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THE FRENCH GEOTHERMAL EXPERIENCE REVIEW AND PERSPECTIVES

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ABSTRACT

The development of geothermal energy in France began as the result of the two energy crisis in the 1970s, with an important development of activity from 1978 to 1987, when the energy prices fell.
More than 70 geothermal district heating operations using low-enthalpy resources were set up during this nine-year period. They were devoted to producing heating and hot water for around 200,000 housing units.
During the same period, research was initiated into the potential of Hot Dry Rock (HDR).
In addition to these two major activities, other actions were carried out, such as:

- the promotion of heat pumps to exploit shallow aquifers for building heating,
- the prospecting and development of high-enthalpy resources in the French Overseas Departments, with the construction of a small electric power unit in Guadeloupe,
- the implementation of operations using low-enthalpy resources for agricultural uses such as fish farming and greenhouse heating.

During the early 1990s, in view of the cheap energy prices, the authorities decided to progressively reduce their financial support for the promotion of renewable energies. Nevertheless, they maintained support for two priorities as regards geothermal energy: (i) resolving the scaling and corrosion problems affecting the geothermal district heating plants located in the Paris region, so that the exiting plants could be maintained in operation, and (ii) the continuation of the HDR research programme.
In 1997, with the Greens being elected into the French Parliament and with the necessity of controlling CO_2 emissions following the recommendations announced during Kyoto Conference, the French authorities once again began to express their interest in renewable energies and energy management. In 1998 they decided to increase their financial support for these activities. An active policy managed by ADEME was set up and became in operation in the beginning of 1999 with the following priorities being planned for geothermal energy:

- continuation of the HDR programme,
- dissemination of ground-source heat-pump technologies,
- development in the use of high-enthalpy resources in the French Overseas Departments,
- development in the use of metropolitan low-enthalpy resources with an extension of the existing geothermal District Heating plants to new consumers, and an extension of the duration of the Long Term Guarantee System by 10 years.

INTRODUCTION

Over the past 20 years, the French have specialised in the development of low-enthalpy geothermal energy resources for urban heating. They also initiated a research programme into the Hot Dry Rock (HDR) potential; this rapidly became a European Research Programme with the participation of the European Union and several European countries.
Following a period of low energy prices, and thus minimal interest for research into renewable energies, in the late 1980s and early 1990s, the French authorities decided in 1998 to boost these non-polluting energies in France, thus offering new perspectives for the development of geothermal energy.
The French geothermal experience and the perspectives for this energy in France over the next years are the subject of this paper.

1. THE FRENCH GEOTHERMAL RESOURCES

France's geothermal resources are mainly low-enthalpy from several aquifers containing hot water at temperatures over 50°C in the two country's major sedimentary basins: the Paris Basin, around Paris, and the Aquitaine Basin in the southwest.
A low-enthalpy geothermal potential also exists in other regions (Alsace, Limagne, etc.), but the geological conditions are more complex and the resources are more localised.
High-enthalpy resources exist only in France's overseas departments: effectively in Guadeloupe and Martinique, two islands situated in the Caribbean Sea, and probably in La Réunion, an Indian Ocean island situated near Madagascar.
France's metropolitan regions also contain a lot of shallow aquifers suitable for exploitation with heat pumps.
Work on the inventory of France's national resources was carried out by BRGM (the French Geological Survey) in collaboration with Elf Aquitaine (a French oil company). This work, especially for low-enthalpy resources, resulted in detailed mapping of depth, temperature, salinity, transmissivity, lithology and thickness for each reservoir.
The characteristics of the France's geothermal resources led, in the early 1980s, to the development of direct-use applications, especially through district heating systems.

2. GEOTHERMAL DISTRICT HEATING SYSTEMS

1969: MELUN L'ALMONT – the first operation

The first French geothermal district heating plant was constructed in 1969 at Melun l'Almont, a town situated in the Paris region, for heating 3000 housing units. Using a

geothermal resource issued from the Dogger reservoir, a carbonate aquifer lying at 2000 m depth and containing large quantities of dissolved salts and gases, this was the plant where the doublet concept (a production well associated on the same site as a reinjection well) was initiated.
The Melun plant, which is still operating, is also the site where the triplet concept was initiated in 1995 with the addition of second production well. This well, of larger diameter and protected against corrosion with *a combined steel casing / fibreglass lining*, was added to the existing 'doublet' loop and designed to operate in 'triplet'. The operation of two production wells and one reinjection well made it possible to increase the geothermal water production and to connect, in 1998, a further 2200 dwellings to the geothermal district heating system.

1980-1986: increase in the number of geothermal district heating plants

In view of the success of the Melun Plant, an installation that had been in operation for 11 years without any problems, the French authorities, confronted with the second oil crisis in 1980, decided to encourage the development of such installations within the framework of a support policy for renewable energies.
The result was that more than 70 operations, essentially devoted to urban heating, were set up between 1981 and 1986 in two main regions: the Paris Basin and the Aquitaine Basin. These operations benefited from the favourable conditions that existed at that time, i.e.:
- high energy costs and a rate of inflation that favoured investment,
- Government incentives, such as the creation of a panel of experts to examine projects and propose financial aids,
- an insurance covering the drilling phase, accompanied by a 15-year guarantee on the resource. This policy, still in effect, was one of the major determining factors for persuading owners to choose geothermal energy.
- regulations governing the exploitation of the subsurface and defining the rights and responsibilities of all involved.

Situation at the end of 1986

By the end of 1986, 74 geothermal plants were in operation: 54 in the Paris Basin, 15 in the Aquitaine Basin and 5 in other regions. Few geological failures had occurred during the drilling phase – the success rate had been 92% in the Paris Basin and 75% in the Aquitaine Basin, although only 11% outside these two regions.

1986-1990: The crisis

1986 saw the dawn of a new energy context with a drop in energy prices and technical difficulties beginning to affect some of the geothermal installations in the Paris Basin. Consequently, geothermal energy was plunged into a depression.
Several reasons contributed to this new situation:
- the prices of geothermal energy were indexed to those of fossil fuels, so revenues steadily decreased,
- the decreasing inflation rate from 1986 led to a progressively increasing the difference between the inflation rate and the interest rate of the loans incurred in the early 1980s to set up the operations (most of the installations had been largely financed through loans).
- the Dogger aquifer, which is exploited by all the existing geothermal plants in Paris Basin, contains large quantities of dissolved salts and gases that must be reinjected. This led to technical problems related to scaling on the metal parts of the geothermal loops due to the corrosiveness of the sulphide-rich geothermal fluid.
- a lack of competence on the part of the owners of the installations (these generally being the local communities) for resolving the financial and technical problems affecting the plants.

1987-1993: Solutions to the crisis

To improve the financial situation of 30 installations in the Paris Basin that showed a deficit, the Prime Minister assigned a Prefect the task of finding permanent solutions that would balance the budget of operating installations. Following negotiations with each owner, a protocol was signed with the French Government defining the obligations of all the parties (debt refinancing, lowering of interest rates, level of financial contribution from the cities, etc.).
The few operations that were not able to break even over the medium term were shut down.

To resolve the technical problems, notably corrosion and scaling of the metal casings, a two-part technical protection project was set up: one programme was devoted to basic research on the problems encountered, and the other to the experimentation and validation of new techniques. Major funding for both programmes was provided by ADEME, with BRGM and European Community, with two priority themes being defined: ***curative*** techniques for the elimination of scale and the reconditioning of the boreholes to restore the hydrodynamic well characteristics to a condition as close as possible to the initial state, and ***preventive*** methods for combating corrosion and scaling (well bottom treatment tubing – WBTT - with continuous injection of corrosion inhibitors). The results have been very encouraging and a ten-fold decrease in casing corrosion was noted after the installation of such a treatment.
Afterwards, all the Paris Basin operations were equipped with *WBTT*, with the financial support of ADEME.

1994-1998: stabilisation of the situation

Most of the problems being solved, the last years have been essentially devoted to optimising the geothermal heating networks and to extending them to new consumers.

1998: The present situation

Out of the 74 plants operating at the end of 1986, only 61 are still in operation today: 41 in the Paris region, 15 in the Aquitaine Basin, 5 in other regions. They heat and produce hot water for around 200,000 housing units, which corresponds to an annual substitution of 170,000 TOE and diminishes the emission of CO_2 by 650,000 tons per year.
In terms of economy, and in spite of a context of low energy prices, around one third of the plants in the Paris Region are profitable, one third break even and one third shows a deficit. Nevertheless, regardless of the varied competitiveness of the existing geothermal district heating plants, it can be shown that a new installation taking into account all the experience gained in recent years concerning design, exploitation, legal and financial existing aspects, would be certainly competitive with natural gas.

Perspectives

Geothermal operations require a very heavy capital investment, i.e. between FF 60 and 90 million (395 to 590 million US$) for a standard plant. It is understandable, therefore, that the present context of low energy prices is not conducive to public or private operators for developing new operations.

One of ADEME's activities over the next few years will be to support the existing installations through continuing the efforts made to optimise and develop them. For example, the potential of hooking up more than 30,000 housing units to existing operations has been identified in the Paris region. This, mostly concerns new housing units in which the heating elements will be adapted to low temperatures. In most of these cases, 100% of the heating-energy demand can be covered without any additional investment in heat production. In this respect, a support procedure based on a grant of 400 Euro (400 US$) per tonne of coal substituted by geothermal energy has been initiated for extending the heating networks.

Another measure is to extend the guarantee against the long-term geological risk. Initially programmed for 15 years, the Long Term Guarantee System will be extended by a further 10 years.

If possible, ADEME will also encourage the development of one or two new operations that takes into account all the experience gained to date. In this way ADEME hopes to demonstrate that a geothermal district system could be an interesting alternative to conventional heating systems.

3. RESEARCH INTO THE HOT DRY ROCK POTENTIAL

As well giving priority to the development of geothermal district heating operations in the early 1980s, France decided to support research into the potential of Hot Dry Rocks. The objective of this research is to develop an engineered system whereby geothermal energy can be extracted from hot rocks that are dry, or with only a low permeability, by artificially fracturing the rock mass and circulating fluid through it. The potential is high, since this type of rock constitutes the major part of the earth's crust and contains a considerable amount of stored energy.

After preliminary experiments in France, it was accepted that such research could not continue without the contribution of other countries. So, in 1987, a French/German collaboration agreement was signed aimed at undertaking a common HDR research programme at Soultz-sous-Forêts, situated in the former Pechelbronn oil field in north of Strasbourg near the border between France and Germany. This is a very suitable site since (i) a high heat flow had been observed in a large number of oil wells when the field was operational and (ii) there was the possibility of re-using old abandoned oil wells.

This Programme rapidly became a European Research Programme when the European Union, interested by the research being undertaken, decided in 1989 to add its financial support.

Eleven years after the beginning of this programme, the results of the experiments that have been carried out through scientific co-operation between French, German, British, Italian, Swiss and Swedish teams, are leading to the progressive validation of an original concept for Hot Dry Rock exploitation. For this reason the experiences of the European HDR research programme are now becoming one of the key elements in world-wide geothermal HDR research strategy: other major experimental programmes are being run in Japan, are under preparation in Switzerland and the USA, and are planned in Australia.

The three main phases of this long-term research programme are:

- a scientific evaluation of the Soultz-sous-Forêts experimentation site (1987→1997),
- the construction and testing of a scientific plant (1998 →2005),
- the construction of an industrial prototype plant **(2005 →)**.

The results of a four-month circulation experiment in 1997 are the best obtained anywhere so far for an HDR system, and have demonstrated that the concept developed at Soultz-sous-Forêts is very hopeful. This consists in establishing connections between boreholes and an open natural fracture system by injecting water at great depth under high pressure, and then adjusting the pressure in order to force the water to migrate between the wells using the natural fracture system.

As a result of this success, the next three years will be devoted to preparing the planned scientific plant. This will comprise a module of three wells, i.e. a central injection well and two production wells with a down-hole pump in each.

4. OTHER ACTIVITIES

Apart the two major activities described above, France has also initiated actions to exploit both very low enthalpy resources and high-enthalpy resources.

Very low enthalpy resources

As mentioned in the brief presentation of France's geothermal resources, the country contains a lot of geographically well-spread shallow aquifers (less than 100 m depth). In the early 1980s, these resources began to be exploited with heat pumps, essentially for collective or individual building heating. At present, several thousand such plants exist and contribute to substituting some 40,000 TOE/year.

Also during the early 1980s, some demonstration plants using groundwater heat pumps were implemented and evaluated. These covered such areas as combined drinking water and heat production, energy storage in the aquifer (warm-well/cold-well system), and the coupling of solar energy and groundwater energy (i.e. the use of solar collectors during summer to thermally recharge the exploited aquifer. Most of these demonstration plants are still in operation.

In the middle 1980s, with the drop in energy prices, groundwater heat pumps became less and less competitive in comparison with more conventional heating technologies, and so these activities rapidly ceased.

Then, in the early 1990s, a renewed interest for groundwater heat pumps was noted in connection with the development, in France, of central air-conditioning in buildings. Effectively, when a system such as a reversible heat pump can satisfy both heating and cooling requirements, then its competitiveness is greatly enhanced.

At the same time, the use of ***ground-coupled heat pumps*** and closed loop systems with horizontal or vertical heat exchangers, began to be developed in North America and certain European countries such as Switzerland, Germany, Sweden and Austria.

In these systems, the heat pump is connected to a heat exchanger comprising a closed loop with polyethylene tubes installed in trenches dug into the soil or in a well, 50 to 200 m deep. A mixture of water and alcohol circulates in the loop and collects the heat contained in the soil, which is then transferred to the heat pump. These systems, still not well known in France, are presently considered as one of the most efficient heating and cooling technologies for residential dwellings and commercial and institutional building applications.

In order to promote ground-source heat pump technologies in France, i.e. groundwater and ground-coupled heat pumps also called ***geothermal heat pumps***, an agreement was signed last year between ADEME and EDF (the French Electricity Board). Within the framework of this agreement, a demonstration programme, devoted in particular to ground-coupled heat pumps with vertical heat exchangers, is being set up in 1999. It is planned, over the next year, to implement around 50 well-instrumented plants for residential dwellings in order to obtain a better understanding of these systems, and then to disseminate them throughout France.

At the same time, actions will be undertaken to promote the use of groundwater heat pumps for the cooling and heating of commercial and institutional buildings.

High enthalpy resources

The existence of potential high-enthalpy resources, prospected in the France's overseas departments during the 1970s, has recently led to an interest in the use of these resources for producing electricity.

Three French overseas departments are concerned: Guadeloupe and Martinique in the Caribbean, and La Réunion in the Indian Ocean. These are all volcanic islands, with 400,000 to 600,000 inhabitants, where the energy situation is quite different from that in metropolitan France. Electricity is produced by conventional diesel-powered plants using imported oil and thus production costs are high. To face up to this situation, it was decided in the early 1990s to develop energy policies in these departments that call for improved management and a greater use of renewable energies, including geothermal energy.

The only active high-enthalpy geothermal operation at present is the Bouillante plant in Guadeloupe. The development of this operation began in 1984 when EDF built a small double-flash power unit (4.7 MWe) that was connected to the local grid in 1985. However, EDF, not being really specialised in geothermal energy, the unit was closed down in 1991 after a lot of problems.

Faced with this situation, ADEME succeeded in persuading EDF to enter into close collaboration with a subsidiary of BRGM specialised in geothermal power plant activity, with the aim of re-opening the Bouillante plant. Detailed studies led to a simplification of the installation design and the power unit was reconnected to the grid in 1996. Today this plant produces 2% of Guadeloupe's electricity.

The next planned phase is to develop the Bouillante field with the objective of increasing its production capacity to 20 MWe (i.e. 10% of the Guadeloupe's electricity supply). To this end, an insufficiently productive well drilled in 1974 was successfully stimulated at the beginning of this year by the injection of a large quantity of cold water to enlarge the existing fractures. In addition, three new wells will be drilled in 1999/2000.

Development of the geothermal electricity potential is also expected in Martinique and La Réunion. These two French Overseas Departments were also prospected in the past, and complementary studies are planned over the next few years.

5. CONCLUSION

Compared to the situation in 1995, there has recently been a renewed interest on the part of the French authorities and the private sector in the potential of geothermal energy. Although the present context of low energy prices is not really favourable for a major development of renewable energies, the advantages of these energies in terms of the environment (no gas emissions in the case of the geothermal district heating in Paris area) are so obvious that they will inevitably take a more important slice of the world energy contribution in the next years

This renewed interest for geothermal energy has been accompanied by a broadening of the development potential for geothermal energy in France. This is due in part to a diversification of the exploitable resources and in art to a diversification in the end-users.

In metropolitan France, the greatest potential for development would appear to be in area geothermal heat pump technologies for air-conditioning (alternate heating and cooling depending on the season) buildings, i.e. groundwater and ground-coupled geothermal heat pump systems. The other area for major development, although still in the longer term, is the Hot Dry Rock potential.

In France's overseas departments, we note an increasing interest for geothermal electricity production.

As regards the existing low-enthalpy operations in France, we can expect to see continued improvement in the production of geothermal heat, despite the fact that no new plants have been constructed. In particular, several positive factors are to be noted where the geothermal urban heating operations in the Paris Basin are concerned, i.e. the 36 doublets and 1 triplet exploiting the deep Dogger aquifer:

- from a technical standpoint, and despite the ageing of the installations (all at present between 12 and 30 years old), there has been no increase in the number of adverse incidents. The corrosion problem appears to have been checked, and the use of corrosion inhibitors is now standard. In addition, we have seen no deterioration in the characteristics of the geothermal resource as far as temperature and yield are concerned.
- from the financial standpoint, following the debt refinancing in the early 1990s and taking advantage of a new legislative context with favourable incentives for the development of cogeneration, many of the geothermal operations have recently equipped themselves electricity production systems, and delivering the residual heat to the urban heating network. The advantageous conditions offered by EDF for purchasing the produced electricity has greatly improved the operating accounts of the plants equipped with cogeneration systems. The tie-in of a gas cogeneration to the geothermal installations has generally led either to an increase in the supply of heat to the network and so allowing new buildings to be connected, or to a lesser call on geothermal heat that, in some cases, has made it possible to pass from a costly submersible pump operation to a purely artesian operation.

Geothermal resources can provide local energy with a large range of possible applications. In France, the industry is mature and the research and demonstration programmes set up over the last 15 years have shown both the reliability and the high degree of innovation where this energy is concerned. With the extensive experience and know-how that have been acquired, the recent decision taken in France to boost renewable energies is a good opportunity to show that geothermal energy can effectively satisfy more energy needs with a respect of the environment.

TABLE 3.1. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT
AS OF 31 DECEMBER 1999

[1)] I = Industrial process heat — H = Space heating & district heating (other than heat pumps)
C = Air conditioning (cooling) — B = Bathing and swimming (including balneology)
A = Agricultural drying (grain, fruit, vegetables) — G = Greenhouse and soil heating
F = Fish and animal farming — O = Other (please specify by footnote)
S = Snow melting — W = Domestic hot water

[2)] Enthalpy information is given only if there is steam or two-phase flow

[3)] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4)] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5)] Capacity factor = [Annual energy use (TJ/yr) x 0.03171]/Capacity (MWt)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

		Maximum Utilization					Capacity[3)]	Annual Utilization		
Locality	Type[1)]	Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outllet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Paris Basin										
Alfortville	H + W	72	74	47			8.1	36	129.6	0.51
Bonneuil sur Marne	H + W	83	79	49			10.4	32	128.2	0.39
Cachan Nord + Sud	H + W	95	70	40			11.9	45	180.0	0.48
Champigny sur Marne	H + W	77	78	45			10.6	45	198.0	0.59
Chelles	H + W	77	68	40			9.0	32	117.0	0.41
Chevilly Larue }	H + W	167	73	43			21.0	60	239.0	0.36
L' Hay les Roses }										
Clichy sous Bois	H + W	50	71	45			5.4	22	75.6	0.44
Coulommiers	H + W	70	83	60			6.7	44	133.9	0.63
Creteil	H + W	83	74	44			10.4	49	194.4	0.59
Epinay sous Senart	H + W	70	74	44			8.8	47	187.2	0.68
Fresnes	H + W	55	72	42			6.9	32	126.0	0.58
La Courneuve Nord	H + W	55	58	40			4.1	32	75.6	0.58
La Courneuve Sud	H + W	50	56	40			3.3	35	73.9	0.70
Le Blanc Mesnil	H + W	70	67	40			7.9	19	69.1	0.28
Le Mée sur Seine	H + W	55	72	40			7.4	33	138.6	0.60
Maison Alfort I	H + W	83	72	42			10.4	39	154.8	0.47
Maison Alfort II	H + W	72	73	42			9.3	33	136.8	0.46
Meaux Beauval 1 + 2	H + W	167	78	45			23.1	84	363.6	0.50
Meaux Collinet	H + W	83	78	45			11.5	30	129.6	0.36
Meaux Hopital	H + W	70	78	45			9.7	29	124.6	0.41
Melun L' Almont	H + W	70	71	41			8.8	32	126.0	0.45
Montgeron	H + W	89	72	42			11.2	27	108.0	0.31
Orly I	H + W	67	75	45			8.4	24	93.6	0.35
Orly II	H + W	70	75	45			8.8	35	136.8	0.49
Ris Orangis	H + W	62	70	40			7.8	29	115.2	0.47
Sucy en Brie	H + W	39	78	50			4.6	23	85.3	0.59
Thiais	H + W	70	76	46			8.8	37	147.6	0.53
Tremblay les Gonesse	H + W	76	73	43			9.5	42	164.9	0.55
Vigneux sur Seine	H + W	83	74	44			10.4	45	180.0	0.55
Villeneuve Saint Georg	H + W	97	76	46			12.2	50	198.0	0.52
Villiers le Bel	H + W	80	66	40			8.7	30	102.9	0.37
TOTAL		**2,407**					**295**		**4,434**	**0.46**

TABLE 3.2. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outllet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
Other Basins										
Blagnac	H + W	12	59	38			1.1			
Bordeaux Benauge	H + W	22	44	26			1.7	4	9.4	0.18
Bordeaux Meriadeck	H + W	25	54	37			1.8	8	18.8	0.34
Hagetmau	H + W	11	31	25			0.3	1	0.9	0.11
Lamazere	G	41	57	22			6.0	12	54.9	0.29
Merignac BA 106	H + W	39	52	42			1.6	25	33.5	0.65
Mios le Teich	F	36	74	50			3.6	22	69.6	0.61
Mont de Marsan I	H + W	66	60	40			5.5	47	125.0	0.72
Mont de Marsan II	H + W	10	56	38			0.8	7	17.7	0.75
Pessac	H + W	55	48	28			4.6	22	58.3	0.40
Saint Paul les Dax	B + H + W	36	65	26			5.9	14	73.2	0.40
TOTAL		**353**					**33**		**462**	**0.44**

Note: please report all numbers to three significant figures.

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF DECEMBER 1999

This table should report thermal energy used (i.e. energy removed from the ground or water) and not the heat rejected to the ground or water in the cooling mode.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Locality	Ground or water temp. (^oC)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr = 10^{12} J/yr)[5]
TOTAL							

Note: please report all numbers to three significant figures

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 1999

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalphy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% capacity all year

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Space Heating[4]	318	4,771	0.46
Air Conditioning (Cooling)			
Greenhouse Heating	6	55	0.29
Fish and Animal Farming	3.6	69.9	0.61
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]			
Other Uses (specify)			
Subtotal	327.6	4895.9	0.46
Geothermal Heat Pumps			
TOTAL	327.6	4895.9	0.46

4) Includes district heating (if individual space heating is significant, please report separately)
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

Note: please report all numbers to three significant figures.

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1995 TO DECEMBER 31, 1999

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)					
Production Expérimentation	>150° C	1				5
	150-100° C					
	<100° C		1			2
Injection	(all)					
Total						

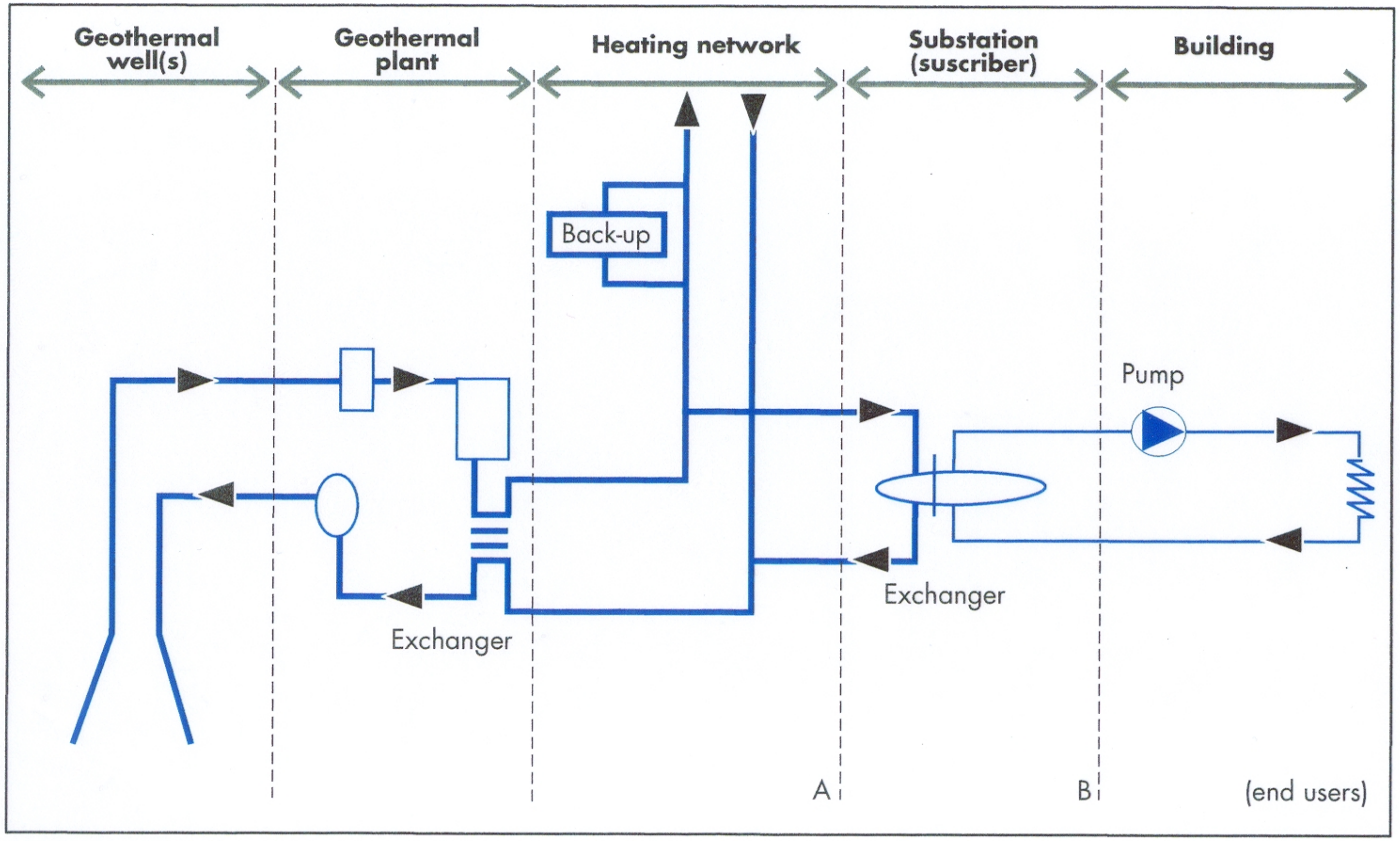
TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with a University degress)

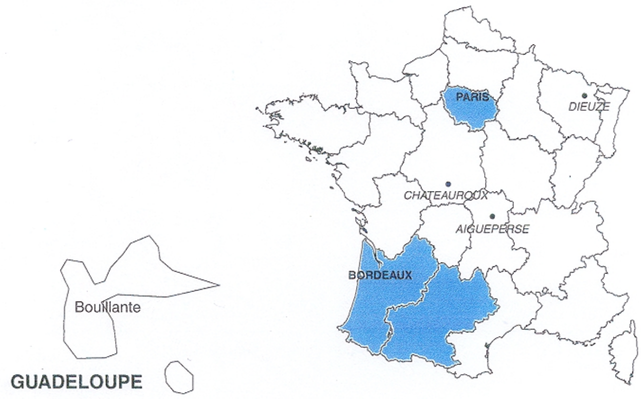
(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributied Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1995						
1996						
1997						
1998						
1999						
Total						

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (1999) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1985-1989						
1990-1994						
1995-1999						


Geothermal well(s)
Geothermal plant
Heating network
Substation (suscriber)
Building
Back-up
Pump
Exchanger
Exchanger
A
B
(end users)



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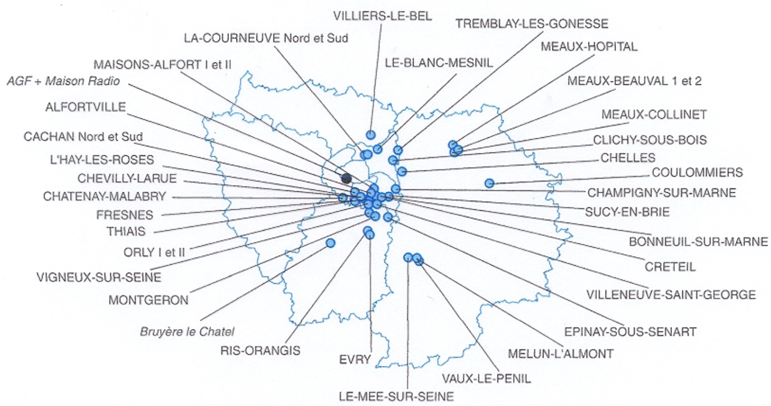

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