user pays a fixed-annual charge and a price for each cubic meter of water used as measured by a water meter. The other system is based on maximum flow restriction; where, the user pays a fixed annual charge and a price related to the maximum flow rate that is equal to the expected demand during the coldest winter period. As most of the systems are direct through-flow systems, conventional energy metering is not suitable, because it would not encourage the users to maximize the heat extracted from the water before it goes to waste (the sewer system). Over the past few years, most of the systems which earlier used maximum flow restriction have changed their tariff systems to water meters. The main reason for this is that the old system did not encourage the users to cut back the flow outside the coldest winter months. Where this change of tariff system has been completed, it has resulted in 20-35% reduction in annual water consumption. As a result, the drawdown in the geothermal reservoir exploited has been reduced and money has been saved by delaying the need for additional drilling or development of new geothermal fields.

Increased attention has been paid to the influence of large-scale production of hot water or steam on the geothermal systems. In several geothermal systems, the water level

**Table 3. Effects of Exploitation on Six Geothermal Reservoirs in Iceland**

| Geothermal Systems | Production Starts | Average Production kG/s | Water Temperature °C | Drawdown m | Cooling °C |
|---|---|---|---|---|---|
| Laugarnes | 1930 | 160 | 127 | 130 | 0 |
| Reykir | 1944 | 920 | 64-100 | 100 | 0/13 |
| Hamar | 1970 | 24 | 64 | 35 | 0 |
| Svartsengi | 1976 | 260 | 240 | 210 | 0 |
| S-Laugaland | 1976 | 42 | 95 | 350 | 0 |
| Urridavatn | 1980 | 19 | 75 | 35 | 2/15 |

continues to drop and in other instances, cold water is starting to invade the systems. The latter may cause changes in both the temperature and the chemical content of the water produced. Lowering the water level and temperature are factors that limit the potential of a geothermal system. Table 3 gives a few examples of these effects on geothermal reservoirs being exploited.

As the effects of hot water production on the reservoirs have become clearer, the district heating services have paid more attention to monitoring of the geothermal fields. During the past five years, the National Energy Authority (NEA) has developed and installed data logging systems at 12 sites for field monitoring. The parameters logged are: water temperature, drawdown, and flow rate from each well. The data is automatically transferred to NEA where it is used for monitoring and for reservoir engineering studies.

Another area receiving increased attention in recent years is the environmental impact of geothermal projects. According to a new Icelandic environmental law, all geothermal development exceeding 25 $MW_e$ gross production, or 10 $MW_e$ net production, have to submit a detailed appraisal of the environmental impacts. The National Energy Authority has, since 1991, been working on a research project in this field in cooperation with some of the largest geothermal companies. A study of all the high-temperature geothermal areas under utilization has been initiated. Several unexploited areas are being studied for comparison. Pollution of air by hydrogen sulphide ($H_2S$) emission and the groundwater by power plant effluents are among the influences considered, as well as thermal pollution and land subsidence.

**SWIMMING POOLS**

From the time of settlement of Iceland some 1,100 years ago until early in this century, the utilization of geothermal resources in Iceland was limited to bathing, washing and cooking. Today, these uses are still important and heating of swimming pools is among the largest segments, after district heating. There are 120 public swimming pools heated by geothermal energy with a combined surface area of 25,000 $m^2$. Most of them are outdoors and in use throughout the year. They are both for recreational use and for swimming instruction, which is compulsory in the primary schools. In general, swimming is a very popular pastime in Iceland and in the Reykjavik area alone, there are five outdoor and three indoor public swimming pools. The largest pool is Laugardaslaug in Reykjavik, with a surface area of 1,500 $m^2$ and five hot tubs with a water temperature ranging from 35 to 42°C. The annual water consumption of Laugardaslaug is 460,000 $m^3$. The total geothermal energy used in swimming pools in Iceland is estimated to be 1,000 TJ per year.

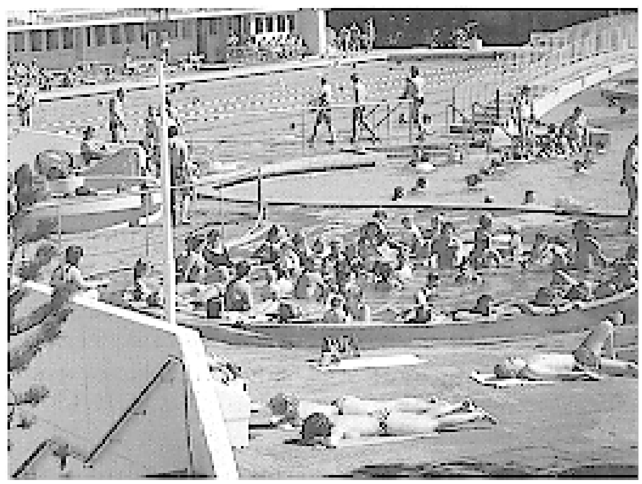

**Figure 3. Laugardaslaug swimming pool in Reykjavik.**

**SNOW MELTING**

The use of geothermal energy for snow melting has been widespread for the past 10-15 years. This kind of utilization gained popularity when plastic pipes for hot water were introduced in the market. Spent water from the houses, at about 35 °, is commonly used for deicing of sidewalks and parking spaces. During the last few years, the extension of snow melting systems has expanded considerably. The total area now covered by snow melting systems is estimated to be 350,000 $m^2$, of which about 250,000 $m^2$ are in Reykjavik. Extensive rehabilitation of the streets in downtown Reykjavik has been undertaken during the past five years. One improvement was to install snow melting systems, covering an area of 50,000 $m^2$, in the sidewalks and streets. This system is designed for a heat output of 180 W per $m^2$ surface area. The annual energy consumption is of course strongly dependent on the weather conditions. Measurements from Reykjavik's center has shown the energy consumption to be 250 kWh/m$^2$-375 kWh/m$^2$ (Jónsson, 1994). The total energy use for snow melting is estimated to be 380 TJ per year.

**INDUSTRIAL USES**

Kísilidjan, the Diatomite plant at Mývatn, near the Námafjall high-temperature field, is among the largest industrial users of geothermal steam in the world. The plant has been in operation since 1967, and the annual production has been between 20,000-30,000 tons of diatomite filter aid which is exported. The raw material is diatomaceous earth taken from deposits on the bottom of Lake Mývatn. After a period with decreasing production, the productivity of the factory has been increased considerably over the last three years. This resulted in a production of 28,100 tons in 1995, which is close to the capacity of the factory. The process requires about 220,000 tons annually of geothermal steam at 10 bar absolute (180$^o$C). This corresponds to an energy use of 515 TJ per year.

At Keykhólar, a seaweed processing plant uses geothermal water for drying. About 28 l/s of 107$^o$ C hot water are used and cooled down to 55$^o$C. The annual use of geothermal energy in the plant is about 150 TJ.

On the Reykjarnes Peninsula, a salt pilot plant was in operation for more than twenty years, but was closed down in 1994 due to bankruptcy. From geothermal brine and sea water, the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export. The annual use of steam was about 400,000 tons at 10 bar absolute (180$^o$C), which corresponds to an energy use of 813 TJ per year. Recently, this plant reopened and is now recrystallizing coarse salt into fine grain mineral salts used in bathing (Saga Salt).

Several small companies use geothermal water for industrial purposes, most of them buying their water from the district heating services around the country. A new survey indicates that 10% of the total energy delivered by the district heating services is used for industrial purposes, including space heating in the industry (Líndal, 1995).

**GREENHOUSES**

Heating of greenhouses with geothermal water began in 1920. Before that time, naturally warm soil had been used for growing of potatoes and other vegetables. Over the past few years, the use of artificial lighting has gained popularity and has extended the growing season to nine months. The total

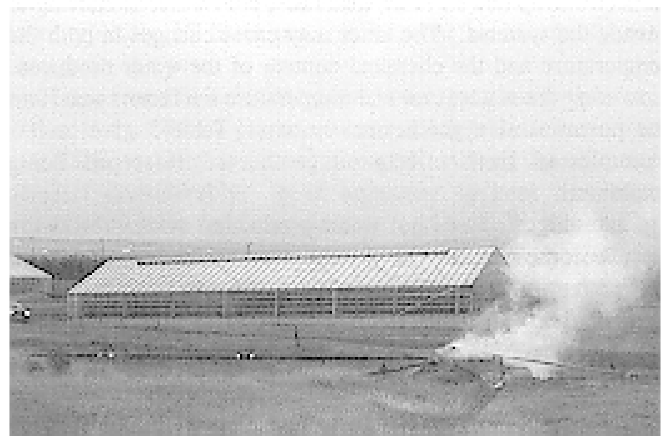

**Figure 5. Greenhouse at Reykholt in western Iceland. Note heating pipes mounted on the wall.**

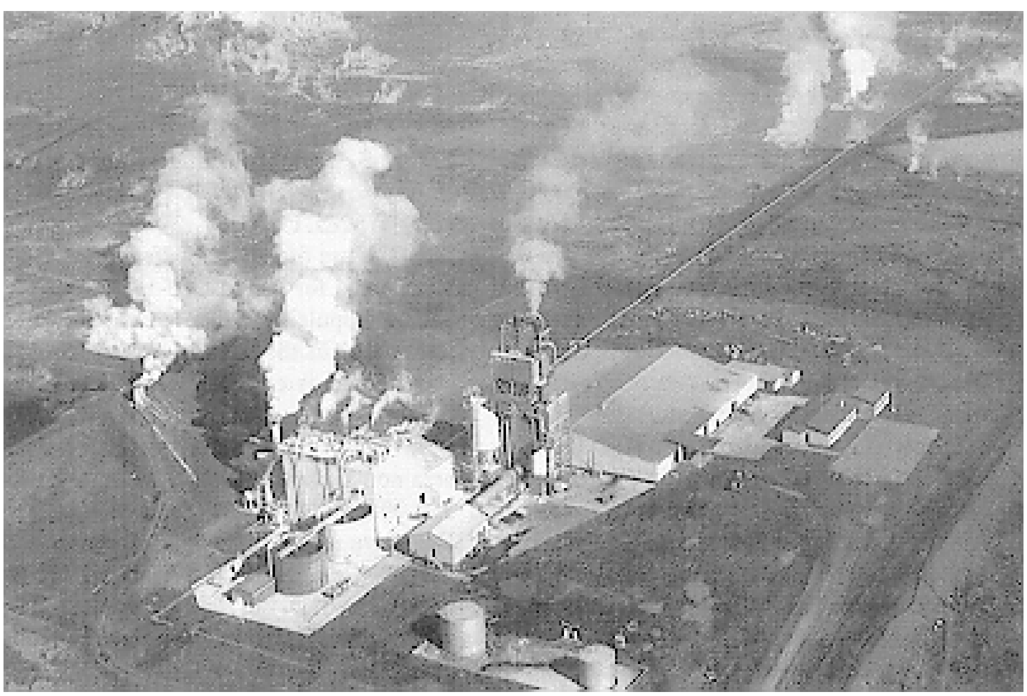

**Figure 4. The Kisilidjan diatomite plant is Iceland's largest industrial user of geothermal energy.**

area under glass has increased over the years to 175,000 $m^2$, and 105,000 $m^2$ of soil is heated by pipes buried in the ground. Tomatoes, cucumbers, paprika, etc., are the most popular crops and greenhouses also supply most of the flowers for the domestic market. The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 830 TJ per year.

## FISH FARMING

In the middle of the 1980s, an explosive growth in fish farming took place and over 120 land-based aquaculture complexes were built. Salmon is the main species, but arctic char and trout have also been raised. This industry has had financial difficulties and many of the farms have gone into bankruptcy, mainly the large installations. Because of this, the anticipated increase in geothermal utilization in the fish-farming sector did not materialize. At present, there are 70 farms in operation. Many of them use geothermal hot water to heat 4-6ºC freshwater to approximately 12ºC, the ideal temperature for rapid development of fish smolt. The total geothermal energy used in the fish-farming sector in Iceland is estimated to be 630 TJ per year.

## GEOTHERMAL ELECTRIC POWER GENERATION

Geothermal resources have only to a limited extent been used for electric power generation in Iceland, because of the availability of relatively cheap hydropower. Geothermal power is produced for the national grid at three high-temperature areas: Bjamarflag, Krafla and Svartsengi.

The first geothermal power plant was built in 1969 when a 3-$MW_e$ back-pressure turbine was installed in Bjamarflag (Námafjall field). This field also supplies steam to the Kísilidjan diatomite plant. The power plant has been operated successfully ever since the beginning 25 years ago. The reservoir temperature is about 280ºC. Steam is separated from the water at 9.5 bar absolute to provide a steam flow rate of 12.5 kg/s to a single-flash turbine. The total electrical production of the Bjamarflag power plant in 1995 was 11.5 GWh.

The Krafla power plant, located about 10 km north of the Námafjall field, has been in operation since 1977. Two units, 30 $MW_e$ each, were purchased but only one of them was installed because of inadequate steam supply. The shortfall of steam was in part due to volcanic activity in the area. At the end of 1975, while the plant was under construction, a volcanic eruption started only 1-2 km from the drilling area. The immediate effect of the eruption was a contamination of the geothermal fluids by the volcanic gases. This caused operational problems in some of the production wells, mostly in the form of rapid scaling of complex iron silicates and also corrosion in the wells. Recent exploration drilling has shown that the concentration of magmatic gases in the steam has decreased drastically. Surface lava flows and earthquakes did not harm the installations. The plant has operated successfully with one unit in spite of nine eruptions, the last one in September 1984. Initially, the power production was 8 $MW_e$, but reached the present 30 $MW_e$ in 1982. The plant is shut down for four months every summer as there is abundant hydropower due to high river flows from snow melt. The production reservoir zone has a temperature of about 210ºC. Steam is separated from the water in two stages, at 7.7 and 2.2 bar absolute, to provide 60 kg/s high-pressure steam and 15 kg/s of low-pressure steam. The installed unit has a double flash condensing turbine, which in 1995 had a total electrical production of 170 Gwh.

The Svartsengi power plant is a co-generation plant, which produces both hot water for district heating and electricity. It is located on the Reykjanes peninsula, about 40 km from Reykjavik. The system was commissioned 1976 and has the main purpose of providing the neighboring communities of about 15,5000 inhabitants and the airport at Keflavik with district heating. The geothermal reservoir fluid is a brine at 240ºC and with a salinity of about two-thirds of seawater. The geothermal heat is transferred to freshwater in several heat exchangers. The effluent brine is disposed of into a surface pond called the Blue Lagoon, that is popular by tourists and people suffering from psoriasis and other forms of eczema, who seek therapeutic effects from the silica-rich brine.

Three single-flash back-pressure turbines were originally installed at Svarsengi: one 6 $MW_e$ and two 1 $MW_e$. In 1989, three Ormat units were installed, each of 1.3 $MW_e$. They are binary systems using low-pressure excess steam from the back-pressure units to produce electricity in a closed organic Rankine cycle. In 1992, four additional Ormat units were

**Table 4. Utilization of Geothermal Energy for Electrical Generation in December 1995.**

| Locality | Power Plant Name | Year Commissioned | No. of Units | Type of Units | Unit Rating $MW_e$ | Total Installed Capacity $MW_e$ | Annual Energy Prod. 1995 GWH/yr |
|---|---|---|---|---|---|---|---|
| Krafla | Krafla | 1997 | 1 | 2-Flash | 30 | 30 | 170 |
| Námafjall | Námafjall | 1969 | 1 | 1-Flash | 3 | 3 | 11 |
| Svartsengi | Svartsengi | 1978 | 2 | 1-Flash | 1 | 2 | 13 |
| Svartsengi | Svartsengi | 1981 | 1 | 1-Flash | 6 | 6 | 39 |
| Svartsengi | Svartsengi | 1989/92 | 7 | Binary | 1.2 | 8.4 | 55 |
| Total | | | 12 | | | 49.4 | 288 |

installed bringing the total installed capacity to 17.1 $MW_e$. The electrical production of Svartsengi power plant in 1995 was 107 GWh.

At the salt plant on the Reykjanes peninsula, a small back-pressure turbine of 0.5 $MW_e$ is installed and provides electricity for local needs only.

At the Nesjavellir high-temperature field, Reykjavik Municipal District Heating has built a co-generation power plant, which was commissioned in 1990. The primary purpose of the plant is to provide hot water for the Reykjavik area 27 km away. It supplements the water from the low-temperature fields in the vicinity of Reykjavik which are fully exploited. Freshwater is heated by geothermal steam in heat exchangers in a similar way as in the Svartsengi power plant. The first phase of the plant was a hot water production of the capacity 100 $MW_t$. The second phase, which was for another 50 $MW_t$, went into operation in 1992. The ultimate goal is to produce 400 $MW_t$ for space heating and 80 $MW_e$ for electric generation.

## EXPLORATION ACTIVITIES

The National Energy Authority, in cooperation with the National Power Company, Reykjavik Municipal Heating and Sudurnes District Heating, has since 1991 been working on a project, which involves exploration of high-temperature geothermal areas with respect to their potential for electricity generation. The project is based on the principle of conducting investigations simultaneously in more than one geothermal area and harnessing the area in relatively small steps. As a part of this project, surface explorations have been carried out in several geothermal fields. Many smaller studies have also been carried out in a number of low-temperature fields for district heating services.

## DRILLING ACTIVITIES

Drilling activity has been slow in Iceland for the past five years, with only two wells drilled in high-temperature areas. A good number of low-temperature wells have been drilled in this period, mainly for new projects in rural areas and for fish farms. Drilling of shallow-temperature gradient wells for exploration has also increased in recent years.

## FUTURE PLANS

About 50% of the electricity production in Iceland is consumed by energy intensive industry. An expansion of the aluminum smelter at Straumsvik, which is now under construction, will increase the total electricity demand in the country by 1000 GWh or 20%. Other possibilities for new energy intensive industry are now under consideration. They include other aluminum smelters and magnesium plant. To meet the increased demand, the second turbine unit is now being installed at Krafla power plant. This will bring the capacity of the plant up to 60 $MW_e$. Also it has been decided to start electricity production at Nesjavellir co-generation power plant in late-1998. The capacity of the plant will be 60 $MW_e$. Additional generation capacity at Svartsengi is also under consideration and a plant at Bjarnarflag is now undergoing environmental assessment. The geothermally produced electricity in the country will, thus, probably triple from the present level in a few years time.


## ACKNOWLEDGEMENT

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