Geothermal Development and Forecasting for Space Heating and Electricity Generation

Egill Benedikt Hreinsson
Department of Electrical and Computer Engineering,
University of Iceland, Hjalðarhagi 6, 107 Reykjavik, Iceland
Email: egill@hi.is

Abstract—Iceland is a country with one of the highest development of geothermal energy in the world. Geothermal energy is used expensively for space heating in the cold climate of Iceland, in addition to using it for electricity generation. The paper presents a survey of this development, current status and future prospects, both the widespread use of geothermal energy for residential space (district) heating, and its history, especially in urban communities. The phenomenally rapid development in electricity generation is also reviewed. The paper also discusses briefly the international situation in geothermal energy and describes the role of geothermal energy in the fuel substitution process in Iceland since the early 20th century. We also characterize major geothermal high temperature areas, their potential output and locations, based on the underlying geological aspects.

Furthermore, the paper presents geothermal energy forecasts and forecasting methods, in particular those published by the public Energy Forecasting Committee (EFC) with the mandate, since 1978, of forecasting future energy use, including the geothermal component.

Geothermal electricity generation’s share in world electrical generation has been approximately constant in the last two decades but grown explosively in Iceland. We review this high growth of geothermal electricity and the developed high penetration of space heating and industrial use in Iceland. This will cast light on the importance of geothermal energy in this very important “geothermal country” of Iceland in international context.

I. INTRODUCTION

Figure 1 shows the world geothermal electrical generation as a fraction of total generation, while Figure 2 shows the same relative growth process in the case of Iceland. Note the explosive relative growth of geothermal electricity generation in Iceland in recent years, as compared to the development worldwide, where the geothermal share has been relatively flat for at least the last 20 years.

These Figures are representative and reflect the unique geothermal situation in Iceland, which also ranks among the countries with highest share of geothermal energy in its electrical energy budget. Figure 3 shows this share as a percentage of total generation for several countries, where geothermal penetration is high in the electrical power system. The Figure also shows the electricity generation in absolute terms in GWh. The United States, here followed by the Philippines, Indonesia and Mexico, lead in terms of quantity.
counted in GWh per year as of 2010. However, ranking the countries when geothermal generation is compared to the total electricity generation, Iceland is at the top of the list followed by El Salvador and Kenya. Once again, Iceland’s position is therefore rather unique, as it is also generally considered a developed country, but is here surrounded by countries that may be considered to be under development.

Figure 4 shows the place of geothermal among other energy resources in the overall energy development of Iceland since before the middle of the 20th century. This includes both geothermal electricity generation and space heating, where the smaller insert in the Figure shows fractional breakdown with a marked increasing geothermal share. From the Figure, we can draw the conclusion, that the majority of gross energy use is from geothermal sources and also the renewable geothermal and hydroelectric indigenous energy resources have developed substantially in the last 30–40 years, thereby replaced imported fuel based energy.

The above Figures and conclusions cast a light on the important position geothermal energy holds in Iceland. Therefore, the purpose of this paper is threefold:

- First, to take a closer look at the geothermal development, and its position in terms of electricity generation in Iceland.
- Second, to review the economically important application of geothermal energy in district heating. This activity, which started in the early part of the 20th century, has been increasing dramatically for the last 40 years, in particular in the 1970s.
- Last but not least, we present a review of forecasts into the future made to map out the potential increased use of geothermal energy in all aspects.

Accordingly, the paper is organized as follows:

- The remainder of the introductory Section I discusses the underlying geological aspects for the geothermally rich Icelandic energy resources.
- In Section II we review the development of electricity generation by geothermal energy in Iceland.
- In Section III we review space heating and other geothermal applications in Iceland.
- In Section IV we present and discuss the most recent forecasts, as published by the official Energy Forecasting Committee (EFC) [2].
- Section V presents discussions and conclusions.
- Finally the paper is concluded with a references section.

Before embarking on the mission of the paper, as stated above, it is worthwhile to take a closer look at the basis of the geothermal development from the point of view of the geology of Iceland and the main drivers in terms of volcanic activity.

Iceland is located in the North-Atlantic ocean on the so-called Mid-Atlantic ridge, where two continental plates meet; hence its well-known volcanic activity. Figure 5 shows a map where the ridge runs through the country from the South and South-West to the North-East, as an active volcanic zone, shown as a ribbon with the darkest color. Note that to the south, this ribbon is split into two "legs". Within this zone the majority of the most active volcanoes are located.

The Figure also shows two categories of geothermal areas, high temperature fields and low temperature fields. Most of the geothermal electric plants are located on high temperature fields, but district heating may be based on low temperature wells. District heating may also be based in connection with electricity generation in a high temperature field.

When comparing Figures 5 and 6 it can be seen that generation is mostly at both ends of the ribbon, as previously mentioned. This location is also closest to the major urban areas (Reykjavik/Akureyri) and closest to the main electricity transmission system (Not discussed here). Therefore the high temperature wells, located in or near the highlands in the middle of Iceland, are mostly unexploited.

There has been much research and discussion on sustainable utilisation as in [8], [7], [9]. The prevalent view is that the underground wells will regenerate themselves with an inflow
of steam and heat and hence be replenished if the outflow into boreholes and man made generators is below a given maximum limit. However, of course, this limit is location specific and may be difficult to estimate, due to the lack of measurable parameters. But on a long time scale, such as 100 to 300 years, if the wells are utilized above this limit, they should be able to be replenished by "resting" them, that is reducing or altogether stopping the utilization for a given period.

Next we turn to an overview of electricity generation in Iceland from geothermal resources.

**II. GEOTHERMAL ELECTRICITY GENERATION**

As previously mentioned, the development of geothermal power for electricity generation has been explosive in recent years and the rapid growth is shown in Figure 6. The Figure shows the location of major generating plants on an inserted map of Iceland, along with the annual electricity generation of new stations in GWh/year. The most recent plants are concentrated in the South-west Reykjanes peninsula and its volcanically active areas of the south-west.

The five largest geothermal stations are presently the following, where the first four are located near Reykjavik or in the Reykjanes peninsula and the last three located in the North-East [10]:

1) Hellisheiði Power Station (303 MW)
2) Nesjavellir Geothermal Power Station (120 MW)
3) Reykjanes Power Station (100 MW)
4) Svartsengi Power Station (76.5 MW)
5) Krafla Power Station (60 MW)
6) Bjarnarflag (3.2 MW)
7) Húsavík (2 MW)

Svartsengi, Nesjavellir and Hellisheiði are combined heat and power (CHP) plants, where geothermal water is diverted to district heating systems in urban communities.

In this paper we will not cover the geothermal technology or cycle, but [11] reviews this for Nesjavellir, [12] discusses the plant design of Hellisheiði plant and [13] discusses apparatus of Svartsengi and Reykjanes plants.

Figure 7 shows an example of a geothermal station, Hellisheiði which is operated by Orká náttúrunnar (ON) [14] a subsidiary of Reykjavík Energy (RE), the municipal utility with the role of generating and selling energy in Reykjavik. Direct utilization, which is the topic of the next section, is discussed in [15], while [16] discusses recent developments.

**III. GEOTHERMAL HEATING APPLICATIONS IN ICELAND**

Heating houses by geothermal water is a very important direct application of geothermal energy in the cold climate of Iceland. Here we will discuss two aspects of "space" heating: (A) the district heating systems and (B), another important "Icelandic" application, namely the use of geothermal water to heat swimming pools.
In addition, a short discussion follows, of the economic significance of having access to the abundant resources in terms of savings in import fossil fuel.

A. District heating

Historically, in this cold climate, the most important aspect of geothermal utilization is probably the space/district heating of houses. Approximately 90% of residences and buildings in Iceland are presently heated with geothermal water and more than 90% of the population is connected to geothermal district heating networks. Iceland is therefore the country with one of the highest penetration of district heating from any resource. Presently, there are about 30 municipal district heating utilities or companies, where Reykjavik Energy (RE) [17] is by far the largest one [18], [19] (See Figure 16).

Drilling for hot water in Reykjavik stems from the year 1928, but geothermal district heating in Reykjavik started a couple of years later, and presently the city of Reykjavik operates the largest district heating network in Iceland through RE. Therefore, the vast majority of the population in the capital Reykjavik and surrounding communities enjoys heating with geothermal water, or approximately 99.9%. The population growth for the urban areas in and near Reykjavik has been high and further increased this activity.

The low-temperature geothermal fields near Reykjavik are presently almost fully utilized, and therefore RE has gradually had to reach further afield for its geothermal wells. Thus the future expansion will likely be based increasingly on high-temperature fields farther away, such as at geothermal power stations. Also deep drilling was started in 2001 and there is hope that this research project will lead to additional energy for space heating in the future [20].

Figure 8 shows the rapidly increasing geothermal part in the overall energy for space heating during the last 45 years. It is notable that in the wake of the first oil embargo in the early 1970s, oil as an important medium for heating houses was rapidly being replaced by geothermal hot water. This occurred largely in one decade, the 1970s, as shown in Figure 8.

B. Geothermal heating of swimming pools

Figure 9 is a pie chart with a break-down of the principal utilization categories for geothermal energy use, both electric and non-electric. Although electricity generation and space heating dominate, heating of swimming pools is an important factor, comprising around 4% of the total. The total utilization per year in 2013 was around 46.7 PJ. Heating of pools is here in the class with, for instance, snow melting in pavements and walkways, and fish farming, each with a few % share. However, note that the melting of snow and ice is generally a lower grade category, than say space heating, as it uses the return water from house plumbing systems, where the temperature is around 20-30 degrees (Centigrade) rather than the 80-90 degrees hot water that usually is needed to enter individual houses from a district heating network.

Heating of pools is an interesting application. Figure 10 shows a map of Iceland with the location of the many swimming pools that are presently heated by geothermal water. These pools are often in smaller communities and rural areas and are popular among tourists as a destination, where one should bear in mind the the explosive growth of tourism in recent years.

C. Economic significance of geothermal energy

We start by presenting two diagrams in order to illustrate, as clearly as possible, the economic benefit of having these geothermal resources.

Figure 11 illustrates the cost of hot water as compared to the cost of oil with comparable energy contents to be used for space heating [22], and how the cost has evolved in the last 45 years. Geothermal water costs are derived from geothermal utility revenues or sales of hot water, as reported in their operational statement or balance sheet. Note that until the year 2000, the average oil price is used for each year. After 2000 the average of January prices for two consecutive years is used to reflect winter prices.
Figure 10. Swimming pools in Iceland. The black circles indicate geothermal pools while the few grey circles are pools heated with other resources such as by electricity. Adapted from [2].

Figure 11. The Figure shows cost of geothermal space heating compared to oil heating if access to geothermal energy were not available. The lower grey/red columns show the cost of geothermal space heating from utility revenues in Million ISK per year, where the current (March 2016) approximate rate of exchange is 130 ISK/US$. The solid higher black columns show the corresponding cost if the energy were to be derived from imported oil. Adapted and redrawn from [22]. (Orkustofnun Data Repository: OS-2015-T009-01).

Although other types of fuel - besides oil - would be conceivable as a benchmark, the economic benefit from having access to the geothermal resources is substantial, as seen in the difference of columns in Figure 11. Note the vertical axis is shown in Million Icelandic kr. (ISK). Another benefit is the stabilizing effect of geothermal energy on fluctuating oil prices and currency exchange rates.

Figure 12 from [23] shows another aspect of the benefits of having these indigenous resources. It shows an estimate [23] of this benefit, in the last one hundred years, as a fraction of the Gross Domestic Product (GDP). The curve swings high in periods of oil price hikes, but is lowered when oil prices fall. It is interesting to see this benefit as a significant fraction, or 1 - 3 % of the GDP, as estimated in [23].

IV. GEOTHERMAL FORECASTING

Finally we will discuss here the geothermal forecasts made by the EFC, as previously mentioned. The forecasts project the future heat use of geothermal energy in Iceland for several decades. The most recent forecast is from 2003 [2], but before that, forecasts were made in 1982 and 1987. We note [2] that the last official forecast from 2003 is 13 years old with an update hopefully coming soon.

Next, we will briefly review the methods and results used in the forecast [2], which presents a projected use of geothermal energy in Iceland up to the year 2030. It is based on projections of population growth and the growth of the GDP, housing and other sectors of the economy using geothermal heat. Then the forecast summarized the projected use and includes transmission losses and unused energy.

The geothermal energy use is separated into space heating, swimming pools, snow melting, horticulture, fish farming and industry. The heat use of energy (As opposed to electricity generation), which was 21,5 PJ in 2001 is projected to increase to a value of 32,5 PJ in the year 2030 or about annual growth of 1,4% annually.

Heating of houses will continue to be the largest factor. Approximately 87% of space in houses was heated by geothermal resources in 2001 and the forecast projects this to become about 92% in the year 2030, where population growth was an important contributing factor.

The share of space heating in the forecasting period is approximately 60% and geothermal heat should increase in all categories except horticulture, as electrical lightning was to increase. Electricity generation was excluded, as it was covered by a separate electrical energy forecast. The results of the geothermal forecast [2] are shown in Table I and Figure 15.

Table I uses directly results of Table I in [2], but we have added a linear interpolation from 2011 to 2015 to illustrate the forecasted results in more detail. How well has this forecast
made about 13 years ago held out? This question will be addressed in the next section.

V. DISCUSSIONS AND CONCLUSIONS

A. General discussion

To answer the question of how well the 2003 forecasted has lasted, let us examine the actual and forecasted values. As seen in Figure 9, according to [21], the actual geothermal energy use in 2014 was 28.1 PJ while the forecasted value for this year according to Table I is 27.1 PJ. The actual use in 2014 therefore exceeds the forecast from 2003 by 1 PJ or by 3.69%.

Undoubtedly, a comprehensive evaluation will be carried out by the EFC of how well the 2003 forecast has lasted. Therefore, it will be of considerable value to get an updated forecast of direct geothermal use in Iceland.

It is interesting to note that, despite the setback of the economic and banking crises of 2008 in Iceland, the consumption has caught up with the forecast made prior to the crisis.

B. Main conclusions

The main conclusions of the paper can be summarized as follows:

- Iceland is in many respects situated at the forefront worldwide in geothermal energy utilization.
• Geothermal energy plays an important role in the general energy framework in Iceland (Figure 18), and a sharply increasing role in overall electricity generation.

• Geothermal energy continues to play a key role in space heating and is very important in the general economy of Iceland to replace fossil fuel cost tat would otherwise be incurred in the cold climate (Figure 17).

• The forecast from 2003 has lasted reasonably well when we compare the forecasted value for 2014 with the actual values of 2014. The actual values, even exceed the forecasted value despite the economic setback in recent years.

REFERENCES


