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GEOTHERMAL ENERGY IN THE WORLD FROM ENERGY PERSPECTIVE

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ABSTRACT

An overview is given of the energy utilization in the world and the operations of the UNU Geothermal Training Programme in Iceland are presented, with emphasis on East Africa. Utilization of geothermal energy in Africa is reviewed and examples are presented from region, as well as from Iceland where geothermal energy plays a larger role than in any other country in the world.

Based on UN World Energy Assessment Report update on the status in 2001, the primary energy consumption in the world was assessed as 400 EJ, with about 80% coming from fossil fuels, and only 14% from renewable energy sources. The contribution of the renewables is discussed and their possibilities. The current share of the renewables in the energy production is mainly from biomass and hydro, but in a future envisioned through depleting resources of fossil fuels and environmentally acceptable energy sources, geothermal energy with its large technical potential is expected to play an important role.

High-temperature geothermal resources within the Great East African Rift Valley have the potential to provide East Africa with the some of the energy it needs for development, and even become one of the main resources for electricity production. Kenya is now producing 130 MWe electricity from geothermal and has set itself a very ambitious goal of adding 1260 MWe in the next 10 years. This is an example for the other East African countries to follow.

1. INTRODUCTION

Geothermal energy is one of the renewable energy sources that can be expected to play an important role in an energy future where the emphasis is no longer on fossil fuels, but on energy resources that are at least semi-renewable and long-term environmentally acceptable, especially with regard to emission of greenhouse gases and other pollutants. For developing countries which are endowed with good geothermal resources, it is a reliable local energy source that can at least to some extent be used to replace energy production based on imported (usually) fossil fuels. The technology is proven and cost-effective. For developing countries that have good resources and have acquired the necessary local expertise it has become very important. A good example of this is Kenya, as well as the Philippines, El Salvador and Costa Rica, where geothermal energy has become one of the important energy sources providing for 10-20% of the electricity production. Iceland should also be mentioned as the only country where geothermal energy supplies more than 50% of the primary energy used, both through direct use for heating, bathing, etc., and through production of electricity.

Geothermal systems can be classified into a few different types but with reference to variable geological conditions each one is in principle unique, so that good knowledge is needed through exploration. Furthermore, development of a geothermal system for electrical production is a capital intensive undertaking, and thus requires financial strength, or at least access to good financing. Thus, for developing geothermal resources, good training and expertise are needed for the exploration and development work, and strong financial backup for the project.

Here, the role of geothermal energy in the world's energy mix is presented with some emphasis on E-Africa, and examples are given on its use in Africa and Iceland. But first the United Nations University Geothermal Training Programme is introduced.

2. THE UNU GEOTHERMAL TRAINING PROGRAMME

The United Nations University Geothermal Training Programme (UNU-GTP) is celebrating its 30th anniversary in 2008. It has operated in Iceland since 1979 offering six month annual courses for professionals from developing countries. From being one of four geothermal schools established in the 1970s the UNU-GTP is now the only international graduate school offering specialized geothermal training. The aim is to assist developing countries, with geothermal potential, in capacity building in order to make the countries self sufficient in geothermal development. The trademark is to give university graduates engaged in geothermal work intensive on-the-job training. The training is conducted in English and tailor-made to suit the needs of the home country. UNU Fellows generally receive scholarships financed mainly by the Government of Iceland. Since 2000, cooperation between the UNU-GTP and the University of Iceland (UI) has opened up the possibility for few UNU Fellows to extend their studies to MSc level, with the six months training adopted as an integral part (30 out of 120 ECTS). In 2008, the cooperation has been expanded to include PhD studies, with two former UNU Fellows commencing PhD studies in the academic year 2008-2009.

As a contribution to the UN Millennium Development Goals and through the contribution of the Icelandic government, the UNU-GTP has expanded its activities by annual workshops/short courses in Africa (started in Kenya in 2005), Central America (started in El Salvador in 2006), and Asia (started in China in May 2008). The events are organised in cooperation with local energy agencies responsible for geothermal development. A part of the objective is to increase geothermal cooperation inside the region, and to reach out to countries with potential and interest in geothermal development who have not yet received quality training. This has made it possible for the UNU-GTP to reach out to an increasing number of geothermal scientists and engineers.

Africa has always been a major cooperating partner of the UNU-GTP. Amongst the 402 graduates of the UNU-GTP (1979-2008), 107 or 26% have come from eleven African countries. Most of these come from the countries of East Africa. The largest numbers have come from Kenya (42), followed by Ethiopia (26), Uganda (11), Tunisia (6), and Eritrea (6). Former UNU Fellows lead the geothermal research and development in all these countries. The political and economic situation in some of the countries has, however, delayed geothermal development, with some of its professionals trained at the UNU-GTP having left their jobs in the geothermal sector and even emigrated to other countries. Out of twenty-six UNU MSc-Fellows participating in the MSc programme, sixteen have graduated. Seven of these have come from Kenya, one from Uganda and one from Djibouti, and three Africans are currently pursuing MSc studies in Iceland, coming from Eritrea and Ethiopia (2). Furthermore, the first two UNU PhD-Fellows are Kenyans. Kenya has been the leading country in E-Africa in geothermal research and development, and many of their specialists have been trained in Iceland. Figure 1 shows the group of UNU Fellows that attended 6 month training in Iceland in 2008.

For more information on UNU-GTP, see e.g. Fridleifsson (2005; 2008) or its web page (www.unugtp.is).

FIGURE 1: The group of UNU Fellows that attended the 6 months training in Iceland in 2008, enjoying life at top of Mt. Leirhnjúkur in the Krafla geothermal area, N-Iceland

3. THE ROLE AND POTENTIAL OF GEOTHERMAL ENERGY TODAY

Geothermal energy is a resource that has been used by mankind for washing and healing through its history. In the 20th century, geothermal gradually came on-line as an energy source for electricity production and to be used directly, besides bathing or washing, for heating of houses, greenhouse heating, aquaculture etc. According to energy reviews based on surveys for 2004, presented in combination with the World Geothermal Conference 2005, geothermal resources have been identified in some 90 countries while quantified utilization is recorded in 72 countries. Electricity is produced from geothermal energy in 23 countries. In 2004, the worldwide use of geothermal energy was estimated to be about 57 TWh/a of electricity (Bertani, 2005), and direct use 76 TWh/a (Lund et al., 2005).

In the modern world, access to clean energy at affordable prices is a key issue to improve the standard of living. However, at present, two billion people, a third of the world´s population, have no access to modern energy services, and in addition the world population is expected to double by the year 2100. Furthermore, the world energy consumption is expected to double in the new century. So the task in providing clean energy to people in the coming century is enormous (Fridleifsson, 2003).

Today´s energy consumption relies on fossil fuels. Table 1 shows the use of primary energy in 2001 based on the UN World Energy Assessment Report update (WEA, 2004). With rising oil prices and environmental concerns expected to play a bigger role, through necessary reduction in emissions of greenhouse gasses, renewable energy sources are expected to play an increasingly bigger role in the 21st century. The technical potential of the renewable energy sources is certainly large enough (WEA, 2004).

TABLE 1: World primary energy consumption (WEA, 2004)

Energy source	**Primary energy EJ**	%
Fossil fuels	**332**	**79**
Oil	147	35
Natural gas	91	22
Coal	94	22
Renewables	**57**	**14**
Traditional biomass	39	9
Hydro, geothermal, wind, solar, tidal	18	5
Nuclear	**29**	**7**

The use of geothermal energy has increased steadily during the last few decades and it has been seated as number three of the renewables with regards to electricity production. The total electricity production from renewable energy sources was assessed as 2968 TWh in 2001 (WEA 2004). Of this 91% came from hydropower, 5.7% from biomass, 1.8% from geothermal and 1.4% from wind, while solar electricity contributed to 0.06% and tidal 0.02%. These are not new data and it can be reasoned that wind energy may probably have passed geothermal today, but geothermal energy is definitely one of the energy components of a greener future.

A comparison of cost of energy between countries is difficult, because of differences in taxation and subsidies. But the survey discussed here proves that the renewables are definitely competitive (WEA 2004), showing the electrical energy cost to be 2-10 UScents/kWh for geothermal and hydro, 4-8 UScents/kWh for wind, 3-12 UScents/kWh for biomass, but higher for solar energy. The investment cost is also assessed to be quite similar for the different energy sources, 1000-3500 USD/kW for hydro, 500-6000 USD/kW for biomass, 800-3000 USD/kW for geothermal and 850-1700 USD/kW for wind. The advantage of geothermal energy compared to other renewables is the high capacity factor, being independent of weather conditions contrary to solar energy, wind energy, or hydropower. The reliability of geothermal plants means that they can be operated at capacity factors in excess of 90%. This is illustrated in Table 2 that shows data on electricity production from four renewable energy resources in 2001 (WEA, 2004).

TABLE 2: Electricity from four renewable energy resources in 2001 compiled from data in WEA (2004)

	Operating capacity		**Production per year**	
	GWe	**%**	**TWh/y**	**%**
Geothermal	8	24.4	53	53.8
Wind	23	70.1	43	43.7
Solar	1.5	4.6	1.9	1.9
Tidal	0.3	0.9	0.6	0.6
Total	32.8	100	98.5	100

In 2004, electricity was produced from geothermal energy in 23 countries, increasing by 16% from 1999 to 2004 (Bertani, 2005). Table 3 lists the top ten countries producing geothermal electricity in the world in 2004, and those employing direct use of geothermal energy(in GWh/year). The largest electricity producer is the USA, with almost 18,000 GWh/a but amounting to only half a percent of their total electricity production. It is different for most of the other countries listed there, with geothermal playing an important role in their electricity production. That certainly applies to the second country on the list, The Philippines where the production of more than 9,000 GWh/a meant that geothermal supplied 19% of the electricity produced. Same applied to Kenya, the total production of 1088 GWh/a only put the country in 10th place with regard to total production but it still amounted to 19% of the total production. For direct use (Lund et al., 2005), China heads the list with Sweden having propelled into second place over a few years through rapidly increasing use of ground source heat pumps, followed by the USA, Turkey and Iceland. With direct use of geothermal energy still insignificant in Africa it is not surprising that no African country is seen among the top ten countries with direct use of geothermal energy.

TABLE 3: Top ten countries in electricity production from geothermal energy in 2004 (Bertani, 2005), and those with direct use (Lund et al., 2005)

Geothermal electricity production			**Geothermal direct use**	
Country	**GWh/a**	**% nat. produc.**	**Country**	**GWh/a**
USA	17,917	0.5	China	12,605
Philippines	9,253	19	Sweden	10,008
Mexico	6,282	3	USA	8,678
Indonesia	6,085	7	Turkey	6,900
Italy	5,340	2	Iceland	6,806
Japan	3,467	0.3	Japan	2,862
New Zealand	2,774	7	Hungary	2,206
Iceland	1,483	17	Italy	2,098
Costa Rica	1,145	15	New Zealand	1,968
Kenya	1,088	19	Brazil	1,840

Focussing on energy use in the East African region, Tables 4-6 show interesting figures. They are based on statistics from the IEA, published in 2005. Table 4 shows the primary energy consumption in four of the East African countries in 2004. It shows well how important biomass and waste are in the region, accounting for 70-90% of the total consumption in the respective countries, and how small the share of the other renewable energy sources is. Fossil fuel supplies some of the electricity and of course the transport sector.

TABLE 4: Primary energy consumption in East Africa in 2004 (IEA statistics)

	Fossil	**Hydro**	**Geoth./ sol./wind**	**Waste/ biomass**
Kenya	16%	2%	2%	80%
Eritrea	29%			71%
Ethiopia	7%	1%		92%
Djibouti				
Tanzania	8%	2%		90%
Uganda				
Total	**10%**	**1%**	**1%**	**88%**

Table 5 shows the installed capacity for electricity production in East Africa in 2004. Here the renewable sources are well represented through hydro providing for 70% of the production capacity, with thermal plants supplying 26%. The Olkaria power plant in Kenya is largely responsible for the remaining 4%. Here a significant change will hopefully be seen in the coming decade.

Finally, Table 6 demonstrates the huge difference in electricity production per capita between the East African countries, varying from 22 to 255 kWh/capita compared to the average value for the OECD countries, about 8000 kWh/capita. It certainly shows the need for improvement in the region, if life standards are to be improved significantly.

For a more thorough overview of the use of geothermal energy in the world and comparison with other energy resources, see e.g. Fridleifsson, 2003 and 2006.

TABLE 5: Electricity production in East Africa in 2004 – installed capacity in MW (IEA statistics)

	Thermal	**Hydro**	**Geoth.**	**Wind**	**Total**
Kenya	346	584	121	1	1052
Eritrea	130				130
Ethiopia	36	671	7		714
Djibouti	85				85
Tanzania	202	561			763
Uganda		300			300
Total	**799** **26%**	**2116** **70%**	**128** **4%**	**1** **0%**	**3044**

TABLE 6: Energy consumption in E-Africa, 2001-2003 in kWh/capita (IEA statistics)

	Population	**GNI $/capita**	**Energy kWh/capita**
Kenya	32 million	390	117
Eritrea	4.4 million	190	42
Ethiopia	69 million	90	22
Djibouti	0.7 million	910	255
Tanzania	36 million	290	59
Uganda	25 million	240	64
OECD			**8,056**

4. UTILIZATION OF GEOTHERMAL ENERGY IN AFRICA

As seen in Section 3, the East African countries have similar energy production and consumption characteristics. Traditional biomass represents by far the largest category of energy produced (Table 4). The extensive use of combustible waste and biomass causes deforestation and contributes to environmental degradation. All the East African countries import petroleum products, mainly for transport and some for electricity production, which is not desirable in times of environmental awareness and high oil prices. Instead local renewable energy sources should be preferred, at least as far as conventional resources allow. For the countries surrounding the East African Rift System (EARS) (Figure 2) with its volcano-tectonic activity, high-temperature geothermal resources have the potential to play a much bigger role and even become one of

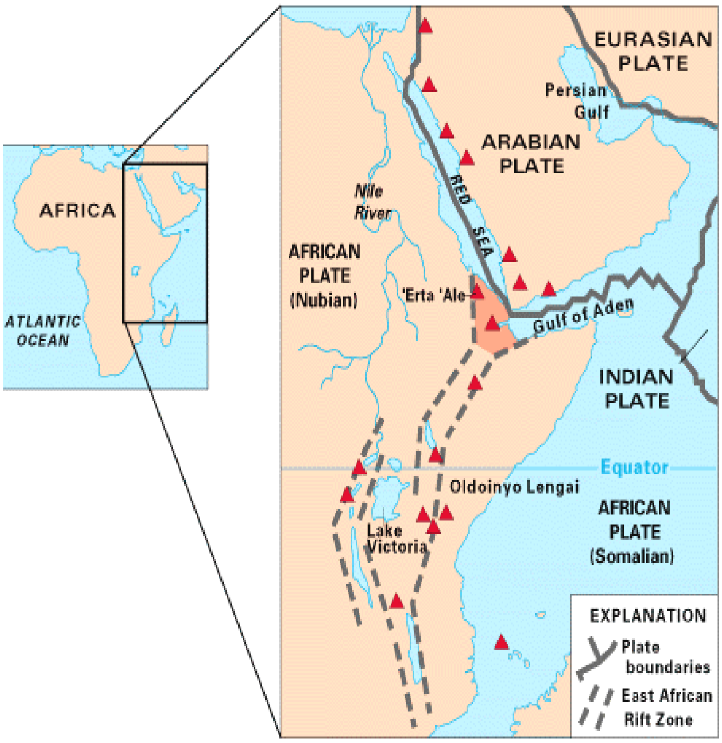

FIGURE 2: The Great East African Rift System (Teklemariam, 2008)

FIGURE 3: The Olkaria II power station in Kenya

the most important resources for electricity production. Currently, renewable energy sources (hydro, geothermal, wind, solar, etc.) represent only a small portion of the total primary energy production, averaging 2% for hydropower, geothermal and solar production combined (Teklemariam, 2008).

Geothermal can also be expected to play an important role in the countries of North Africa. However, the geothermal resources in this part of Africa are of the low-temperature type, and thus the practical utilization is mainly limited to direct uses, i.e. space heating, agriculture, aquaculture, recreation, etc.

With the technology of today, East Africa has the potential to generate energy in the range 2,500-6,500 MWe from geothermal power (assessment by GEA, 1999). Despite that, Kenya is now the only country harnessing this resource to a significant extent. It has the richest potential, with the geothermal resources having been estimated to exceed 4000 MWe (Simiyu, 2008). Since the early 1980s, Kenya has slowly been increasing its total geothermal power generation from 15 MWe to 130 MWe at the Olkaria geothermal area (Figure 3), to increase to 166 MWe before the end of 2008. But more importantly, Kenya has recently put forward a very ambitious plan to add a total of at least 1260 MW of geothermal power on-line in the next 10 years (Simiyu, 2008). It should also be mentioned that at Lake Naivasha, Kenya, geothermal water and carbon dioxide from geothermal fluids are used in an extensive complex of greenhouses for growing roses (Figure 4). Using geothermal heating to improve the quality of the products started in 2003. The farm is now (2008) the biggest geothermal greenhouse farm in the world, with 50 ha. of greenhouses being heated with geothermal to produce high quality cut flowers. Rose exports from this "geothermal" farm alone have totalled USD 300 million per year (Mwangi, 2005).

FIGURE 4: Roses grown in a greenhouse heated with geothermal at the Oserian farm, Kenya

In Ethiopia, the Aluto-Langano pilot power plant, built in 1998 for producing 7.2 MWe on-line, has been only in partial operation since few months after its opening about 10 years ago, with mechanical problems in the plant and limited steam supply being difficult problems to overcome. This has lead to no or low production for long periods of time. After restoration, the plant is now producing 3 MWe (Teklemariam, 2008).

Geothermal exploration and research have been undertaken in Djibouti, Eritrea, Uganda, Tanzania, Zambia, Malawi, and most recently in Rwanda. The potential to use geothermal energy for electricity production may be greatest in Kenya, Djibouti and Ethiopia, but countries like Eritrea, Uganda, Tanzania and probably also Rwanda should not be discounted here. Ambitious exploration projects, including in some cases exploration drilling, are now in the initial stages in several countries, like Djibouti, Ethiopia and Eritrea, in cooperation with foreign companies and/or investors. The Geological Survey of Germany (BGR) must be mentioned, having been very active in the area in recent years, promoting geothermal exploration through its Geotherm programme. This effort has got geothermal exploration going in some countries where not much had been done for a long period of time, such as in Tanzania, Rwanda and Yemen (which partially belongs to the EARS), not forgetting the BGR projects in e.g. Uganda and Ethiopia. The same can be said about the Icelandic Development Agency - ICEIDA with its project in Uganda and an upcoming project in Eritrea.

The status of exploration and utilization of geothermal energy resources in the East African region for the last three decades has been summarized by Teklemariam (2008):

- The region has a large untapped geothermal resource potential;
- The geothermal resources are an indigenous, reliable, environmentally clean and economically viable, renewable energy resource;
- Development of geothermal resources is constrained by
    i. the risks that are associated with resource exploration and development;
    ii. the financial risks that are associated with investment in power development projects; and
    iii. lack of appropriate investment and institutional settings in many East African countries;
- Diversified use of geothermal energy augments energy supply from hydropower plants and improves the generation mix. It avoids vulnerability to drought and oil price fluctuations.

To light up East Africa by geothermal electricity, investors and financial assistance from international agencies are necessary, and the human capacity to deal with the exploration and development needs to be built up further.

In North Africa, low-temperature waters for direct use have been utilized successfully in Tunisia where hot water intended for irrigation is cooled down in greenhouses thus allowing production of quality products, such as cucumbers and melons, mainly for export to Europe (Figure 5). In 2008, the total area heated in geothermal greenhouses in Tunisia reached 147 ha, making it one of the largest producers in

FIGURE 5: A geothermal green house in Tunisia,
the hot water flows through plastic pipes at the ground surface

the world from geothermally heated greenhouses. Extensive use of geothermal water for bathing can be added to this as an important cultural habit with roots stretching back some thousands of years. Direct use of geothermal energy is also recorded for Algeria, and Morocco has been exploring for geothermal resources, but Tunisia provides the example for the other countries of North Africa to follow (Ben Mohamed and Said, 2008).

5. EXAMPLES OF USES OF GETHERMAL ENERGY IN ICELAND

Iceland is a unique country with regard to utilization of geothermal energy, with more than 50% of its primary energy consumption from geothermal energy. Direct use plays the most important role here with 89% of houses in the country heated by geothermal energy. Other uses include greenhouses, fish farming, industry, snow melting, swimming pools, etc., but even so only a fraction of the potential is used. Electrical production from geothermal power plants has also been developed rapidly in the last 5 years, amounting to about 25% of the total electrical production at the end of 2007 with an installed capacity of about 480 MWe (Figure 6), having since gone beyond the 500 MWe mark.

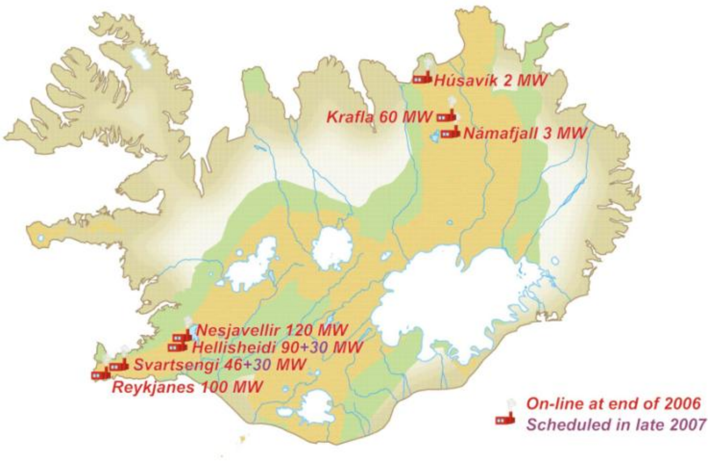

FIGURE 6: Geothermal power plants in Iceland in 2007

It can be said that geothermal energy is a way of life in Iceland. Reykjavik Energy supplies the capital, Reykjavik, and its surroundings, in total close to 200,000 people, with hot water for heating through 12 months of the year, making it the largest municipal heating service in the world. The geothermal swimming pools in Iceland are found in almost every village and small town. The most famous bathing place is, however, the Blue Lagoon (Figure 7), a byproduct of the Svartsengi power plant and located in a hostile lava field, 5-10 km from the nearest towns. It has become a landmark for Iceland and a must for any tourist to visit.

FIGURE 7: UNU Fellows bathing in the Blue Lagoon in 2003

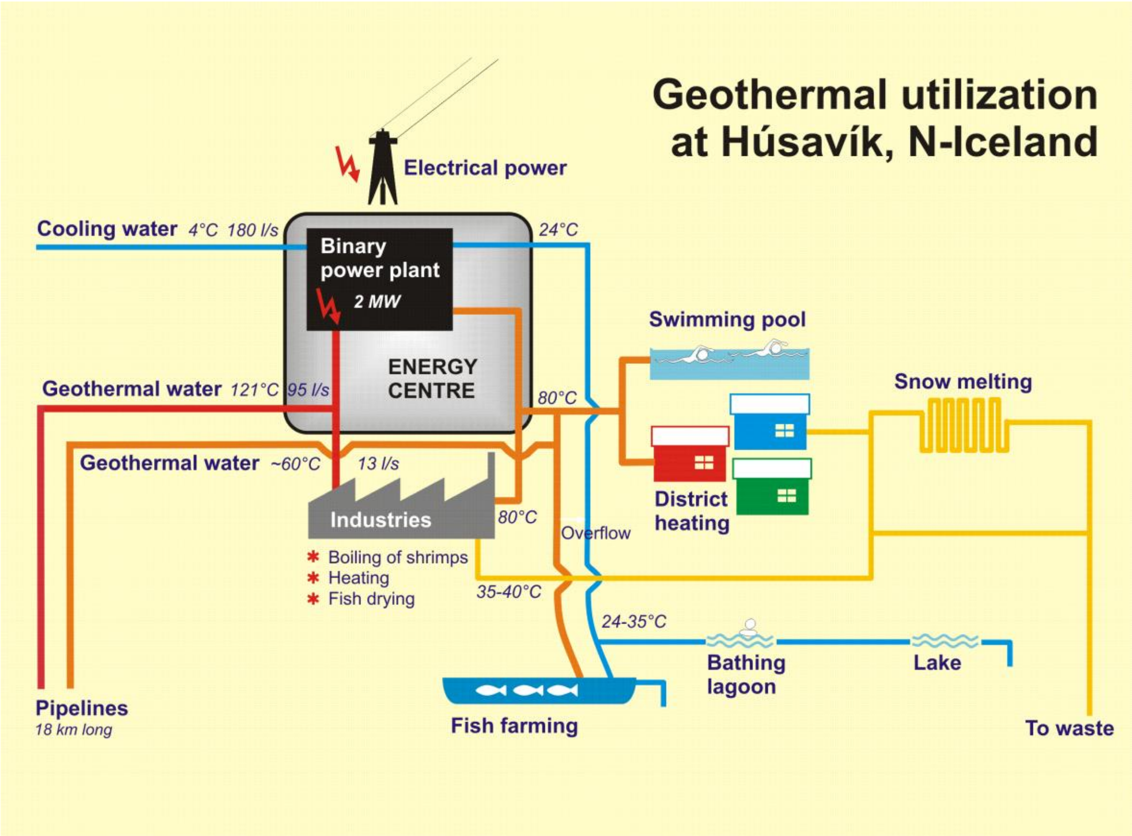

FIGURE 8: Schematic drawing of the Husavik Energy Centre and utilization of hot water at Husavik (Georgsson et al., 2005, modified from Husavik Energy, 1998; and Hjartarson et al., 2003)

The pioneering Husavik Energy Centre has been a prime example of cascaded uses of geothermal energy, with optimal use of the energy as the goal. Husavik, a coastal town of 2500 inhabitants in N-Iceland, had enjoyed a geothermal heating system since 1970, being supplied with its hot water from the Hveravellir geothermal field 18 km inland via an asbestos pipeline. In the late 1990s an extensive project plan for a new energy centre was put forward and initiated. This included renewal of the main supply pipeline from Hveravellir to enable the full use of the energy content of the geothermal water. A new pre-insulated steel pipeline with 400 mm diameter was built from Hveravellir to Husavik and carries 95 l/s of 124°C water to Husavik with only 3°C cooling on the way. The flexible cascading system built included a binary power plant based on the Kalina power cycle (e.g. Valdimarsson, 2003), with an initial installed capacity of 1.6 MWe that uses the power from the hot water upon cooling it from 121 to 80°C. The electrical production was designed to supply about 2/3 of Husavik's needs for electricity. During the years 2000-2004, the average annual production was about 9.4 GWh/a, very close to the designed values. Water and steam is also supplied for industrial use at temperatures up to 121°C. At temperatures from 80 down to 35°C the main utilization continues to be district heating at Husavik. At still lower temperatures, the water is used for bathing, snow melting and fish farming. Figure 8 shows the Husavik Energy Centre and the utilization of the geothermal water schematically. Some difficulties have been experienced in the material selection for the Kalina power system leading to mechanical problems. Improvements have been carried out and more are still needed, but that should not stop this novel system (Hjartarson et al., 2003; Georgsson et al., 2005).

6. THE GEOTHERMAL FUTURE

In a future where the emphasis is no longer on fossil fuels but on renewable and environmentally acceptable energy resources, geothermal energy is bound to have an important role. For developing countries which are endowed with good geothermal resources, it is a reliable local energy source that can, at least to some extent, be used to replace energy production based on imported (usually) fossil fuels. The technology is proven and cost-effective, and the technical potential is huge.

Geothermal energy is now on the threshold of becoming big in East Africa. Kenya has set itself very ambitious goals to reach in the coming decade, by declaring that geothermal is to become their main source of additional electricity in the near future. From current production of about 130 MWe, the plans are now to install additional 1260 MWe on-line by the year 2018 from geothermal.

Other countries in the region are slowly following in Kenya's footsteps. Ethiopia, Eritrea, Djibouti, Uganda and Rwanda are taking significant steps through new projects, partially in cooperation with foreign companies or investors, in exploration and development of their geothermal sources. The time has, however, come to take it one step further, to the energy production. That should be the trademark of the next decade in East Africa.

The UNU-GTP looks forward to see geothermal turn on the lights in the East African countries, and is determined to provide the training opportunities which the region needs, both in Iceland and hopefully also through a future UNU-GTP training centre in Kenya in cooperation with Kenya Electricity Generating Co. – KenGen.

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