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DIRECT UTILIZATION--THE INTERNATIONAL SCENE

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ABSTRACT

Direct utilization of geothermal energy has been practiced for centuries by the Japanese, Turks, Icelanders and Maori of New Zealand for bathing, cooking and space heating. Today over 7000 MW (thermal) are utilized in the world for space heating and cooling, agriculture and aquaculture production and for industrial processes. The most important developments outside of the U.S. are in Iceland, New Zealand, USSR, Japan, Italy, and Hvngary. Direct utilization has certain advantages over electrical generation in that a lower temperature resource can be used, the conversion efficiency is higher, and development time is shorter. In all of the international examples, the cost of the geothermal utilization is below that of comparable fossil fuel energy, and will be more competitive with future rises in fossil fuel costs.

Introduction

Direct utilization of geothermal energy was probably practiced by early man for cooking and heating. Recorded history shows uses by Romans, Japanese, Turks, Icelanders, Central Europeans, and the Maori of New Zealand for bathing, cooking and space heating. This use has continued to today where, for example, over 1,500 hot spring resorts exist in Japan, visited by 100 million guests every year. Early industrial applications include the use by the Etruscans of boric acid deposited by the steam and hot water at Larderello, Italy. They used the deposits to make enamels to decorate their vases. Commercial extraction of the acid started in 1818, and by 1835, nine factories had been constructed in the region. Municipal distric heating was first undertaken in Reykjavik, Iceland in 1928.

Today, over 7000 megawatts thermal (MW_t) are utilized in the world for space heating and cooling, agriculture and aquaculture production, and for industrial processes. Of this figure, over 1200 MW_t are used for space heating and cooling, approximately 5500 MW_t for agriculture, aquaculture, and animal husbandry, and over 200 MW_t for industrial processes. Typically, the agriculture-related uses require the lowest temperatures, with values from 25° to 80°C being typical. Use of wastewater has wide applications here. The amount and types of chemical and dissolved gases are a major problem for this use, such as boron and arsenic. Heat exchangers and proper venting of gases may be necessary in some cases to solve this problem. Almost all of the agricultural-related energy utilization is in the Soviet Union where over 5000 MW_t is reported being used. Space heating requires temperatures in the range of 65° to 100°C, with 40°C being used in some marginal cases and heat pumps extending this range down to 20°C. The leading user of geothermal energy for space heating is Iceland where over 50 percent of the country is provided with geothermal heat. The only known cooling is in Rotorua, New Zealand, at the International Hotel. Industrial processing typically requires the highest temperature, using both steam and superheated water. Temperatures above 150°C are normally desired; however, lower temperatures can be used in some cases, especially for drying of various agricultural products. Though there are relatively few examples of industrial processing use of geothermal energy, they represent a wide range of applications from drying of wool, fish, earth and timber, to pulp and paper processing, and to chemical extraction. The two largest industrial uses are the diatomaceous earth drying plant in Iceland and the paper and wood processing plant in New Zealand. A summary of the world utilization is shown on the maps in Figures 1, 2, and 3.

Application and Economics

Traditionally, direct use of geothermal energy has been on a small scale by individuals. Surface hot springs and shallow wells could be justified with on-the-spot use or short transmission distances in uninsulated pipes or channels. However, at today's prices for development and hardware, the cost savings of these individual uses are often marginal. Large-scale demands require more productions and can thus justify deeper wells, longer transmission distances, more sophisticated utilization and lower temperatures.

Most of present day international developments involve large-scale projects such as district heating (Iceland), greenhouse complexes (Hungary), or major industrial use (New Zealand). Heat exchangers are also becoming more efficient and better adapted to geothermal use, allowing the use of lower-temperature waters and highly saline fluids. Heat pumps are extending geothermal development into

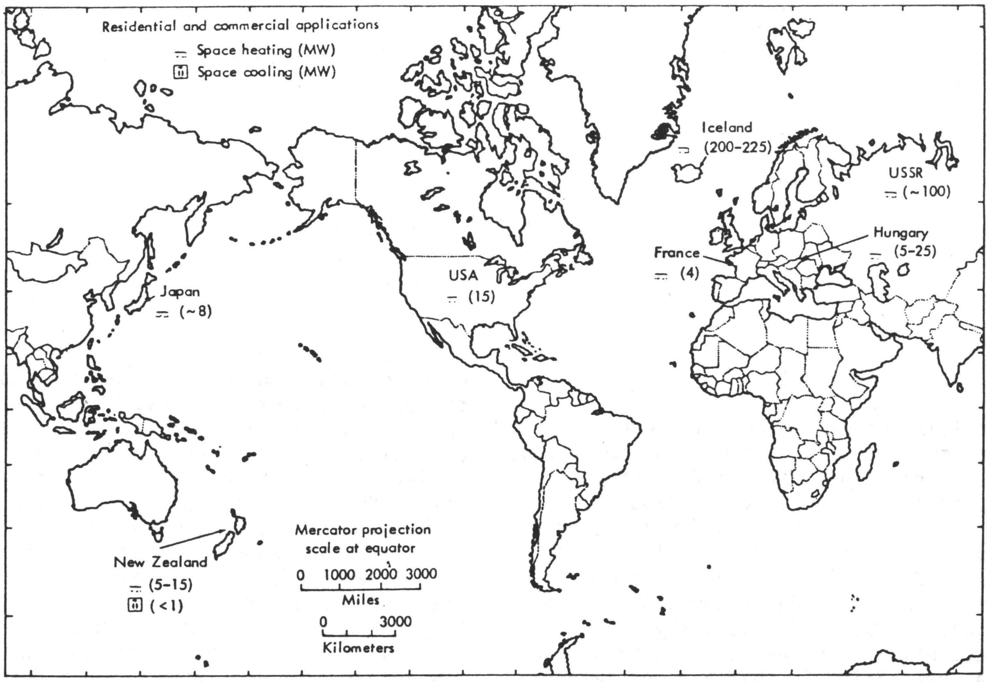

Figure 1. Space Heating and Cooling Applications.
(Howard, 1975)

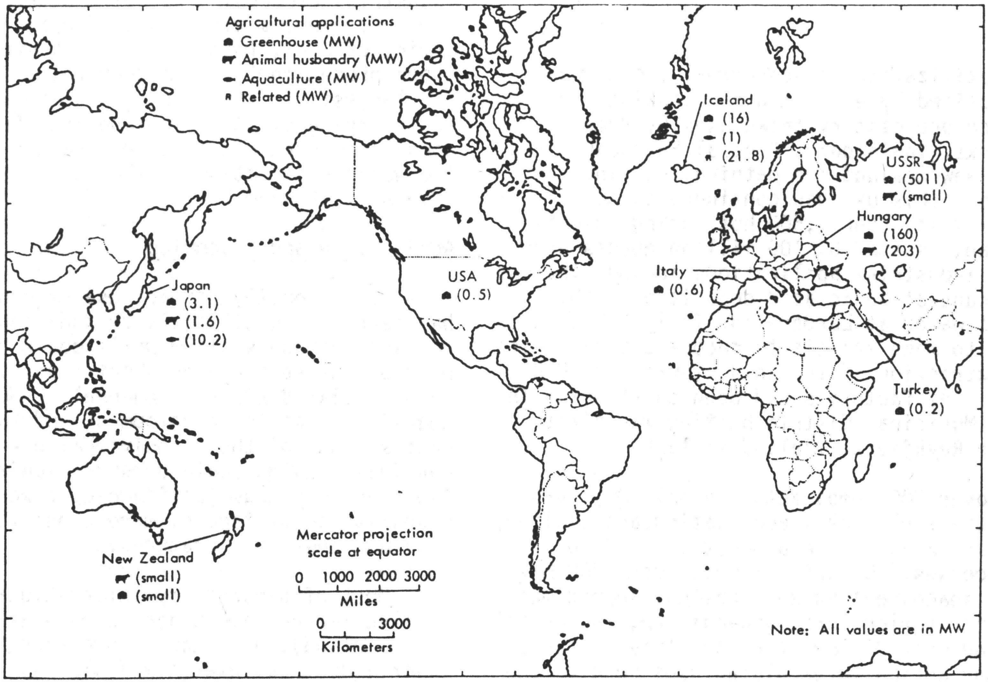

Figure 2. Agricultural Applications in Various Geothermal Regions.
(Howard, 1975)

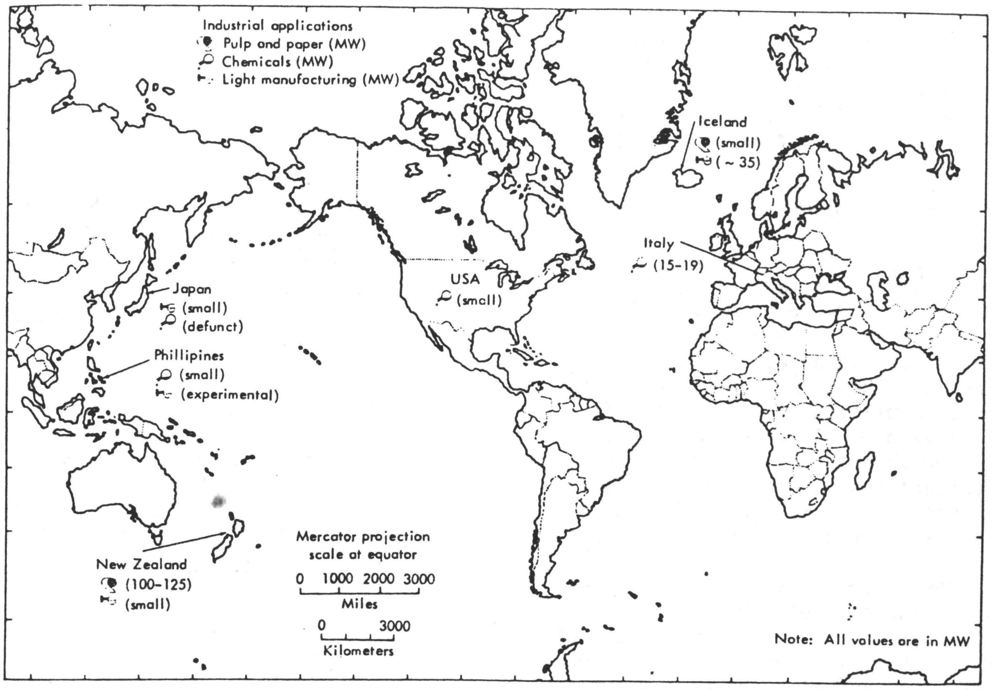

Figure 3. Industrial Applications in Various Geothermal Regions. (Howard, 1975)

traditionally nongeothermal countries such as France, Austria and Denmark.

Transmission distances of 50 and 100 km are being considered and proven economical on paper (Akureyri, Iceland), with 20 km presently a reality (Reykjavik). Transmission temperature losses in the below 100°C range are around 0.1°C/km for insulated pipe and 1°C/km for uninsulated pipes. Steam and superheated water cannot be transmitted long distances economically due to the higher temperature differences. Well depths of 2000 to 4000 m are now being used where 500 m was economical before. Deeper wells also allow use of the geothermal gradient to advantage in lower-temperature areas.

The main advantages with direct utilization of geothermal energy are:

1. High conversion efficiency (80 to 90 percent).
2. The use of low-temperature resources, which are numerous and readily available.
3. The use of many off-the-shelf items for exploitation (pumps, controls, pipe, etc.).
4. Short development time as compared to electrical energy development.
5. Lower-temperature resources require less expensive well development (and shallower in some cases), can be drilled with conventional drilling equipment in many cases, and the resource can be transported great distances.

All of the previous advantages give a favorable economic situation when compared to conventional fuel. At present day prices, the geothermal application will cost 60 to 75 percent of the corresponding fossil fuel cost. Due to the expected escalation of fossil fuel prices, the costs of the geothermal system will reduce to 30 to 40 percent in 20 years. Most geothermal direct-use systems will pay for themselves in 5 to 10 years from savings in conventional fuel.

The economics are greatly enhanced where cascading (multistage use) is considered. The Japanese optimize cascading where geothermal fluids are first used for electrical power production, then space heating, cooking and bathing (Otake). Here, an attempt is made to "squeeze" the "last drop of energy" from the fluid. Lower-temperature cascading could consider space heating, agriculture, bathing (swimming pools), and snow melting.

A specific example of geothermal costs are shown by two district heating projects in Iceland (Reykjavik and Akureyri), where the proportions of cost are as follows:

Production costs (wells and wellhead pumps):	15 to 25 percent
Transportation (main pipelines from fields):	18 to 20 percent
Storage and distribution system (tanks, pumping stations, local pipelines):	58 to 66 percent

The Akureyri system will cost about $20 million for 12,000 inhabitants (20,000 projected) and the Reykjavik system has a present replacement cost of $60 million for over 100,000 inhabitants. This results in a capital cost of from $150 to $200 per installed kW of thermal capacity or 0.5 to 1.0¢/kWh. Annual maintenance and operation costs are about 4 percent of the capital cost.

An example of industrial processing is the use of geothermal steam for the Tasman Pulp and Paper Company in New Zealand. Here from 100 to 125 MW (18 tons/hr steam) of thermal energy is used for the timber drying, black liquor evaporation and pulp and paper drying. The total investment cost for geothermal is $6.8 million, the majority of which is for well development. This amounts to approximately $70 per kW_t and will reduce the price of energy to 70 percent that of conventional fuels for an annual savings of $1.3 million. The annual maintenance costs are 2 percent of the capital cost.

The cost of greenhouse operations are more difficult to estimate. The main economic advantage is that geothermal energy allows operation in areas of colder climate where operation would not be economically feasible with fossil fuel. The best example of this is the location of greenhouses by every hot spring and geothermal pipeline in Iceland for the growing of flowers and vegetables (tomatoes and cucumbers).

A visual representation of the required temperature for various direct thermal uses is shown in Figure 4 (Lindal, 1974--OIT Proceedings). Here both water and saturated steam are shown and cascading can be easily visualized.

The major geothermal developments and utilizations in various international countries are briefly described in the following sections. No attempt was made to give details on each project due to space limitations. The details can be found in the reference listed at the end of this paper.

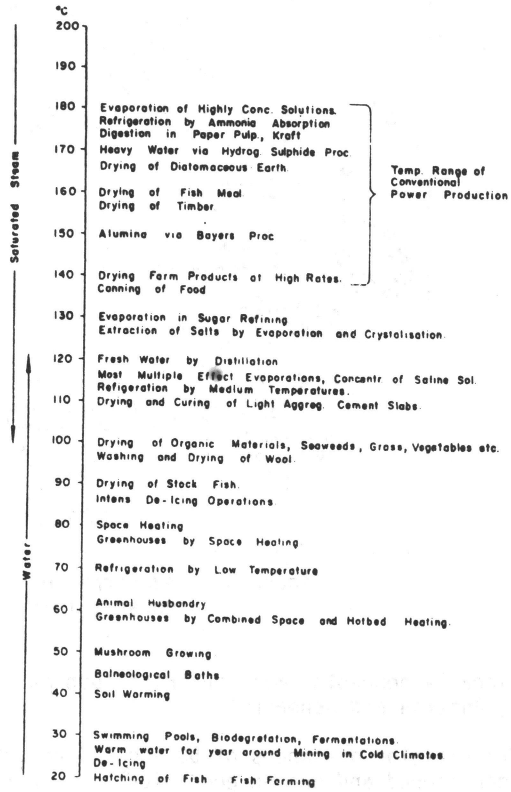

Figure 4. The Required Temperature of Geothermal Fluids (Approximate)(Lindal, 1974).

Iceland

Iceland is located on the crest of the mid-Atlantic ridge and thus is the center of much volcanic and geothermal activity. Both high- and low-temperature systems exist in the country with the former being used for electrical power generation and industrial processing, and the latter used for space heating and greenhouses. At the present time, about half of the country is heated by geothermal energy and by 1980 to 1982, 80 to 85 percent of the country will be heated with geothermal energy. Almost every hot spring and known source of geothermal energy is being utilized to some extent, with areas having no nearby geothermal source to be supplied with hydroelectric power or electrical power from the geothermal plant under construction at Krafla.

The most noted direct thermal applications in the country are: the Reykjavik municipal heating project serving about 97 percent of the 113,000 people in the area; the Hveragerdi greenhouse community in southwestern Iceland where individual homes, greenhouses, a greenhouse restaurant and a horticulture college are all heated by geothermal hot water and steam--in total over 140,000 m^3 of greenhouses are heated by geothermal in Iceland; the Myvatn diatomaceous earth drying plant in northern Iceland using high-temperature steam to remove about 80 percent of the moisture from a diatomaceous slurry dredged from nearby lake Myvatn; and various experimental projects for the drying of wool, fish, seaweed, hay and other grains. Other projects of interest are the Sudurnes Regional Heating project presently under construction on the Reykjanes peninsula, heat exchanging deep saline geothermal fluids with shallow fresh water, the latter which is then piped through a large above-ground distribution system; the Husavik district heating project transporting geothermal hot water 18 km in an economically earth insulated pipeline; and the Akureyri district heating project in northern Iceland, to provide heat for a city of 12,000. A summary of the district heating projects in the country are listed in Table 1 (Einarsson, 1975--UN Proceedings).

Table 1. Geothermal Space-Heating Systems in Iceland.

Location	Power (MW)	Number of people served
1. Systems in operation, 1975		
Reykjavik	385	88 000
Seltjarnarnes	22	2 500
Selfoss	12	2 700
Hveragerdi	9	1 000
Hvammstangi	1.7	400
Saudarkrokur	9.4	1 800
Olafsfjordur	3.2	1 100
Dalvik	3.5	1 100
Hrisey	1.3	300
Husavik	15	2 100
Myvatn	1.1	200
Laugarvatn	1.5	200
42 Rural boarding school centers	10	
Subtotal	474.7	101 400
2. Systems in construction to be commissioned, 1975/76		
Kopavogur	46	11 700
Hafnarfjordur	43	10 900
Gardahreppur	14	3 400
Subtotal	103	26 000
3. Systems being planned		
Svartsengi Project (Keflavik Airport and neighboring communities)	100	10 300
Subtotal	100	10 300
Total	677.7	137 200

Since a variety of transmission lines are being used in Iceland representing various conditions of buried and above-ground installations, typical cross sections of these are shown in Figures 5, 6, and 7. Figure 5 is typical of the Reykjavik pipeline, Figure 6 is typical of the Sudurnes project, and Figure 7 is typical of the economical Husavik project. The larger diameter pipelines will cost $150 per meter above grade and $250 per meter when buried in a concrete conduit.

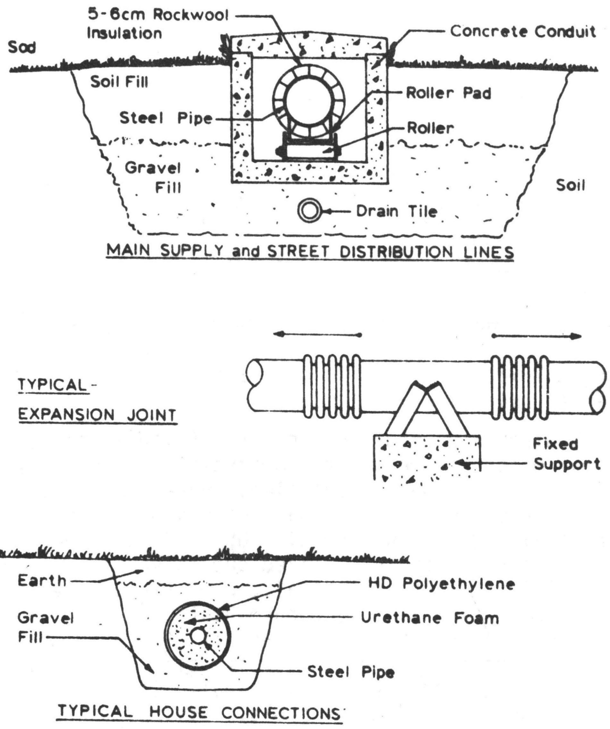

Figure 5. Cross-Section of Supply Lines.

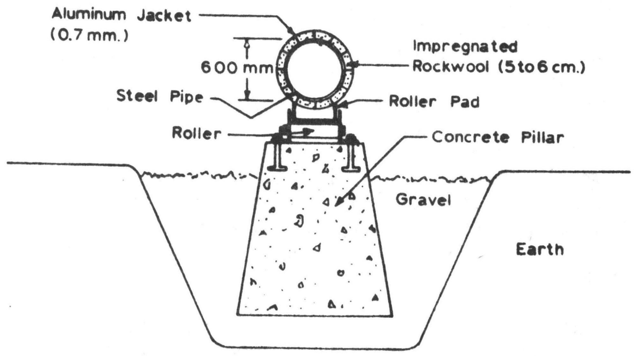

Figure 6. Above Ground Main Supply Lines.

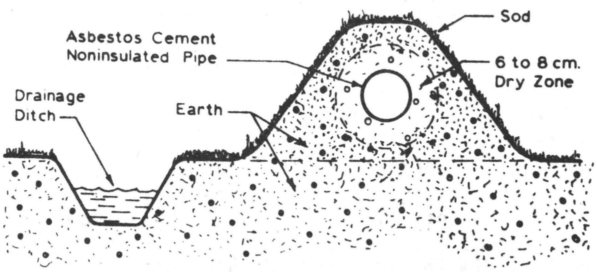

Figure 7. Long Distant Supply Line to Few Customers

New Zealand

This country is also noted for its variety of direct geothermal applications. All of the sources are located in the Taupo volcanic depression of North Island in the vicinity of the Wairakei and Broadlands electrical power generation fields. At Kawerau, the Tasman Pulp and Paper company uses high temperature steam for timber drying, black liquor evaporation, pulp and paper drying and electric power generation. Approximately 345,000 tons of newsprint, 160,000 tons of kraft pulp and 190,000 m^3 of timber are produced annually. Six wells are presently being used to provide 180 tons/hr of steam. One of the largest wells in the world is located here, estimated to produce over 25 MW of thermal energy (170 tons/hr).

At Rotorua, the second most extensively exploited geothermal resource in the country is located. Steam and hot water from approximately 350 shallow wells has been used on a small scale to heat homes and buildings, domestic hot water supplies, steam cooking boxes and swimming pools. Geothermal steam and hot water are also used in mineral bathing pools, for hot hours horticulture and soil sterilization, kiln drying of timber, and to drive a large hotel air conditioning refrigeration plant. After use, the geothermal effluent is discharged down shallow soak holes. Rotorua is known for the numberous mineral hot baths and therapeutic baths. The Queen Elizabeth Hospital was built during the war for U.S. servicemen and eventually was developed by the Department of Health as a national hospital for the treatment of rheumatic diseases. The hospital has 200 beds, an out-patient service and a Cerebral Palsy unit. Both acid and basic heated mud baths are used for the treatment of rheumatic diseases. The Forest Research Institute just outside the city limits, uses geothermal energy of space heating, timber drying, and seed drying and extraction. Future plans are to use the geothermal energy for refrigeration.

In the vicinity of the Broadlands field are several unique applications of geothermal energy. At the Lands Survey Nursery in Taupo, greenhouses are heated by geothermal steam and soil is sterilized (pasteurized) at 60°C to kill insects, fungus, worms and some bacteria. At Lake Rotokaua, an estimated 20 million tons of sulfur lie within 60 meters of the surface having a purity of up to 80 percent. Originally, the sulfur was extracted by the Frasch process using geothermal steam injected in 4 bore holes. Presently, they are strip mining the low grade surface deposits and using geothermal steam to extract the sulfur. The sulfur is then combined with cold water in a slurry and shipped by tanker truck for use in fertilizer production. At Broadlands, a cooperative of 12 farms have joined together to construct a geothermal alfalfa (lucerne) dehydration plant. The plant uses 135°C steam in a large forced air heat exchanger for drying. The drier is a simple fixed bed, double pass drier, discharging into a hammermill and pellet press for the final product. The plant produces one ton of compressed pellets per hour from five tons of fresh alfalfa. The annual production is from 1,000 to 1,500 tons, with a production of 10,000 tons possible.

Japan

Many diverse uses of geothermal fluids have been attempted in Japan in addition to the well known power generation and bathing. Most of these uses have been on a small scale, however, their commercial importance is now being recognized. A list of the uses is shown in Table 2.

Greenhouses cover about 15,500 m^2 in Japan where a variety of vegetables and flowers are grown. Many large greenhouses are operated as tropical gardens for sightseeing purposes. Raising poultry through the use of geothermal energy has been a very successful enterprise. Here, under-the-floor heating is utilized in sheds that raise 40,000 chickens annually. Fish breedings is another successful business where carp and eels are bred and raised. The eels are the most profitable and are raised in 24 cm diameter by 6 m long earthenware pipes. Water in the pipes is held at 23°C by mixing hot spring water with river water. The adult eels weigh from 100 to 150 grams, with a total annual production of 3,800 kg. Alligator and crocodiles are also raised in geothermal water. These reptiles are being bred purely for sightseeing purposes. In combination with greenhouses offering tropical flora, alligator farms are offering increasingly large inducements to the local growth of the tourist industry.

Some space heating is undertaken, but only on a very limited scale. Most hot spring bathing resorts are heated geothermally, as well as communities downstream from the Otake geothermal plant. In this later case, the waste water from the plant (165 tons per hour) is used for space heating, baths and cooking. Plans are being developed for large scale space heating projects in the Sounkyo and Hokkaido areas of Japan.

Japan has also used geothermal hot water for melting snow on highway pavements. The best known location is near the Jozankei Spa, Sapporo City on Hokkaido, where a narrow road with an 8 percent grade has been constructed with pipe laid beneath the pavement. In this 600 m long section, 88°C hot water is circulated by means of pumps at a rate of about 100 l/min and discharged at 65°C where it is reused for bathing. The system is designed for a 1.7 cm/hr snowfall and cost \$8.67 per square meter to construct and \$0.13 per square meter to maintain.

Diversified Use	Area Tried
Space heating	Narugo and Jozankei
Melting road snow	Jozankei
Sewerage heat treatment	Kamisuwa (now suspended)
Livestock barn heating	Kannawa
Poultry raising	Beppu and Shimogamo
Tropical animal breeding	Kannawa, Atagawa, and Nagashima
Tropical fish breeding	Various places
Food fish breeding	Shikabe
Prevention of freezing of fire fighting water	
Cooking	Various places
Bathing	Various places
Heating swimming pools	Various places
Sinter extraction (alum)	
Collection of dissolved gases	
Salt-making or desalting sea water	Shikabe, Ibusuki, Obama, and Shimogamo (now suspended)
Greenhouse horticulture	Shimogamo and Beppu
Tropical botanical gardens	Various places
Growing of sapling	
Soil disinfecting	
Heating irrigation water	Kawazu
Food drying and processing	Ibusuki and Kannawa
Mineral water	Shimobe
Medicinal uses	Various places

Table 2. Geothermal Uses Attempted in Japan.

Hungary

Geothermal energy in the form of low enthalpy thermal water has been used commercially in Hungary since 1962. At the present time, there are over 130 geothermal wells in Hungary with a peak production of almost 800 MW thermal. Only 30 to 35 percent of this energy is utilized due to variations in seasonal loads. The principal use of the energy is for space heating and greenhouse heating. The main geothermal district heating plant is at Szeged in southern Hungary. Here, university clinics, 1,200 flats, schools and several municipal buildings are heated along with swimming pools. Several other communities which include factories and hospitals are heated by individual wells.

The greenhouse heating is second only to the USSR, with over 1.2 million m^2 being heated. Many of these greenhouses are built on rollers, so they can be pulled from their location by tractors, the ground cultivated with large equipment, and then the greenhouse returned to its location. In addition, to minimize cost, much of the building structure pipe supporting system also acts as the supply and radiation system for the geothermal fluid. About 60 wells are used for animal husbandry projects, mainly for heating and cleaning of animal shelters. Priority is given to agricultural use of geothermal energy in Hungary, as this increases the volume and variety of production.

Some experimental work is being performed with grain, hay, tobacco and paprika drying. In these cases, hot water supplies heat to forced air heat exchangers, and 50° to 60°C air is blown over the product to be dried.

Italy

Historically, boric acid was obtained from the geothermal fluids at Larderello in Tuscany. Originally the boric acid was obtained by boiling off the geothermal water using firewood as a heat source. From 1827 onwards, geothermal steam was used as the energy source. With increase in production, growth in trade, and refinement of the process, a wide range of boron and ammonium compounds were produced in the early 1900s. This process continued until World War II, where a total of 6,500 tons had been produced. After the war, the plant was put into operation again, only this time the raw product was imported from Turkey, and geothermal steam used as the drying source. Approximately 30 tons of steam per hour are used in the process.

Residual steam for older and low production wells in the Larderello and Castelnuovo area of Tuscany are used for space heating and greenhouse operation. A total of 350,000 m^3 of space is heated, the majority of which is industrial. In addition, a total of 7,000 m^2 of greenhouses are heated. The savings amounts to $600,000 per year when compared with fuel oil. Another 20,000 m^2 of greenhouses are also heated in the Province of Padua. Here, 74 hotels-spas and some private homes are heated with 450 l/sec of 65° to 87°C water. Several other smaller locations exist in Italy where hot springs are utilized in spas and then for domestic heating of the same building.

France

The geothermal temperature gradient in France is around 36°C per km. Using the geothermal gradient, two heated aquifers can be found in the Paris region, one at 30°C and the other at 70°C. Relatively pure water from the cooler layer has been used in heat pumps to service the Radio Paris building for over 12 years. During the summer, the heat pump is used for air conditioning. A cost comparison at the time of construction indicated that the capital cost of the heat pump (including the well) and a comparable fuel fired boiler were about the same. The annual operating cost of the heat pump was significantly less, and provided an added bonus in that the water could be reused for domestic purposes in the building instead of purchasing city water service.

More recently, the higher temperature layer of water has been used to heat part of a 3,000-dwelling development of social housing in Melun, near Paris. Here, 2,000 apartments are heated by two wells pumped at a rate of 1400 l/min. The geothermal water passes through a heat exchanger (due to high salinity) and the secondary side at 55°C is heated by two peak load boilers to 85°C. The geothermal provides just under half of the total heating and domestic water requirements of 11 million Kcal/hr. The two peaking boils are only required during the winter and late fall and early spring. The system has been in operation since 1970 and the only major trouble encountered was the failure of the heat exchanger after six months due to corrosion. These have been replaced with ones of titanium, which have solved the problem. Residents pay an initial hookup fee, and then a flat rate for the quantity of water used.

USSR

The USSR has enormous geothermal reserves with 50 to 60 percent of the country underlain by hot water suitable for commercial use. This resource has temperatures from 40° to 200°C, dissolved solids up to 35 g/l and exist to a depth of 3500 m. The two main uses of direct geothermal energy is for space heating and agriculture. The majority of the utilization is in the regions of Georgia and Daghestan between the Caspian and Black Seas, and on the Kamchatka peninsula of eastern Siberia. Approximately ten different communities are provided with a portion of their space heating by geothermal and over 25 million m^2 of agricultural land is heated by geothermal. The latter figure probably includes about 100,000 m^2 of greenhouses, with the remainder being heated ground either uncovered or provided with only minimal protection against the elements. Heat pumps are also apparently being utilized to a great extent. Future uses include thawing frozen ground, salt extraction and ore processing.

Other Countries

Several other countries are using goethermal energy to a minor amount. Germany, Austria, and Czechoslovakia have used hot springs for bathing and heating of spas for centuries. Present plans are to expand the use of these localized geothermal sources for district heating. India is doing some experimental work with greenhouse in the southern Himalayas, and Turkey is doing experiment work in the Kizildere field with a 1000 m^2 pilot greenhouse. On Taiwan, experiment work is being undertaken with a lumber-drying kiln to produce 240 m^3 of kiln-dried lumber per month, a greenhouse for vegetables and flowers, and a laboratory to test technical procedures of soil sterilization, grain drying, and fish and poultry production with 25° to 60°C fluids. The pilot project will be supplied by one well producing

3.5 tons of dry steam per hour at 130°C. An experimental project at Tiwi on the Philippines is being used for salt production, grain drying, fish canning and refrigeration. A single well in the Tiwi field, providing almost 8 tons of steam per hours is being used in this research project.

Summary of Present Utilization

Based on communications with personnel in other countries, personal visits to some countries, and references, the following is an estimate of the current international utilization of geothermal energy for nonelectric or direct thermal applications:

Country	Space Heating/ Cooling (MW_t)	Agriculture/ Aquaculture (MW_t)	Industrial Processes (MW_t)
Iceland	680	40	50
New Zealand	50	10	150
Japan	10	30	5
USSR	120	5100	--
Hungary	300	370	--
Italy	50	5	20
France	10	--	--
Others	10	10	5
USA	75	5	--
TOTAL	1245	5570	230

This gives a grand total of 7045 MW_t peak use in the world.

Future Trends

The main emphasis will be in space heating and agricultural production in the future. Large scale and more efficient district heating projects will be undertaken (such as is being proposed in Rotorua, New Zealand). Space heating will become more and more economical with futher escallation in conventional fuel prices. Nongeothermal countries such as Denmark are investigating the use of fluids heated by the normal geothermal gradient. Since 43 percent of the energy consumed in the country is for space heating, the use of geothermal is of interest. The project in Melun, France will serve as a model, using heat pumps or conventional fuel to peak the low temperature geothermal fluid. Agriculture will have great emphasis placed upon it to increase food production and to grow crops in colder climates where none could be grown before on a commercial basis. Soil warming will be used to extend the growing season. Aquaculture will be developed in colder climates, as it has been shown that outdoor ponds can be kept at nearly constant temperature, even in below freezing temperature (Klamath Falls, Oregon). Growth rate and reproduction can be increased with these constant temperatures, an advantage over warm climate locations where solar heating varies. Industrial processing will also increase, but not to the extent of space heating and agriculture. Some existing plants will be retrofitted due to shortages of conventional fuel--however these plants will be competing for high temperature resources that are traditionally used for power generation. In arid climates, such as the Middle East, geothermal deposits will be used to purify salt water for domestic consumption. The main emphasis for direct thermal use and development will be the national interest of various countries to become less dependent on imported fuels.

References

The details of most of the projects listed in this paper can be found in the following references:

1. Geo-Heat Utilization Center, Quarterly Bulletin, Oregon Institute of Technology, Klamath Falls, Oregon, May, 1975, to date.

2. Howard, J. H., Editor, "Present Status and Future Prospects for Nonelectrical Uses of Geothermal Resources," Lawrence Livermore Laboratory, Report UCRL-51926, Livermore, California, October 3, 1975.

3. Lienau, Paul J. and John W. Lund, Editors, "Multipurpose Use of Geothermal Energy," Proceedings of the International Conference on Geothermal Energy for Industrial, Agricultural, and Commercial-Residential Uses, Oregon Institute of Technology, Klamath Falls, Oregon, October 7-9, 1974.

4. Lund, John W., "Geothermal Energy in Iceland," Report prepared for USDI-Geological Survey, Oregon Institute of Technology, Klamath Falls, Oregon, August, 1977.

5. Peterson, Richard E., and Nabil El-Ramly, "The Worldwide Electric and Nonelectric Geothermal Industry, Geothermal Energy Magazine, Vol. 3, No. 11, November, 1975.

6. Proceedings of the Second United National Symposium on the Development and Use of Geothermal Resources, Volume 3, Section IX, "Space and Process Heating," and Section X, "Other Single and Multipurpose Developments," San Francisco, California, May 20-29, 1975.