Multiple integrated applications for low to medium temperature geothermal resources

ELÍASSON, Einar Tjörvi[1]
BJÖRNSSON, Oddur B.[2]
[1] *Krete ehf, Hjardarhaga 50, IS-107 Reykjavik, Iceland, email: einart@enex.is*
[2] *Fjarhitun hf* [1], *Borgartun 17, IS-105 Reykjavik, Iceland, email: oddur@fjarhitun.is*

Abstract

The world's population calls for greater and faster energy development to help improve its lot through more employment and better living conditions. Conscious of the apparent deterioration of the environment as manifest in deforestation, despoiling of lakes and rivers not to mention greenhouse effects, it is, however, not prepared to sacrifice too much of the natural environment. This puts pressure on scientists, engineers and developers to find ways and means to meet this new challenge of sustainable energy development. The new focus is therefore on sustainability and alternative renewable energy resource development.

Sustainability may be achieved in a number of ways; the way most likely to achieve rapid increase in energy output without consequent deleterious environmental impact is the revamping and integration of what we already have.

This paper attempts to address sustainability as it applies to geothermal energy development. It outlines concept of multiple integrated use of geothermal energy whilst pointing out tenable benefits attainable through applying this concept, such as improved reservoir life and sustainability, lower specific environmental impact, and greater marketing flexibility and profitability. The paper point out the paramount importance of striving at maximum effective temperature drop across the application. This is commensurate minimum flow rate, optimal pumping requirements and minimal fluid extraction from the geothermal reservoir. In geothermal house heating systems this requires the adoption of:

- Large and effective radiators.
- Double pipe heating system.
- Thermostatic control on each radiator.

Where modification of existing house heating systems, e.g. conversion from a single pipe to a double pipe system or installation of larger radiators is not feasible, cascaded flow of the geothermal fluid through a combination of heating systems of different temperature levels presents a solution.

Economic criteria favour direct use of the geothermal water where its chemical quality is suitable. Otherwise heat exchangers of resistant materials are necessary to isolate the geothermal fluid from the heating fluid where corrosion or scaling of the piping and radiator system is to be expected. Such heat exchangers must be designed for maximum temperature drop of the geothermal fluid.

---

[1] Fjarhitun hf. is a member of enex of Iceland

The paper describes heating system configurations and characteristics of geothermal heating systems, their automatic control systems and recommended geothermal field management and monitoring systems.

A few actual project examples demonstrate what has been done and what can be done; and ideas are put forward for new developments and innovations to make geothermal energy more generally attractive and useful worldwide.

Keywords: geothermal, sustainability, direct use, multiple uses, cascaded uses, integration

1 Introduction

In the nineteen forties, fifties and sixties Icelandic homes were converted from oil and coal fired heating to geothermal heating. They have therefore undergone the necessary changes from a conventional fuel heated house system to a geothermal one. Experience shows that this was a wise decision.

In Iceland, the economy of properly designed and operated geothermal district heating systems is far superior to that of a conventional fossil fuel system:

- Heating cost is from 20% to 80% of the cost of heating with oil.
- [2]Cost of heating-energy to the customer in Reykjavik is 2 US cents/kWh
- The most expensive district heating in Iceland charges 3 US cents/kWh.
- Reduced tariff is offered for recreation facilities such as for swimming pools and heating of soccer fields.

The first deliberate multiple integrated utilisation of geothermal high temperature resource started in Iceland about 1978 in the Svartsengi Geothermal Co-generation Plant. The principle reasoning for this was the locality specific need for electrical power independent of the grid for distributing the hot water, the existing transmission grid being weak with limited load capacity.

This idea caught on in a wider sense, viz. as a vehicle to increase the amount of thermal energy removed from the fluid drawn from the substrata and thus both increase the overall conversion energy and potential diversity and flexibility of use simultaneously with improving the development's financial profitability.

Today almost no geothermal development, be it high or low or medium temperature one, is started in Iceland without this concept being upheld. Recent examples in Iceland of the first mentioned is the Reykjavík Energy's Nesjavellir Development and of the last mentioned the Húsavík Energy Supply System, which was granted a financial support via the EU Fourth Framework Programme.

2 Sustainability

The concept "sustainable development" became fashionable with the Bruntland report in 1987. Sustainable development is in the report defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

There is no universally agreed definition of the concept of sustainability and instead of plunging into the mire of controversy over the diverse definitions and underlying

[2] The price of energy is a calculated value based on 40°C temperature difference

argumentation; the authors chose to state what is meant by sustainability in the following presentation, namely:

a. **Resource:** Long-term utilisation of any given geothermal resource in a manner that ensures maximum longevity of the resource through optimal attainable use of the energy consistent with eking out of the fluid most of the thermal energy

b. **Environment:** Geothermal resource development in a manner commensurate with minimal harmful ecological and environmental impact in the short and the long term

c. **Economics:** Striving for the greatest economic profitability attainable within the constraints imposed by criteria a. and b. above

In this presentation the authors try to put forward arguments and examples in support of their contention that this can best be achieved by careful design, thorough monitoring, effective control, stepwise development and multiple integrated use of the energy resource.

2.1 Resource aspects of the sustainable use of geothermal energy

2.1.1 Direct use

If the chemical composition of the geothermal fluid permits, direct use in the house heating systems is preferred. Heat exchangers of resistant materials are necessary where corrosion or scaling of the piping system may be expected. The heat exchangers should be designed for maximum temperature drop of the geothermal fluid.

Low cost of operation and high cost of initial investment is what usually characterises geothermal district heating systems. The high initial cost involves the exploration and the drilling of the geothermal wells, as well as the development of the production field. The investment and cost of operation is directly related to the quantity of the geothermal fluid in motion, i.e. the number of wells, pumping from the well, and transmission to the market area and distribution to the customer. Therefore:

- The supply temperature to the customer is kept constant throughout the heating season and as high as legally permitted (normally 80°C in Iceland).
- The return temperature is made as low as possible (35°C or lower in Iceland).
- All hot water is metered by volume.
- The tariff system provides the client with an incentive to use the heat from the purchased water efficiently.
- High initial investment requires that the geothermal energy be used as base load (see the typical load duration diagram below)

Maximum effective temperature drop in the house heating systems - hence minimum flow rate - is of fundamental importance in geothermal systems calling for:

- Large and effective radiators
- Double pipe heating system.
- Thermostatic control on each radiator or a group of radiators in a room

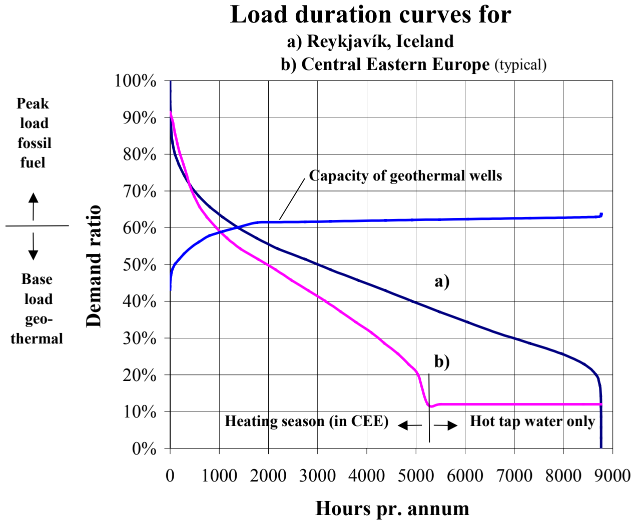

Figure 1 Typical load duration curves (1). Curve a) depicts a district heating system with a high load factor and b) system with a low load factor (no space heating during summer season)

Where modification of existing house heating systems, e.g. conversion from a single pipe to a double pipe system or the installation of larger radiators, is not deemed feasible, cascaded flow of the geothermal fluid through a combination of heating systems of different temperature levels may be the solution.

- Example of first stage use is radiant space heating of buildings incl. greenhouses.
- Examples of second stage use (in cascade with the first stage), floor heating of buildings, soil heating for agriculture inside greenhouses or outside, pedestrian street and sidewalk snow-melting, direct or indirect heating of swimming pools, health spas and aquaculture facilities.

2.1.2 Direct use example

Figure 2a) to 2d), depicts a few examples of direct use where the chemical quality of the geothermal fluid permits the water to be used directly for house heating without fluid separation. In such cases the following technical solutions have been used:

a) *Single pipe system*: This single-pass or once-through system uses the geothermal fluid (temperature below 100°C) directly for heating in radiators, floor coils etc. The spent fluid from the radiators is discharged to secondary user or re-injected. Due to safety limits to maximum temperature of hot tap water, usually 55 to 60°C (38°C for baths), heat exchangers or automatic mixing valves are employed. In the former case cold water is heated with geothermal water through a heat exchanger to the required temperature and in the latter the geothermal water is mixed directly with cold water.

b) *Dual pipe system*: A part of the spent return water from the house system (temperature 30°C to 40°C) is collected and mixed with the geothermal supply water (temperature 100°C - 130°C) to obtain a constant supply temperature (e.g. 80°C) irrespective of weather conditions. The excess return water is discharged to secondary user or injected back into the reservoir (re-injected). In some cases it may be beneficial to employ heat pumps to boost the temperature of the supply water and lower the return temperature of the used geothermal water at the same time.

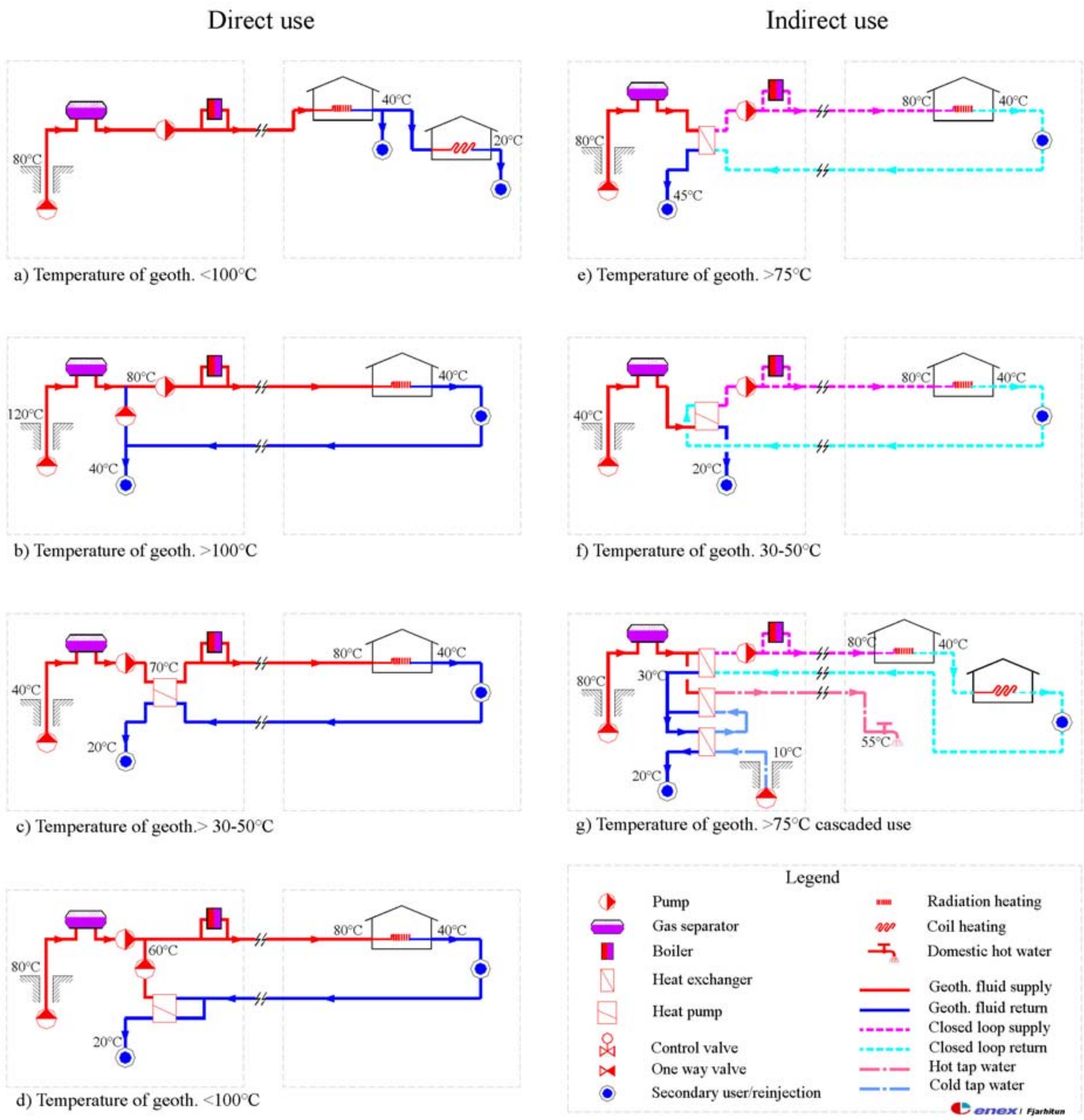

Figure 2 Examples of district heating network with geothermal water (2)

2.1.3 <u>Indirect use</u>

In this case, see Figure 2e to 2g, the geothermal water is separated from the district heating water by heat exchangers. This may be necessary due to the chemical characteristics and/or high temperature and pressure of the geothermal fluid used. Such an arrangement also offers more flexibility if the geothermal source becomes for instance temporarily inoperable.

The purpose of the heat exchangers is to transfer the heat from the geothermal to the heating system medium whilst keeping the two separated.

The district heating system as well as the hot tap water system are each a separate closed-loop network in the residential unit or apartment in question. After passing through the house heating systems the secondary system heating water is collected and transmitted in pipes to the heat exchangers, where it is reheated to the required supply temperature. The secondary side of the hot tap water heat exchanger is connected to the municipal cold water supply system, which then is heated to the required temperature for the hot water taps (55-60°C).

2.1.4 Indirect use example

The geothermal water is in this case only used in the primary system.

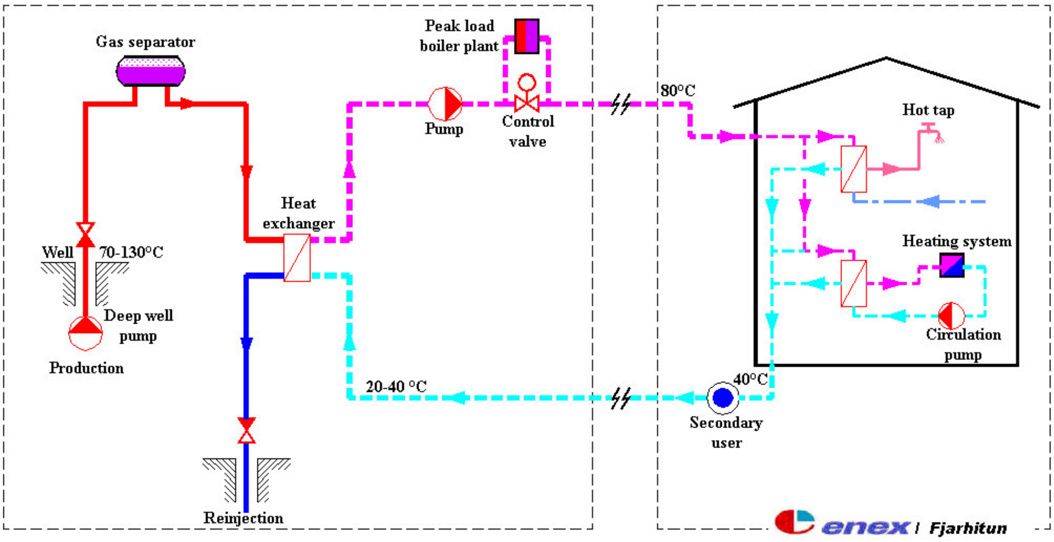

Figure 3 Process diagram for indirect use of geothermal energy with heat exchangers at the geothermal field and a double transmission pipeline.

The above process diagram, Figure 3, shows a double transmission pipeline and a heat exchanger station located in the geothermal field. The whole system outside the geothermal field is a traditional closed loop system with treated clean water. The geothermal fluid is never brought out of the geothermal area. A portion of the primary fluid may be used for production of electricity in a binary power cycle. As for the other options the utilisation of the primary fluid for production of electricity or other uses depends on various conditions such as the reservoir temperature, the well characteristics and the market situation. The temperature drop of the geothermal fluid depends on the chemical composition of the fluid and the environmental conditions.

The simplified process diagrams presented here are examples of utilisation of geothermal energy for district heating. They are not to be taken as exact solutions for geothermal district heating or other applications. On the contrary all geothermal projects are tailor made in compliance with local geological and market situations.

2.2 Operating aspects of the sustainable use of geothermal energy

2.2.1 Peak load plant

It is generally found to be more economical to install fossil-fuelled boilers to handle the usually brief periods of peak heat demand, than to provide geothermal capacity sufficient for all load situations especially in places where the load factor is low (Figure 1~~Figure 1~~ depicts typical energy duration curves for Iceland with high load factor and Central Europe with low load factor.) A boiler plant requires a comparatively low capital investment but is expensive to operate. This in turn makes boiler plants for heat generation typically more economical for intermittent peak load applications, than would the provision of additional geothermal well.

The geothermal well is generally found to be more expensive than a boiler plant of similar thermal capacity. Heat pumps may alternatively be employed to boost the thermal base load capacity.

2.2.2 Optimal combination – lowest overall energy cost

Following is an example; see Figure 4, to demonstrate how a peak load boiler can lower the energy production cost for a heat market. It is assumed that the market is large in relation to the available geothermal resource. The price of geothermal energy is normalised for a system of 4400 equivalent peak-load hours pr. year where the cost is estimated 1 US cent/kWh.

First we look at an alternative with no boiler and 10 MW available geothermal power. Thus, the maximum demand of the market that can be served is 10 MW. Annually 25 GWh of geothermal energy can be delivered to that market. The corresponding peak-load hours are 2500 pr. year and the specific geothermal energy price is 1,7 US cent/kWh. That means 25 GWh of geothermal energy will annually replace another energy source, usually decentralised burning of oil or lignite coal. The total production cost will be 435 000 USD and the specific production cost of energy equal to the production cost of geothermal energy namely 1,7 US cent/kWh.

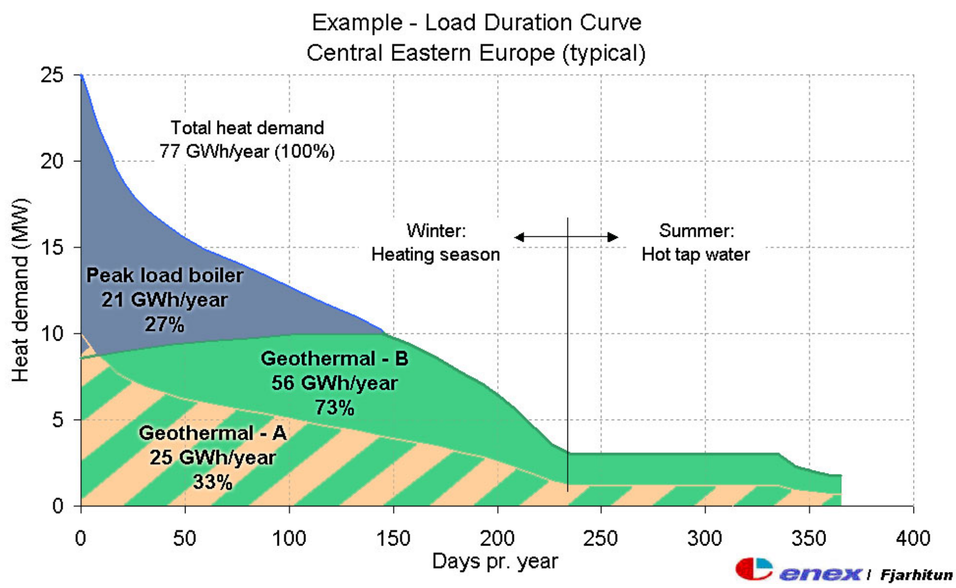

Figure 4. Optimal combination of geothermal base load and fossil fuel peak load. Load duration curves typical for Central and Eastern Europe.

If we now install a peak load boiler that covers 60% of the maximum load demand, the market that can be served will increase from 10 MW to 25 MW maximum load demand. Referring back to the load curve, we now see that although geothermal power is only 40% of the maximum power demand it will be cover 73% of the annual energy demand. That means geothermal energy will provide 56 GWh of the 77 GWh total energy demand[3]. Or in other words, for each 10 MW geothermal power installed 56 GWh of geothermal energy will

[3] 56 GWh at 10 MW peak capacity of the geothermal resource corresponds to 5600 peak-load hours pr. year and specific energy price of 0,8 US cent/kWh. 77 GWh at 25 MW peak load corresponds to 3100 peak-load hours pr. year and specicic energy price, if all the energy is supplied by geothermal, of 1,4 US cent/kWh

replace another energy source instead of 25 GWh annually, if a peak load boiler is not installed. If the price of peak load energy is 2,5 US cent per kWh, the total cost will be 962.000 USD/year and the production cost of energy will be reduced from 1,7 US cent/kWh to 1,25 US cent/kWh.

This is an example of how a peak load boiler can influence a geothermal district heating project, both the size of the market that can be served and the cost of energy production. In a real project it is important to optimize the size of a peak load boiler, taking into account the marginal cost of installed geothermal power, cost of peak load boiler, cost of fuel and the cost of an increased market.

2.3 Environmental aspects of the sustainable use of geothermal energy

The most important contribution of geothermal development is its contribution towards replacing conventional fossil fuelled systems used in the heating of domicile and industrial space. The atmospheric pollution so avoided is quite considerable. The major attractions of geothermal energy in this respect are:

- Insignificant atmospheric and in most cases liquid pollution
- High degree of availability compared to most other RES
- Low land use
- The resource is indigenous

The following subchapter gives typical atmospheric pollution rates for different geothermal application and corresponding ones for conventional fossil fuel energy.

2.3.1 CO_2 Emissions

Typical CO_2 emission data for fossil fuelled electrical power plants are in the order of:

- Coal, in power plant operating at 35% efficiency, 915 g/kWh
- Fuel oil, in power plant operating at 35% efficiency, 760 g/kWh
- Natural gas, in power plant operating at 60% efficiency, 315 g/kWh

Some 73% of the plants surveyed were found to have a MW weighted average emission rate less than 150 g/kWh (3). The results are summarised graphically in Figure 5 below.

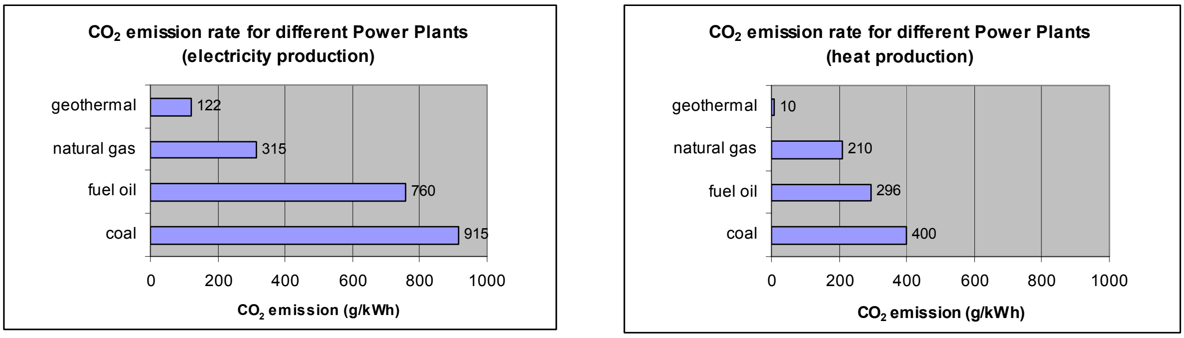

Figure 5. Typical CO_2 emission rates for a) electrical power plant, b) for heat producing plant (3)

3 Multiple integrated uses of geothermal energy

The prevailing general policy of geothermal development in the world has until in recent years been developing the energy resource for a virtually single purpose (stand-alone development), e.g. electricity production, industrial use, space heating, greenhouse heating or health tourism. The choice of application has largely been dictated by resource temperature and short-term financial gains rather than consideration of sustainability and/or socio-economic benefits. The notable exception to this has in the past been Iceland where the multiple integrated use principle has been foremost in geothermal development philosophy for the last two decades.

3.1 Integrating other energy resources with geothermal energy

Multiple integrated uses do in its wider context not only apply to integrated use of one or more geothermal resources in cascade/tandem for a few or several different applications in one energy supply system. It applies equally to the integration of geothermal resources with different types of other resources (both conventional and alternative renewable ones) into a single efficient and economical energy supply system that meets modern sustainability criteria better than stand-alone developments ever can.

There are, as previously stated, not many examples of different energy sources integrated with geothermal resources into a single energy supply system. The only operational one the authors know of is the heating system of Akureyri depicted in Figure 6 below. This system integrates 5 individual geothermal reservoirs of different temperatures ranging from 60°C to 95°C into a single energy supply system (4). The return water from heating the densely populated business sector of the town is re-circulated and reheated to the supply temperature using a large (2x2 MWt) electrically driven heat pump pair. It moreover uses high voltage electrical boilers for boosting purposes and an oil fuelled boiler for peak loads and emergencies. Return water from part of the heating system is re-injected at 12°C to sustain reservoir pressure and mine heat from surrounding formations. A highly sophisticated automatic control and data acquisition system is used for heating system control, geothermal system and reservoir monitoring.

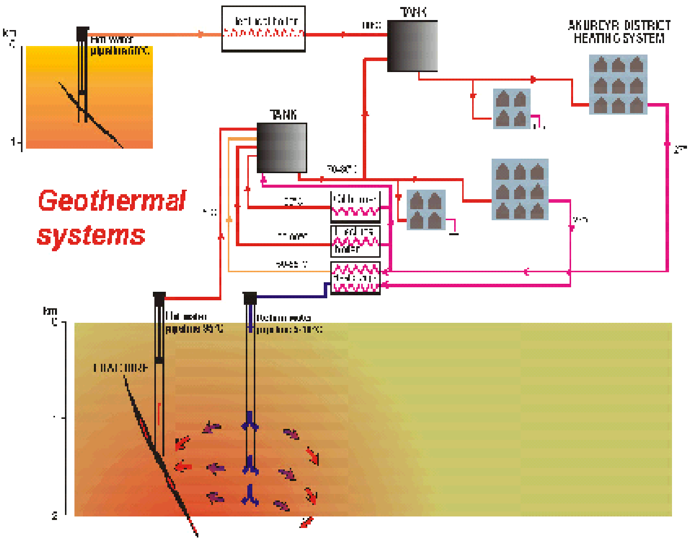

Figure 6. Akureyri District Heating System
(Courtesy Norðurorka)

The hot water produced is prominently used for space heating purposes, heating of sports facilities, for swimming facilities, industrial uses and snow melting. Some of these applications are in cascade but more generally in parallel.

3.2 Multiple integrated uses of geothermal energy

An excellent example of multiple integrated use of a medium temperature use is depicted in the diagram below (Figure 7). It depicts a utilisation scenario where water at 124°C is transported (5) via an insulated 13 km long part surface and part buried steel pipeline to an Energy Central on the outskirts of Húsavík township with some 2.500 inhabitants in the north-east of Iceland. Some of the hot water is used en route for use in the neighbouring countryside for heating of living space and greenhouses, and for trout rearing.

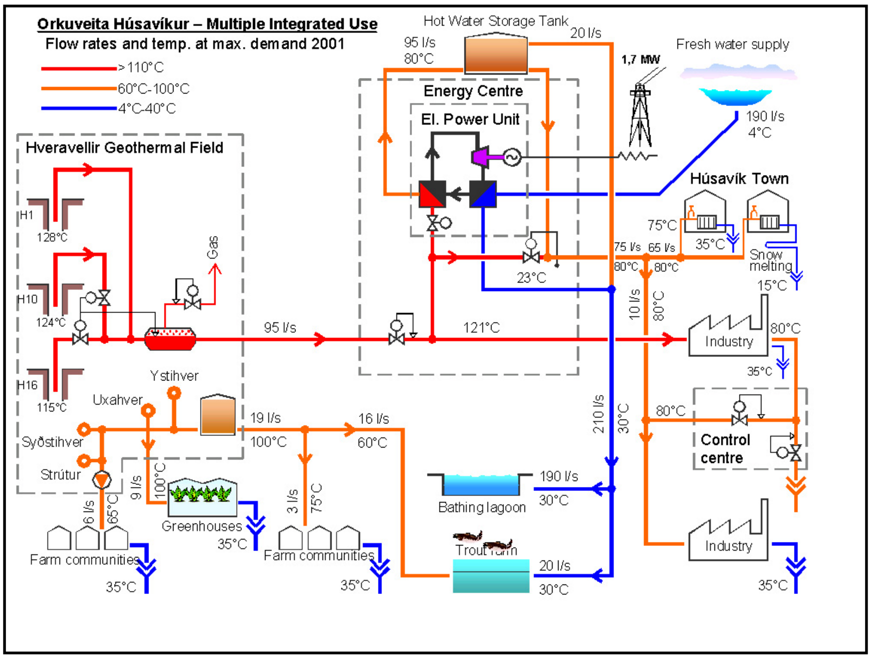

Figure 7. The Húsavík Energy System (Courtesy Orkuveita Húsavíkur)

The water entering the Energy Central has lost some 3°C en route and is used to generate some 1,7-1,8 MWe electricity in a binary unit. The fresh cooling water from the binary unit is used directly at about 30°C in an open-air bathing lagoon, for trout rearing and wetland recovery. The geothermal at exit from the binary unit is used at about 80°C for hard wood drying and space heating etc. Some of the 121°C geothermal water is by-passed and used in for shrimp boiling, pasteurising and cleaning purposes.

The electricity production costs are below the wholesale price the township pays for electricity from the grid.

Other examples involving multiple integrated high temperature geothermal resource exploitation for combined hot water and electricity production, such as the Svartsengi and the Nesjavellir Plants, are left out. These have been quite adequately reported in the literature and are likely to be of less interest for this conference.

3.3 Main advantages of multiple integrated use

There are numerous advantages and possibly a few disadvantages to this development philosophy, and the authors will endeavour to list the important ones in the following:

Advantages:

- Greater versatility and flexibility both as regards marketing the energy and adjusting the energy facility to variety in demand.
- Better overall energy efficiency and use of the energy resource and therefore better resource and environmental sustainability.

- Stepwise development. It brings about smaller capital investment steps and project earnings start coming in earlier. Time for market promotion and long-term planning becomes easier.
- Great socio-economic potential through new job creation and SME participation.
- Ideal for small community development.

Disadvantages:

- Increased development complexity and risk
- Increased control and management complexity
- Greater total capital investment
- Doubtful profitability

References

(1) Björnsson, O.B. *"Heating Plants, Electric Power Plants, Co-Generation Plants",* European Union Thermie B Action, Seminar on Transfer of Geothermal Technology and Knowledge, Reykjavík, Iceland, November 15-17, 1998

(2) Björnsson, O.B. *"Geothermal District Heating",* International Workshop on Direct Use of Geothermal Energy, Chamber of Commerce and Industry of Slovenia, Ljubliana, Slovenia, November 16-17, 1999

(3) IGA, *"Geothermal Power Generating Plant CO_2 Emission Survey".*

(4) Flóvenz, Ólafur et al; "*Direct Utilisation of Geothermal Water for Space Heating in Akureyri, N-Iceland",* World Geothermal Congress, Florence, Italy, 1995

(5) Hjartarson, Hreinn, *"Multiple-use of geothermal energy in Húsavík",* Nordvarme (Association of Nordic Heating Companies) Conference, Nyköping, Sweden, June 10-11, 2002