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MULTIPURPOSE USE OF GEOTHERMAL ENERGY

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ABSTRACT

Hot natural water and steam is used to meet human needs for a variety of uses. If there is a geothermal source, one surely can find an application for it in most regions of the world. Statistics covering geothermal utilization worldwide will be described, where it is reported and the criteria applied for the energy calculations. A few examples are mentioned about the multipurpose use, to illustrate how broad the area of application is.

1. INTRODUCTION

Geothermal energy has traditionally been classified by use into two categories, namely: electrical generation and direct use. The generation of electricity is achieved by converting thermal energy to mechanical energy where a turbine drives an electrical generator. With present technology this requires a source with 130-300°C water or steam. Depending on the conditions and technology the conversion process is 10-30% efficient. Direct use of geothermal energy is where the heat itself is used (calories), such as for space heating, bathing or in industry. This covers a variety of uses where there is need for heat. The application temperature range is wide and the thermal efficiency of direct use can be in the range 50-80%. In a few cases the two classes go together, first the electricity is generated and then the heat goes to direct use, so called co-generation. Other such cascaded uses will be mentioned. Still the most extensive direct use is for balneology, for spas and such. Geothermal house heating is applied in the cold regions of the world and heating of greenhouses is another popular application found even hot regions. Normally conventional equipment and materials can be used, with a few exceptions. The main design challenge is the use of lower temperature sources than is the norm. Where the source temperature is low it is possible to upgrade it by the use of electrically driven heat pumps. Examples of the possible use of geothermal heat in industry are numerous, but up to now it has not seen widespread applications. Some of these are nevertheless mentioned to indicate the broad area of application possible. Statistical information on the use of geothermal energy has been collected worldwide, where the main classification is into electrical generation and direct use. Some surveys on direct use break it into use categories according to type of use. The paper will start by describing the main sources of such data and the calculation criteria that are applied.

2. GEOTHERMAL ENERGY STATISTICS BY TYPE OF USE

2.1 Primary energy - used energy

All energy originates in natural sources and in that form is referred to as primary energy. Primary energy generally has to be transformed into a form which is more suitable for its final use, such as electricity. In this transformation, a portion of the energy is generally lost. According to standard calculating methods, to 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 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.

When geothermal energy is used for heating purposes we calculate the used energy as that part of the primary energy that is used in the heating process. The rest is discharged in form of waste water. The main calculation methods for evaluating used energy are described below.

It is important to note the big difference in the way Primary Energy Supply and Used Energy is calculated. The energy is calculated as the difference between the two heat streams, what comes in minus what goes out. Both have for heat flow that comes in, the multiplication of the flow of the water and its temperature (enthalpy). They differ, however, in the definition of the lower temperature state. The Primary Energy considers all the heat available or down to 0°C, 15°C or the average ambient temperature. For Used Energy, on the other hand, the lower temperature state is the discharge temperature, which is usually much higher. If you take a district heating system in Iceland as an example the assumed temperature difference for Primary Energy is: 80°-15°=65° whereas for Used Energy is 80°-35°=45°C, or 44% higher for Primary Energy. For electrical generation the difference in the results is more dramatic. Reporting on a 10 MW plant generating solar or hydro-power and the same size of geothermal, is just 10 MW in Primary Power Supply for the solar or hydro case but 100 MW for the geothermal one. If the desire is to show a large number in the statistics for geothermal, relative to other energy sources, report it as Primary Energy Supply!

2.2 Calculation criteria

Energy statistics are always based on some rules for calculation and presentation of the data that is collected. In case of electricity generation by geothermal energy it is relatively simple to handle the data for energy consumption since the basic source of information is the amount of electricity produced. This is measured at the power plant as the number of kWh produced over a time period. The main question here is whether we measure the output from the turbines or the output from the plant because the electricity consumption of the plant itself can be a significant part of the production, especially in binary power plants.

Preparation of reliable data about consumption of geothermal direct uses or consumption for heating purposes is usually more complicated than handling data for electricity generation. Usually we are interested in used energy, but not the primary energy consumed. The source of information here is usually a given amount of water in m^3 consumed at a fixed supply temperature in °C. It is also common to give the consumption as an average flow rate in l/s, but this can easily be converted to volume consumption. The energy content of the water depends strongly on the temperature. After using the water for heating the consumer discharges it at a lower temperature and roughly speaking we can say that the energy consumed is proportional to the temperature difference between water inlet and outlet from the consumer. Thus the main parameters for measuring the energy consumed is the volume of consumed water and the temperature difference ΔT.

The International Geothermal Association (IGA) has established a methodology for reporting the use of geothermal energy for heating (direct use). The main principle is to report the amount of energy actually consumed by users within a given consumer group, based on reference values for both inlet and outlet temperatures that are characteristic for users within the specific consumer group. The following formulas can be used to calculate the capacity, energy use and the capacity factor for geothermal heating processes like for example district heating systems.

Capacity (MWt) = Max flow rate (kg/s) x [Inlet temp. (°C) – Outlet temp. (°C)] x 0.004184
Energy use (TJ/yr) = Ave. flow rate (kg/s) x [Inlet temp. (°C) – Outlet temp. (°C)] x 0.1319
Capacity Factor = [Annual energy use (TJ/yr) / Capacity (MWt)] x 0.03171

2.3 World surveys

A worldwide overview of geothermal utilization is presented at the World Geothermal Congress organized by the International Geothermal Association (IGA, iga.igg.cnr.it) every five years. The last World Geothermal Congress was held in Antalya, Turkey, in May 2005 (WGC-2005). The organizers of the congress request representatives of every country with known geothermal potential or geothermal utilization to submit a so-called country update paper to the congress. These papers give a comprehensive summary of the geothermal activity in each country and a large part of them is presented orally at the conference. To make the presentations as uniform as possible and make the comparison between countries easier the authors receive a set of standard tables that they are asked to fill in and include in their papers. In addition to the country update papers two summary papers are presented at the WGC. They are based on the country update papers and give a worldwide overview of the geothermal development. One of the summary papers is on electricity generation and the other on direct utilization of geothermal energy.

The World Energy Council (www.worldenergy.org) publishes a report called Survey of Energy Resources every three years. The last one of these reports was presented at the World Energy Congress in Rome, Italy in November 2008 (Survey of Energy Resources 2008, SER-2008). Each of the main energy resources is described in a separate chapter. The main part of the geothermal chapter is so-called commentary that describes the geothermal resources as well as the utilization worldwide. Environmental issues and outlook for the future are also discussed. In addition to the commentary the geothermal chapter in SER-2008 contains a brief summary of the situation in each country with geothermal utilization. It is based on a questionnaire that is sent to institutions or organizations in the WEC countries together with similar forms for other energy sources. The information collected this way about geothermal energy is only a brief overview and much less detailed than the information presented at the WGC congresses. Therefore the WGC data is also used a source of information for the SER publications.

The International Energy Agency (IEA) is the most important organization that collects general international energy data. A large part of it is available on the web (www.iea.org).

2.4 Electricity generation

Electricity is produced by geothermal energyin 23 countries. In 2004, the worldwide use of geothermal energy amounted to about 57 TWh/a of electricity (Bertani, 2005) and 76 TWh/a for direct use (Lund et al., 2005). The electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). The direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). Table 1 lists the top fifteen countries in geothermal electricity production and in geothermal direct use in the world in 2004.

TABLE 1: Top fifteen countries in geothermal use in 2005.
Data on electricity from Bertani (2005) and on direct use from Lund et al. (2005)

Geothermal electricity production		**Geothermal direct use**	
	GWh/a		**GWh/a**
USA	17,917	China	12,605
Philippines	9,253	Sweden	10,000
Mexico	6,282	USA	8,678
Indonesia	6,085	Turkey	6,900
Italy	5,340	Iceland	6,806
Japan	3,467	Japan	2,862
New Zealand	2,774	Hungary	2,206
Iceland	1,483	Italy	2,098
Costa Rica	1,145	New Zealand	1,968
Kenya	1,088	Brazil	1,840
El Salvador	967	Georgia	1,752
Nicaragua	271	Russia	1,707
Guatemala	212	France	1,443
Turkey	105	Denmark	1,222
Guadeloupe (France)	102	Switzerland	1,175

The electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). The direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). Only a small fraction of the geothermal potential has been developed so far, and there is ample space for an accelerated use of geothermal energy both for direct applications and electricity production.

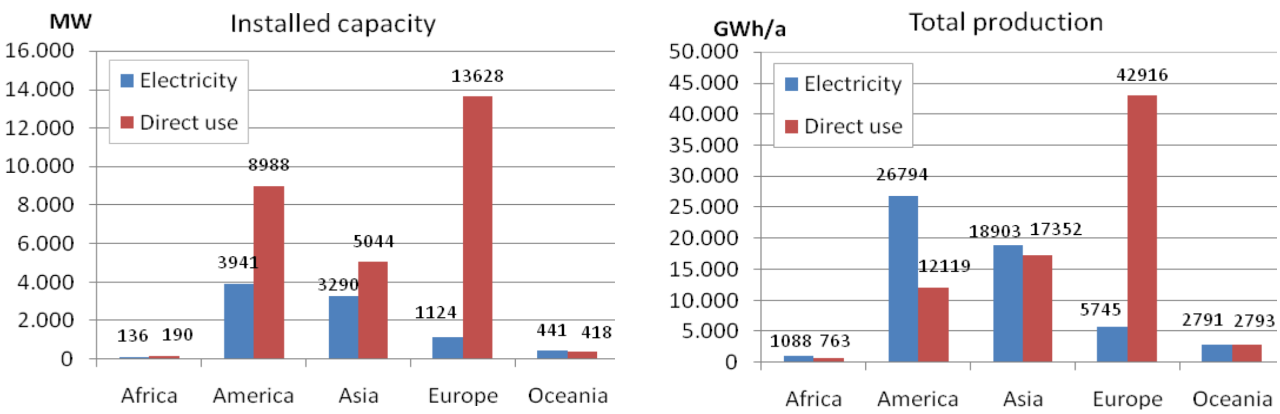

FIGURE 1: Installed capacity (left) and energy production (right) for geothermal electricity generation and direct use (heating) in the different continents (from Fridleifsson and Ragnarsson 2007, based on data from Bertani, 2005 and Lund et al., 2005). The Americas include North, Central and South America.

2.5 Direct utilization

The main types of direct use of geothermal energy are space heating 52% (thereof 32% using heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and fish farming 4% (Lund et al., 2005). Figure 2 shows the direct applications of geothermal worldwide by percentage of total energy use. The share of each utilization sector is based on the amount of energy consumed. This is calculated on the basis of estimated temperature differences between inlet and outlet water temperatures as explained above. For space heating a typical temperature drop is from 70°C down to 35°C, although this will vary from place to place. Industrial uses are often based on higher temperatures and in many cases steam. Other utilization sectors use similar temperatures as space heating, but in many cases it is difficult to estimate the outlet temperature because of lack of measured values or unclear definitions of the outlet conditions. Geothermal uses for bathing have for example often been excluded from statistical data of this kind because of lack of information.

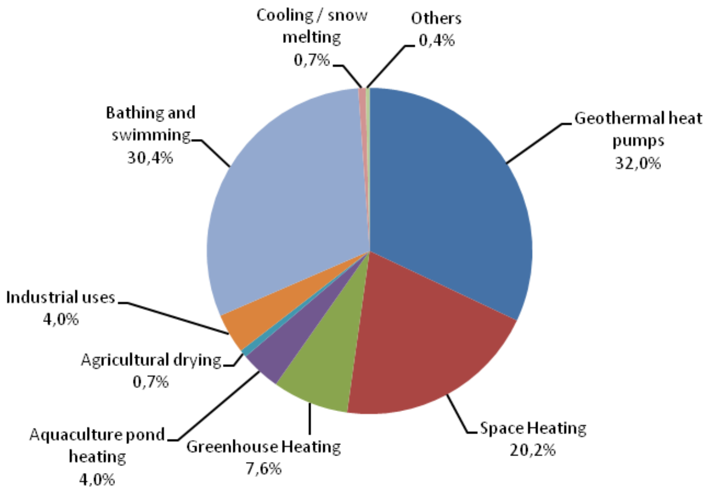

FIGURE 2: Direct applications of geothermal worldwide in 2004 by percentage of total energy use (data from Lund et al. 2005).

The main growth in the direct use sector during the last decade has been in the geothermal (ground-source) heat pumps. This in part due to the ability of geothermal heat pumps to utilise groundwater or ground-coupled temperatures anywhere in the world.

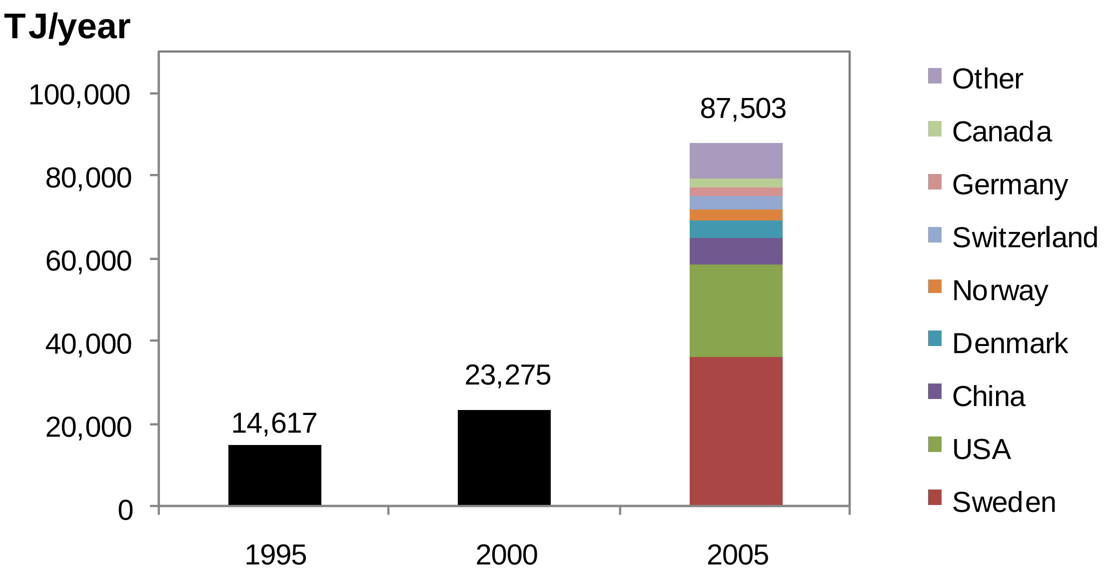

FIGURE 3: Worldwide growth of ground source heat pump applications and the leading GHP countries. Data from Lund et al. (2005).

Until recently, almost all the installations of the ground source heat pumps have taken place in North America and Europe, increasing from being used in 26 countries in 2000 to 33 countries in 2005

(Lund et al., 2005). China is, however, the most significant newcomer in the application of heat pumps for space heating. According to data from the Geothermal China Energy Society in February 2007, space heating with ground source heat pumps expanded from heating 8 million m^2 in 2004 to heating 20 million m^2 in 2006. Conventional geothermal space heating in the country had grown from 13 million m^2 in 2004 to 17 million m^2 in 2006. This reflects the policy of the Chinese government to replace fossil fuels where possible with clean, renewable energy. The "Law of Renewable Energy of China" was implemented in 2006.

3. MULTIPURPOSE USE

The temperature at which geothermal fluids can be produced influences the type of use possible. This was recognized a long time ago and diagrams were presented to illustrate the opportunities (Figure 6). Multipurpose relates to the idea that the geothermal fluid can be re-used or passed from one user to the other, sometimes referred to as cascaded use. This is easier when the source temperature is high, especially from high-temperature areas. In low-temperature regions there are also some possibilities, but despite considerable promotion in the past, and the fact that it contributes to good energy efficiency, there are not so many glowing examples of its use. The production of electricity from 120°C water at Husavik in Iceland and then using the water afterwards for house heating and aquaculture is one example The electricity generation is however not simply a by-product, as the water flow had to be doubled to meet the requirements of the plant. Much of the waste water from the Reykjavik district heating system goes to snow melting outside buildings. In several places the waste water goes to aquaculture like a shrimp farm that uses heat from the waste water from the Wairakei power plant in New Zealand.

3.1 District heating

To maintain comfortable temperatures inside houses (18-23°C) in cold weather, heating systems are installed. Simple systems often use fireplaces or individual heating units either gas or kerosene. For central heating hot air is distributed in ducts or pipes convey hot water or steam to radiators and more recently to floor heating units. Electrical resistance heating is used in places where there is ample electric power and also air to air heat pumps (air-conditioners). When several houses or whole cities are connected to a common pipe grid supplying hot water, it is called district heating. Early such systems were supplied with steam (New York and Paris) but now most district heating systems use hot water. The conventional district heating systems (heated by boilers) are designed for high delivery and return temperatures (e.g. 90/70) but this is not ideal where geothermal water supplies all or part of the heat. Geothermal district heating systems have been installed in most cities in Iceland and in rural areas as well, meeting 90% of the country´s needs. In Europe a geothermal heat source is incorporated into a few district heating schemes and also in China. There it is important to maximize the temperature drop at the consumer is by returning the water from the radiators at 35-40°C. That way geothermal water having a temperature of say only 60°C can be utilized for pre-heating the water at a heating plant which then heats it to the final temperature in a boiler. Where the water is of high enough temperature (>50°C, but preferably around 80°C) it can be used directly without further heating. Either the geothermal water is piped directly to the consumer, as is the case in Iceland, or passes through a heat-exchanger in the network. Heat exchangers are very commonly used in district heating systems to isolate the geothermal water from the system water. This way any problems of corrosion or scaling are limited to the geothermal side where it can be dealt with effectively. Figure 4 shows several different flow-diagrams for geothermal district heating systems.

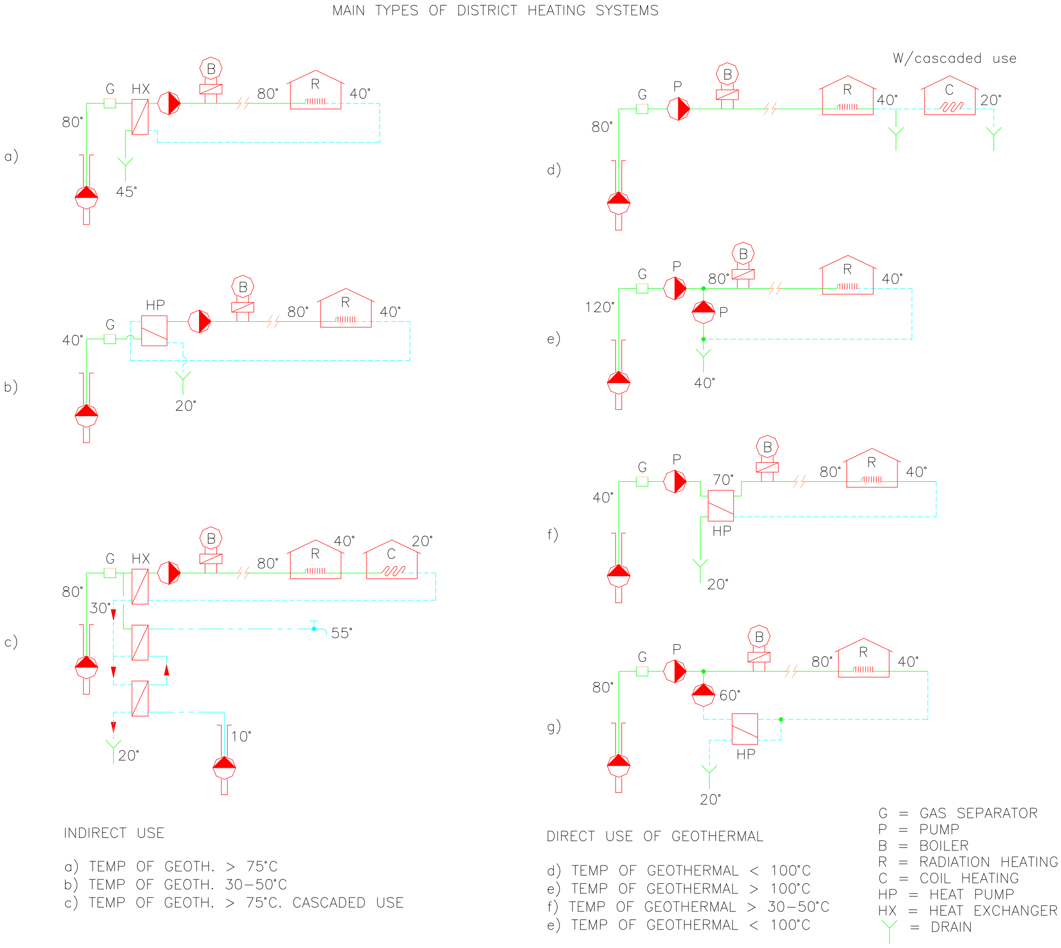

FIGURE 4: Types of geothermal district heating systems in Iceland.

3.2 Balneology

Hot water has been used for bathing or spa use wherever thermal springs are found. Such use is firmly engraved in the history and culture of many countries. The therapeutic properties have been documented and are mainly due to the effect of temperature and pressure or the massage effect of water jets, rather than by its chemical composition. Some skin ailments are kept at check by geothermal brines. One Icelandic study on the therapeutic effects of geothermal water found a lack of clinical proof of benefits that can be attributed to the waters' composition (Björnsson, 2000). One of the largest use of geothermal heat is for recreation and geothermal tourism, or 30,4% (Figure2). This is a big industry in the Japanese "onsen" and in most other countries with access to geothermal water. One example is the Blue Lagoon in Iceland which is a magnet for tourists. The silica rich water is spent brine from the co-generation plant at Svartsengi, thus the white-bluish colour. A clinic there treats skin diseases and finally the silica and salts produced from the geothermal brine are incorporated into a broad line of skin care and beauty products. The site at Svartsengi is a good example of multipurpose use, what the power company Hitaveita Suðurnesja likes to refer to as a "resource park".

FIGURE 5: The Blue Lagoon draws over 350.000 guests per year and is open year round.

3.3 Industrial uses

Industrial uses of geothermal heat have not gained popularity for various reasons, in spite of a fair amount of promotion in the last 25 years. Iceland has had access to geothermal heat for a long time, but now there are only a limited number of industrial users. It is at present used for drying seaweed, some drying of fish and as washing water in the food industry. In spite of the proximity of geothermal sites to the food growing regions of California, there is only one plant drying garlic onions in Nevada. In New Zealand, there is a factory that dries lumber and a paper factory that gets a part of its steam from geothermal. Grain drying is found in Serbia and coconut drying in the Philippines.

Several reports have been written in the past to identify sectors where geothermal heat could play a role. Such studies have been made by Lindal (1974, 1993), Reistad (1975), Howard (1975 and Lienau (1991). A list based on Lindal (1974) shown below is from a World Bank webpage (www.worldbank.org /html/fpd/energy/geothermal/index.htm) and Figure 6 shows a greater number of possibilities (Lund et al 1998).

180°C Evaporation of highly concentrated solutions, Refrigeration by ammonia absorption
Digestion in paper pulp (Kraft)
170°C Heavy water via hydrogen sulphide process. Drying of diatomaceous earth.
160°C Drying of fish meal. Drying of timber.
150°C Alumina via Bayer's process.
140°C Drying farm products at high rates. Canning of food.
130°C Evaporation in sugar refining. Extraction of salts by evaporation and crystallization.
Fresh water by distillation.
120°C Most multi-effect evaporation. Concentration of saline solution.
110°C Drying and curing of light aggregate cement slabs.

100°C Drying of organic materials. Seaweed, grass. vegetables etc. Washing and drying of wool.
90°C Drying of stock fish. Intense de-icing operations.
80°C Space-heating (buildings and greenhouses).
70°C Refrigeration(lower temperature limit)
60°C Animal husbandry. Greenhouses by combined space and hotbed heating
50°C Mushroom growing. Balneology.
40°C Soil warming Swimming pools, biodegradation. Fermentations.
30°C Warm water for year-round mining in cold climates. De-icing. Hatching of fish.
20°C Fish farming.

Most of these applications have at one time or other been realized in Iceland, except the ones shown for 180°C, heavy water, drying of fish meal, alumina, canning, fresh water distillation, sugar refining and refrigeration at 70°C.

One might ask: Why is there not more use of geothermal heat in agriculture and industry?
In spite of proven long term success stories when it comes to agricultural or industrial uses of geothermal energy, new projects have been few and older ones have been shut down. To explain this one needs to look at some of the present constraints.

Low temperature water:

- The temperature is too low – limited possibilities (e.g. aquaculture and soil warming or de-icing) as can be seen from above.
- Low temperature water can be used for house heating where the price is better than for process heat.
- Low energy content (enthalpy), large volume required.

Lack of availability of steam:

- Steam sources are only found in volcanic regions.
- Steam can only be transported over relatively short distances (~2-20 km).
- Geothermal steam is not yet a “commodity” - it cannot be purchased from a pipeline or at an industrial park.
- Most installations to date are dedicated to a single user.
- There are few geothermal developers.
- The development of geothermal fields takes a long time (5-8) years.
- Temperature and pressure limitation of geothermal steam:
  Delivery pressure is usually limited to the range 5-10 bar-g. This pressure is common in fuel fired industrial boilers. The corresponding steam temperature is 159-184°C but it means that the reservoir temperature has to be at least 200°C or 250°C.

Financial:

- The initial investment cost is high for geothermal field development, drilling and distribution. Equivalent to buying all the "fuel" up front for decades of operation.
- The transport distance from the geothermal field is limited to few km for steam and several tens of km for water due to cost and loss of pressure.
- High-temperature areas are mostly in remote volcanic regions away from population centres. “Green field” development.
- The cost of steam and water, although important, rarely exceeds 5% of the production cost of the given product.
- Investors are frequently sceptical and unfamiliar with this energy source.

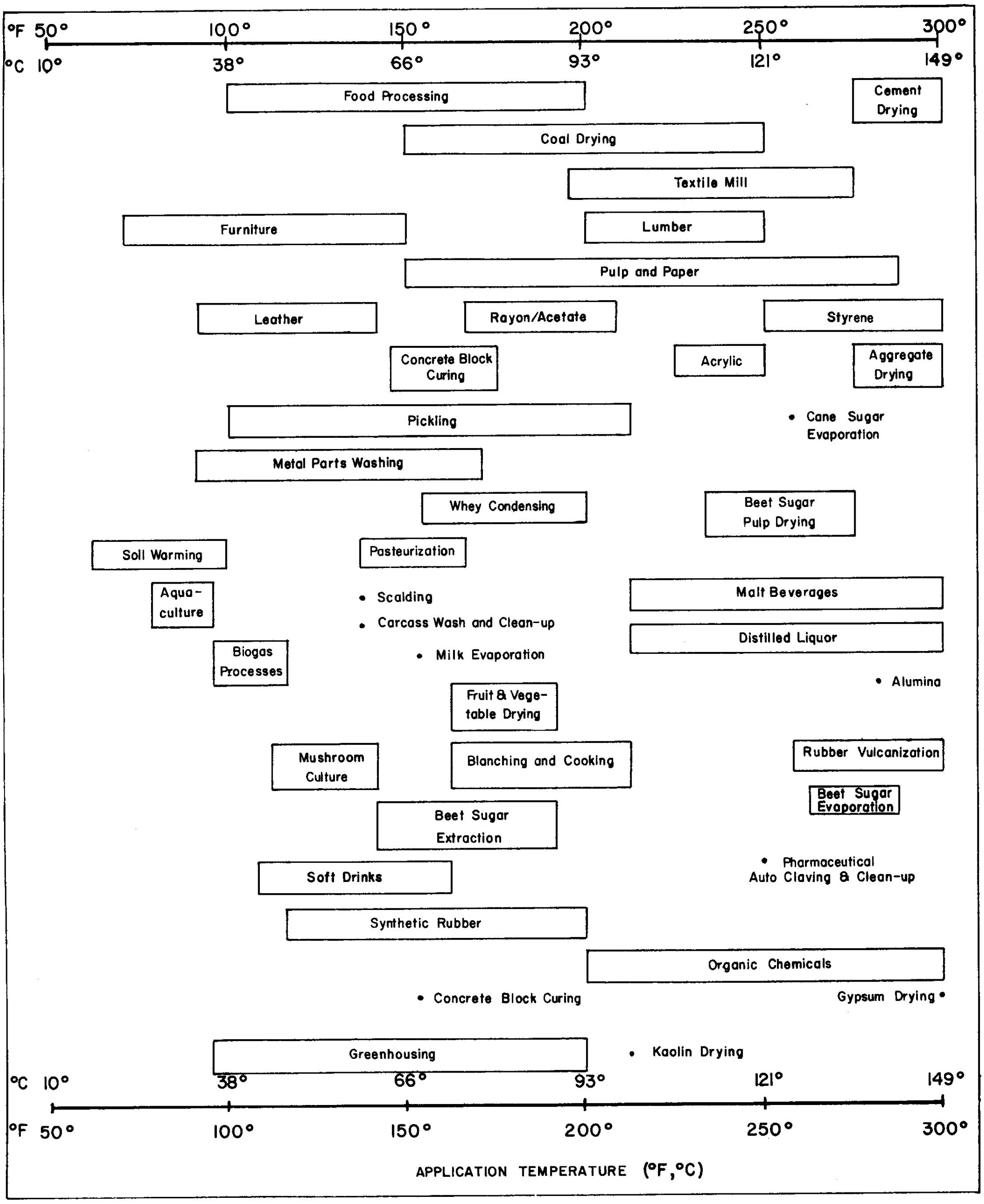

FIGURE 6: Application temperature range for some industrial processes and agricultural operations (Lund, J. et al 1998)

Institutional:

- Lack of suppliers. There are very few companies selling geothermal steam and geothermal water to designated industrial parks. The present day operators are utilities or companies that have their primary interests in power generation but have as yet shown limited interest in small-scale industrial uses.
- Limited private development. Geothermal energy has not graduated from government enterprises or from geological- and volcanological institutes.
- The geothermal law and leasing of geothermal rights is new or non-existent. Obtaining

environmental permits and resource concessions take time and at times meet public resistance.

Environmental:

- High temperature areas are usually found in rugged and beautiful natural settings. Many are within national parks or protected areas. Permission to exploit the resource can be difficult to obtain.

So what are the opportunities in Asia? The use of geothermal heat to dry agricultural products or natural materials is a possibility. One must then look for two things, the location of the resource and what can be grown or is available in the not too distant area. High value crops such as coffee, spices and fruits come to mind and a company that would specialize in the drying of a variety of crops could have work for a good part of the year. Such a custom dryer might also have facilities to steam sterilize the spices and other products for added value. Processing of natural fibres is a possibility and a variety of dying cloths and washing of laundry. Candy production by melting sugar into bon-bon´s and adding flavors and color and also a variety of food products could be prepared in steam heated kettles.
There is also the possibility to dry fish or meat and this requires slow drying at not very high temperatures. If the temperature is too high it cooks the fish and also results in too high a drying rate that leaves the outside hard, thus hindering the drying process. Pre-cooking of food and food preparation on a large scale can also make use of geothermal heat. Industrial laundries can serve hospitals and the local community. Much of this does not require sophisticated equipment or large users. Thus granting access to steam or hot water close to the geothermal field can be of considerable economic benefit. This means that land will have to be developed for industries close to the geothermal fields as transportation of steam for more than say 2 km becomes uneconomic.

Industries that make use of steam for curing the rubber on retread tires, steam forming of wood for furniture, steam washing to degrease motor parts for rebuilding etc., are all examples of small industries that might benefit. In the rural setting of the geothermal areas, just having access to electricity steam and running water should be enough to spur good ideas. The main thing though is that any steam consuming industry can use geothermal steam in much the same way as it would use steam from a conventional boiler.

3.4 Agriculture

The main direct use in agriculture is for greenhouse heating that is at present reported in 30 countries, for heating the equivalent of 1000 hectares (Lund et al, 2005). Interesting examples are for humidity control at night to reduce fungicide use for rose growing in Kenya and use of the CO_2 non-condensable gases from a nearby power plant for enrichment inside the greenhouses. In Tunisia the desert cold at night is kept a bay and the waste water used for watering the plants. There is also the use of geothermal heat for crop drying reported in 15 countries. Low temperature water is moreover used for aquaculture in China, USA, Iceland, New Zealand, and Italy.

There is an interesting use of the geothermal carbon dioxide gas for the enrichment of the atmosphere inside greenhouses to enhance the growth. Winter growing in artificially lighted greenhouses would not be possible if it were not for the CO_2, which comes from geothermal wells. For this to be possible the hydrogen sulphide gas has to be cleaned from the gas. In Iceland soft drink grade CO_2 comes from geothermal wells, after cleaning to less than 0.1 mg/kg of H_2S.

Many farms in Iceland have been connected to a geothermal district heating system even if it means running a 1 km long branch to a single farm. This has in part been made possible by the introduction of plastic (PP and PB) pipelines. Most of the water is used for heating of the home and farm buildings. There are cases where the water is used for incubation of eggs, watering the animals and grain drying. Some years ago hot air drying of the hay in barns was used because of the wet climate. This has, however, been made obsolete due to the introduction of plastic wrapping of rolled hay bales.

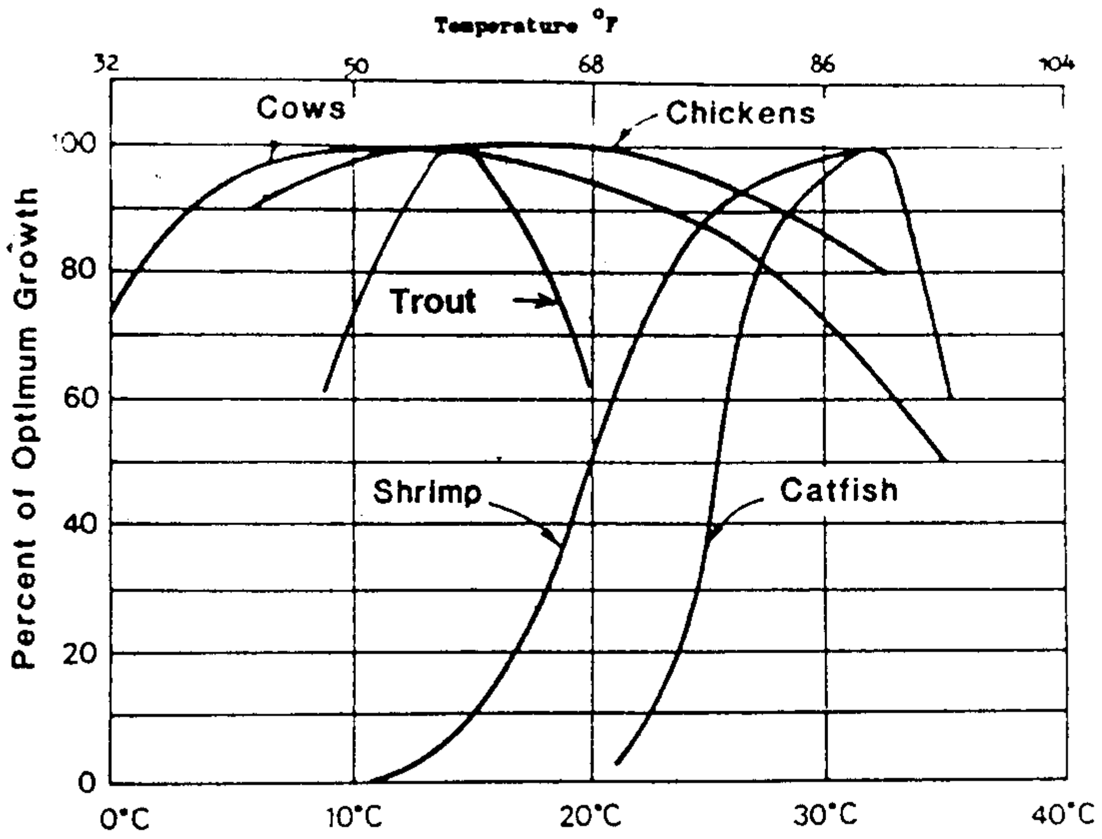

FIGURE 7: Optimum growing temperatures for selected animal and aquatic species (Lund J. 1996)

REFERENCES

Bertani, R., (2005): World geothermal power generation in the period 2001-2005. *Geothermics, 34,* 651-690.

Bjornsson, Olafur Grimur (2000) Balneology, medical science and bath culture (Baðlækningar, læknavísindi og kúltúr), National Energy Authority, (Orkustofnun, Auðlindadeild), Report OS-2000/027

Fridleifsson, I.B. and Ragnarsson, A., (2007). Geothermal Energy. In: 2007 Survey of Energy Resources, 427-437. World Energy Council 2007. (Available on www.worldenergy.org).

Líndal, B (1974) Process Heat. Multipurpose use of geothermal energy. Poceedings of the international conference on geothermal energy for industrial, agricultural and commercial - residential uses : Oct. 7-9, 1974, Oregon Institute of Technology, Klamath Falls, Oregon

Lund, J.W., Freeston, D.H., and Boyd, T.L., 2005: Direct application of geothermal energy: 2005 Worldwide review. *Geothermics* 34, 691-727.

Lund J., Freeson D.H, and Boyd T.L. (2005) Word-Wide Direct Uses of Geothermal Energy 2005, Proceedings World Geothermal Congress 2005, (http://iga.igg.cnr.it).

Lund J. (1996) Lectures on Direct Utilization of Geothermal Energy. United Nations University. Geothermal Training Programme, (http://www.os.is/page/unugtp)

Lund J., Lineau P.J., Lunis B.C. (1998), Geothermal Direct-Use Engineering and Design Guidebook. Geo-Heat Center, Oregon Institute of Technolgy.