INSIGHT INTO GEOTHERMAL RESERVOIR MANAGEMENT DISTRICT HEATING IN THE PARIS BASIN, FRANCE

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SUMMARY

The first attempt to exploit the hot waters occurring in the Dogger carbonate formations of mid-Jurassic age dates back to year 1962, at Carrières-sur-Seine west of Paris. The well, despite its high productivity, was abandoned due to highly mineralized brine incompatible with the disposal of the wastewater in the natural medium (a surface stream). This led, in 1969, Sthal, a private joint venture (Cgc, now Vivendi, operator, and Laurent-Bouillet) to commission the first field application of the geothermal doublet concept of heat mining combining a production well and an injection well pumping the heat depleted brine into the source reservoir.

The doublet (two deviated, 7" cased, wells) produced in self-flowing mode was put on line in 1971 on the Melun l'Almont emblematic site, south of Paris, to supply heat and sanitary hot water to the local residential dwelling compound. It enabled the use of the new titanium alloyed plate heat exchangers able to cope with a corrosive geothermal fluid -- a slightly acid (pH = 6), saline (30 g/L eq. NaCl) and hot (74°C – 165°F) brine. The system has been operating satisfactorily since start up, the doublet moving in the meantime towards a triplet array including two injector and one new, innovative, production well combining steel casings and freely suspended, non cemented, fiberglass liners. Noteworthy is that this pioneer achievement was completed independently from any energy crisis or public subsidies whatsoever. Regarded at the time as a technological, fairly exotic curiosity, it has been extended since then to the whole Paris Basin geothermal district heating schemes.

The energy price crisis following the 1970s oil shocks led the French authorities to promote, among other alternative energy sources, low-grade geothermal heat as base load to district heating grids and other space heating systems. This was concluded by the development, in the Paris Basin, of fifty-five geothermal doublets of which thirty-four are still operating to date (Figure 1).

This is indeed an outstanding, almost unique accomplishment comparable to the heating of the city of Reykjavik in Iceland, which belongs; however, to a significantly different geological (volcanic rocks, high source temperatures), technical (no reinjection) and socio-economical (insularity) context.

It has undoubtedly benefitted from three main driving factors: (1) the evidence of a dependable geothermal reservoir (Dogger limestones) of regional extent, identified thanks to former hydrocarbon exploration drilling (Ungemach, 1988); (2) a strong voluntary commitment of the State in favor of alternative energy sources and ad-hoc accompanying measures (mining risk coverage, mutual insurance–sinking funds against exploitation hazards, financial support to district heating grids and miscellaneous incentives); and, (3) last but not least, the location above the geothermal resource of large residential dwelling buildings, eligible for district heating, which are numerous throughout the Paris suburbs.

This stated, the geothermal venture did not avoid contagion from infantile diseases inherent to the implementation of new technologies as evidenced by various symptoms, mainly:

- Structural: lack of expertise from operators (chiefly of the public sector) in managing industrial installations and energy processes with a strong mining impact,
- Technical: insufficient mastering in operating heating grids, under a retrofitted scheme combining several base load, back-up/relief energy sources and fuels, repeated failures of submersible pump sets and, above all, devastating corrosion of casings, well heads and equipment by the geothermal fluid,
- Administrative and managerial: imprecise definition of the duties and obligations of concerned intervening parties (operators, engineering bureaus, heating companies, consultants) and of relevant exploitation/service contracts, inefficient marketing and negotiation of heat sales and subscription contracts, and
- Economical and financial: severe competition from conventional fossil fuels (heavy fuel oil, natural gas) penalizing heat sales and revenues, persistent low energy prices in the aftermath of the second oil shock, adding to a debt nearing 85 % of total investment costs in a capital intensive (5 to 8 Meuros(ε) ~ 4.5 to 7.2 million US$), low equity, high interest rate (12 to 16 %) environment; this clearly placed most geothermal operators in a typically third world situation.

With time and experience, structural and technical problems were overcome in many respects by (1) systematic monitoring of the geothermal fluid and primary production/injection loop, (2) periodic logging inspection of well casings, and (3) innovating work-over and chemical inhibition processes aimed at restoring well performance and preventing corrosion/scaling damage; the latter supported by the State through relevant R & D programs and funding.

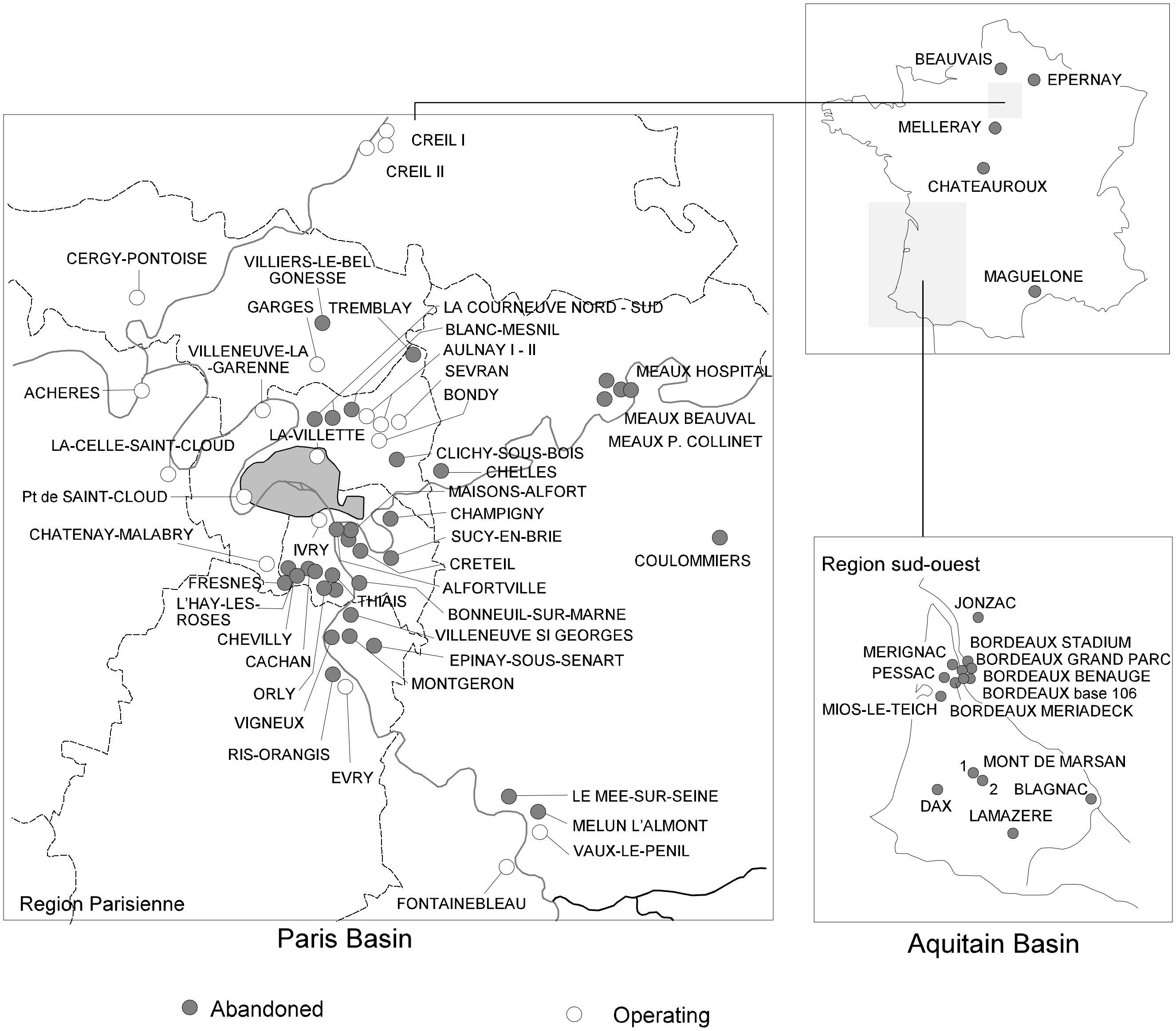


Figure 1. Location of French geothermal sites.

In the early 1990's, the so-called "Brosse Mission" made it possible to mitigate the debt charge, which was renegotiated via a spreading out of annuity repayments and interest rate reductions. Tax deductions were applied to geothermal operators, regarded therefore, as energy producers, the most significant one addressing the VAT (value added tax) (set a 5.5 % instead of the former 18.6 % rate). Simultaneously, improved administrative and financial management of geothermal district heating grids could be noticed among most operators.

The revival of a technology, at a time endangered to such a point that its abandonment has been seriously envisaged. This could be achieved at the expense of the shut in/cementing of 22 doublets, i.e. ca 40 % of the initial load and of a subsequent loss in heat supplies summarized in the following figures:

	1986 (target)	2000 (actual)
• number of operating doublets	54	34
• installed capacities (MWt)	360	227
• yearly heat supplies (heating + SHW) (GWht/yr)	2,000	1,240
• yearly fossil fuel savings (toe's)	135,000	225,000

The situation, although stabilized, remains precarious on purely economic grounds. As a matter of fact, falling energy price trends ultimately condemn geothermal district heating with the exception of 10 to 12, presently profitable, doublets.

The challenge is clear. To remain competitive, the geothermal MWht selling price must stand at ca 200 FRF (30 ε ~ 27 US$)(i.e., no more than 10 % above the natural gas) (LCI - lower calorific index) price according to the B2S (distribution) tariff offered to industrial users. Consequently, gas co-generation appeared to many geothermal operators, while negotiating renewal of past heat subscription contracts, as the only viable issue securing the survival of their grids and installations. Hence, as of late-2000, 12 combined gas co-generation plants and geothermal district heating grids were operating, a figure likely to match the twenty marks at the November 2001 deadline.

Gas co-generation provides stable earnings from sales to the utility (Electricité de France, Edf) of the whole generated power at a high contractual purchasing price, guaranteed over 12 years, elsewhere indexed on natural gas prices (i.e., at minimum financial risk). Co-generation supplies cheap heat as an electricity by-product recovered via the cooling of the generating units (gas engines or turbines). Maximization of power revenues causes co-generation to be operated as base (constant) load over the 151-calendar day contractual period (from 1st November to 31st March). This is at the detriment of geothermal heat whose contribution during winter drops by 40 %, if not more, when no extension of the existing grid is commissioned in the meantime (only three sites, out of 12, to date).

Environmental, clean air, concerns and limitation of greenhouse gas (mainly CO_2) emissions could turn geothermal district heating into an asset favoring its sustainability, if not its (re)development. Such a statement, however, ought to be mitigated in consideration of recent government measures and those likely to be decided with respect to energy and environmental fiscal matters which presently lack consistency.

First, the VAT applicable to heating grids subscription contracts has been reset at the 20.6 % rate against the former 5.5 % rate, the latter still in force for gas and power subscriptions as well as for maintenance/repair works in collective buildings and individual residences. This indeed penalizes geothermal heating grids vis-à-vis building fossil fuel fired boilers or gas/electricity individual heating as exemplified by the following costs (heating service charges/maintenance costs amounting to 3,500 FRF (530ε ~ 480 US$)(all taxes included) applicable in 1999 (Finance Law 2000, in force as of September 1999):

	FRF (VAT free)	FRF (VAT included)
• building heating, geothermal grid	2,920	3,462
• building heating, gas fired boilers	2,920	3,399
• individual gas heating	2,945	3,320
• individual electric heating	2,920	3,414

Second, the modification of the professional tax penalizes heating grids operated under lease/concession contracts (non-deductible infrastructure rental costs).

Thus, the fiscal prejudice amounts, for a heating grid serving 5,000 dwellings, to ca 450,000 FRF (68,600ε ~ 61,700 US$) (VAT free). It represents a serious handicap, especially while negotiating heat subscription contracts with, often shortsighted ownership representatives and other building managers. It clearly defeats the district heating route previously promoted by the State.

The State issued White Book introduces in its ecotax project (the so-called TGAP, general tax on polluting activities) a damaging discrimination aimed at exempting individual users (families) in the name of the principle that ecological taxation cannot apply to them! In fact, available energy consumption statistics, summarized hereafter:

	Fuels (Mtoe's/yr)	Electricity (TWh/yr)
• domestic uses (families): residential	34	119
• transports	24	58
• corporations, transports	25	8
• tertiary sector	10	91
• industry	26	131
• agriculture	18	30

This highlights the dominant share from individual consumers and speak for a uniform ecology taxation unless deliberately contradicting its meaning.

Summing up, the outlook for geothermal district heating seems presently limited to the operation of the thirty or so doublets online and to the implementation of gas co-generation units on two thirds of the existing grids, restricting geothermal heat supplies to ca 1,000 GWht/yr (Ungemach, 2000).

Privatization of geothermal doublets/heating grids, widely initiated in the past years under the form of acquisitions, concessions, leases and public service delegations should address in the short run over 15 installations equally shared between the three leading heating/energy groups: Dalkia/Edf/Vivendi, Elyo/Suez Lyonnaise des eaux and Cofatec/Coriance/Gaz de France. Only the Public and an established State policy, as was the case in the mid-1970s/ early-1980s, reverse these adverse trends and reactivate geothermal heating which, everything considered, has proven its technological and entrepreneurial maturity (Ungemach, 1998).

Last but not least, the impact among the Public of recent climatic disasters attributed to global warming and of high oil prices could initiate the necessary stimulus. In this perspective, the taxation of CO_2 atmospheric emissions, once scheduled by the Government, at a rate ranging from 200 FRF (30 ε ~ 27 US$) (2001) to 500 FRF (76 ε ~ 68 US$) (2010) per tonne of carbon, is obviously critical.

MILESTONES

The Paris Basin geothermal development milestones are highlighted in historical sequence, in which six main steps are distinguished and briefly commented on:

Pre-oil shock, 1960s. This addresses the first abandoned attempt to tap the Dogger geothermal aquifer, followed in 1969, by the successful completion of the first geothermal district heating doublet at the emblematic Melun l'Amont site.

Post-first oil shock, 1973-78. Completion of four geothermal district heating doublets, three (Creil and Le Mée-sur-Seine) combining vertical production/injection wells and one (Villeneuve-la-Garenne) deviated production/ injection wells fiberglass (7") cased. Three doublets (Creil and Villeneuve-la-Garenne) were equipped with electric submersible pump (ESP) sets, the fourth (Le Mée-sur-Seine) being produced in self-flowing mode. Simultaneously, the legal framework was enforced by the State via a relevant geothermal act classifying geothermal fluids as a mineral resource subject to the mining code and to exploration/ exploitation leases and concessions.

Post-second oil shock, 1979-1986. This period produces the Paris Basin geothermal development effort with the completion of 51well doublets of which one (La Villette) will never be exploited and a second (Melleray) exploiting the Triassic sandstones underlying the Dogger carbonate reservoir. The legal/regulatory/lobbying framework was finalized by the creation of the Comité géothermie, SAF Environnement, Afme/Ademe, Géochaleur and Agémo. The Triassic target, once contemplated west of Paris, was abandoned due to negative testing (resulting mainly from poorly completed wells) resulting in exploitation concentrated exclusively on the dependable Dogger reservoir. The success ratio was high as only two doublets (Fontainebleau and Fresnes) met the (semi) failure criteria set forth by the Comité géothermie, responsible for supporting geothermal ventures deemed feasible and thus eligible for the geological risk allocation and related subsidies. The first well damages and production pump (ESPs and line shaft pumps - LSPs) failure were experienced in the mid-1980s.

Early exploitation phase, Late-1980s. Most doublets had undergone severe exploitation problems as a consequence of (initially overlooked) hostile thermo-chemistry and subsequent corrosion/scaling damage, pump failures (lower than one year average lifetimes), hesitant management, poor heating practice (mainly regulation and monitoring) and, above all, critical financial losses aggravated by oil depleted prices. This implemented conventional well work-overs and of the first chemical inhibition trials.

Technological/managerial maturation and debt renegotiation, 1990-97 . In 1990, the State committed Brosse Mission led most geothermal operators to renegotiate their debt (loans mostly contracted with State owned banks) via a moratorium including a three-year grace period, extended annuity redemptions and lower interest rates. Expert advice was also provided regarding heating exploitation concession and contracts. Simultaneously, concerned governmental departments and agencies (Energy and Raw Materials Directorate, Industry and Research Directorate, Afme/Ademe) refueled the SAF mutual exploitation insurance (long-term) fund and promoted specific R&D actions aimed at designing and implementing novel well work-over/ restoration/ stimulation and thermo-chemical preventing techniques. The latter proved rewarding in upgrading restoration of casing status and related well productive/injection capacities and limiting corrosion/scaling damage at attractive cost to performance ratios. Doublets facing irreparable physical and/or financial damage, or in several instances managerial laxness, ceased commercial exploitation and these wells were cemented in compliance with petroleum/geothermal well abandonment regulations.

Still the economics remained fragile as a result of reduced oil prices and a highly competitive energy market dominated by heavy fuel and, at a greater extent, natural gas contenders.

New challenges, Starting 1998. Geothermal district heating in the Paris Basin demonstrates a mature–below ground and surface technology, clearly assessed exploitation and mining risks, controlled operation/maintenance/work-over costs, experienced management, socially accepted environmental benefits, seconded by instrumental expertise and services. Of the 54 completed doublets, 34 (i.e. 60 %, a reasonable score indeed) of the initial load, remain online as of mid-2000, with a reliably targeted 10-year life expectation, the duration of the recently extended SAF Environment mutual insurance contracts. However, the fierce competition prevailing while negotiating heating contract renewals prompted many geothermal operators to award co-generation (combined cycle) contracts or leases to the dominant heating groups (Vivendi, Suez-Lyonnaise des eaux, Gaz de France). This was in the wake of (partial) power deregulation and incentives in favor of gas co-generation initiated in France in the mid 1990s. This policy conformed to a survival rationale keeping most geothermal district heating grids alive, at the expense, in most instances (no grid extension), of decreasing supplies of geothermal heat no longer utilized as base load during the contractual one hundred and fifty one day (1^{st} November to 31^{st} March) winter heating period allocated to cogenerated heat. The spectacular rise in oil prices noticed since late 1999, peaking at ca 32 US $/bbl, likely to be followed by natural gas tariffs, alongside greater sensitivity of the public to global warming damage, and taxation envisioned by the State of greenhouse gas emissions (estimated at 40ε . 36 US$/tonne of carbon starting rate) could radically change the former bleak outlook. Instead of surviving, geothermal district heating could be given a second chance and momentum.

STATUS

Well Record

Fifty-six geothermal doublets have been completed during 15 years (from 1971 to 1986) at vertical depths ranging from 1,165 (Beauvais) to 1,980 m (Coulommiers) at locations mapped in Figure 1. The Melleray doublet, devoted to greenhouse heating, located 140 km south of Paris, addressed the Triassic sandstones and the La Villette doublet has never been exploited so far. The Ivry doublet aimed at preheating the steam fed into the Paris steam heating grid.

As of mid-2000, 34 doublets remain on line. The completion/abandonment record is displayed in the following historical sequence (Figure 2).

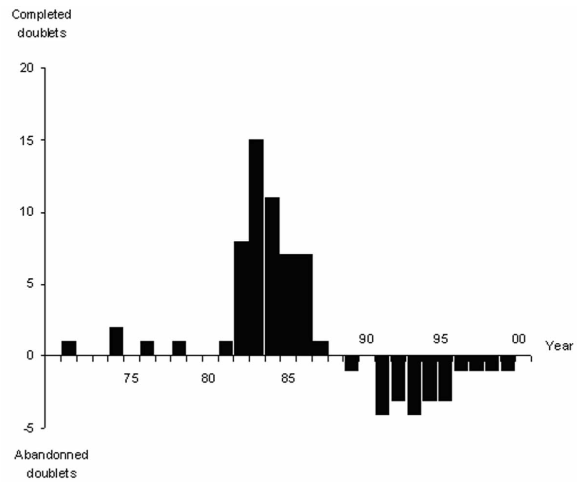


Figure 2. ***Completion/abandonment of doublet well over time.***

Geothermal district heating doublets have undergone over 90 heavy duty work-overs, this figure not including the 22 abandonment cementing jobs. The State elsewhere funded, between years 1990 and 1995 (out of the over 90 figures), 41 specific well cleaning/corrosion preventing operations for implementing novel casing jetting techniques and downhole chemical injection lines.

Out of the 68 operating to date, 30 damaged (leaky, pierced casings) wells (23 production, 7 injection) were reconditioned either via casing lining (18 producer, 7 injector, total 25) or casing patches (5 producer wells). Reconditioning of production wells dealt, in all cases, with the repair (by lining or patching) of a damaged 13 3/8" pumping chamber and for one well only (Villiers-le-Bel/Gonesse) was added the 7" lining of the underlying 9 5/8" production casing.

Exploitation Update

Relevant figures, from early expectations to reality, are summarized below:

	Target	Achieved	
	(1985)	1990	2000
Operating doublets	55	43	34
Total installed capacity (MWt)	360	260	227
Produced heat (GWht/yr)	2,000	1,455	1,240
Unit capacity (MWt)	6.5	6.0	6.7
Unit yield (MWht/yr)	36,000	33,800	36,200
Artificial lift wells	49	36	27
Self-flowing wells	6	7	7

At the beginning of heating year 1987-88, 54 doublets were assumed operational, thus close to the anticipated figure. Actually no more than 48 were in service, of which one-third were undergoing severe exploitation problems resulting in temporary shut in periods attaining in many instances several months.

In 1990, 43 doublets were serviced and about 1,450 MWht delivered to the heating grids (i.e., 25 % below initially projected yields). In year 2000, the annual delivery dropped to 1,230 GWht as a result of lesser operating doublets (34) and start up of 10 combined geothermal/gas co-generation systems. Despite this downward trend, optimiza-tion of the most productive doublets, which happen to coincide with the most recently completed (third generation) ones, resulted in unit capacities (6.7 MWt and 36,200 MWht/yr) close to initially anticipated targets. However, future implementation of commissioned and projected cogeneration systems is likely to reduce these unit capacities.

TECHNOLOGY

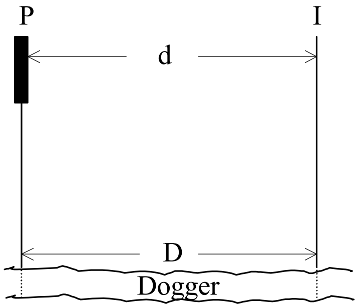
Well Completions and Doublet Designs

As a matter of fact, the geothermal doublet typology followed the patterns sketched in Figure 3. This strategy was largely inspired by the views of the National Geological Survey (BRGM) appointed by the State to launch the geothermal development programme. This strategy prevailed in spite of the early achievements pioneered by designers from the oil industry, on private investment bases, on the Melun l'Almont (1971) and Villeneuve-la-Garenne (1976) sites, the latter adding an innovative fiberglass casing ingredient. Those remained the exception until wide acceptance and generalization (third generation doublet) of this pertinent design in the mid 1980s.

First generation doublets. Two vertical production/injection wells. This configuration has been implemented at Creil (1974), Le Mée-sur-Seine (1978), Cergy (1982) and Achères (1983). The production well includes a 13 3/8" casing, to accommodate a 11" submersible pump, followed by a dual 9 5/8" x 7" casing protection (400 to about 1,000/1,200 km) of the intermediate Albian/Neocomian fresh water aquifers and a 7" production casing, the target Dogger geothermal reservoir being produced in open hole (6" diameter). The injection well replicates the dual 9 5/8" x 7" casing design with a single 7" injection column, and a 6" open hole reservoir section. A 1,000 to 1,400 m well spacing secures a useful system thermal life of 20 to 25 years (i.e., until damaging, 3 to 5°C (5 to 9°F), cooling of the production well occurs).

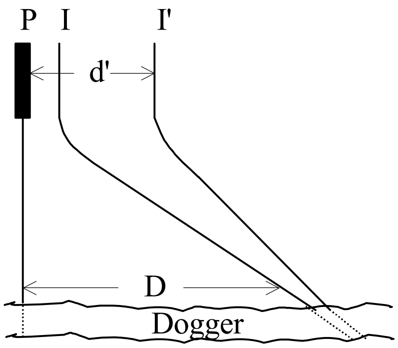
Second generation doublets. Vertical production well. Deviated injection well. Casing/open hole diameters and dual casing protection of the intermediate Albian/Neocomian fresh water aquifers identical to those adopted for the first generation doublets. Wells are drilled from a single plateform (eight doublets drilled between 1981 and 1985) with the exception of Meaux Collinet (1982) and Evry (1983); where, the well head spacings (200 to 300 m) enabled to reduce the injection deviation (slant) angle.

Third generation doublets. Two deviated production/injection wells drilled from a single platform. Two designs depending on production/injection casing diameters, either 13 3/8" (exceptionally 10 ¾") x 7" (production) and 7" (injection) including a dual 9 5/8" x 7" cased protection of the Albian/Neocomian fresh water aquifers (22 doublets) or a 13 3/8" x 9 5/8" (production) and 9 5/8" (injection) casing string with no dual casing protection of the Albian/Neocomian fresh water aquifers (nine doublets). In this latter design, the 9 5/8" production/injection casing is occasionally thicker than in



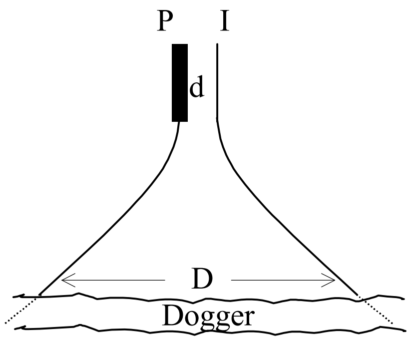
1[st] generation doublets

2 vertical wells
Diameters
P : 13 3/8” x 7" or 10 ¾” x 7"
I : 7"
Double 9 5/8” x 7" casing protection of Albian/Neocomian aquifers



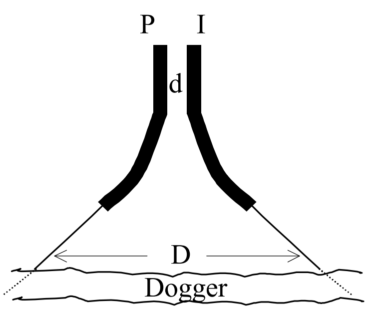
2d generation doublets

1 vertical (P) well, 1 deviated (I, I') drilled from one (I) or two (I') platforms
Diameters
P : 13 3/8” x 7" or 10 ¾” x 7"
I, I' : 7"
Double 9 7/8” x 7" casing protection of Albian/Neocomian aquifers



3rd generation doublets

2 deviated wells drilled from a single platform
Diameters
(a) P : 13 3/8” x 7" or 10 ¾” x 7"
I : 7"
Double 9 5/8” x 7" casing protection of Albian/Néocomian aquifer
(b) P : 13 3/8” x 9 5/8”
I : 9 5/8”
No double casing protection of Albian/Néocomian aquifers



4th generation doublets

2 identical wells.
Increased pumping chaber length
Diameters
P : 13 3/8” x 9 5/8”
I : 13 3/8” x 9 5/8”
No double casing protection of Albian/Néocomian aquifers

P : production well
I : injection well
D : doublet spacing at top reservoir
d, d' : well head spacing
z : pumping chamber

Figure 3. Geothermal doublet typology.

previous completions. Bottom hole (top reservoir impact) spacings are designed in compliance with doublet cooling specifications.

Fourth generation doublets. Two identical production/injection well 13 3/8” x 9 5/8” casing programs allowing for production/injection replication. The 13 3/8” casing is set at a (deviated) depth of 900 to 1,100 m (i.e., vis-à-vis the Albian/Neocomian freshwater aquifers whose protection is ensured via an increased steel thickness over the concerned interval).

Casing specifications conform to K55 soft carbon steel grades, compatible with service in the CO_2-H_2O aqueous system, either VAM or Buttress (BTC) threads, 9 to 11.4 mm wall thickness and range 3 lengths. Deviation (slant angles) vary between 30 to 55° with a build-up gradient of 1°/10 m initiated at depths (KOPs) ranging from 200 to 500 m.

New Well Concept

The novel geothermal well design was conceived to reduce corrosion and scaling that had severely affected the integrity and lifetime of Paris Basin geothermal district heating wells. This new generation geothermal well, which represents a material alternative to corrosion, was successfully completed at Melun-l'Almont on March 1995.

Under this new concept, the wells are completed by combining cemented steel casings and fiberglass liners while the annulus is kept free. The casings provide mechanical strength (propping function), while the liners furnish chemical resistance (corrosion and scaling protection). The free annular space allows: (1) circulating corrosion/scaling inhibitors and/or biocides, which otherwise would need to be circulated using a downhole chemical injection line; and, (2) removing and, if necessary, replacing the fiberglass liner whenever damaged. It is noteworthy that this design can accommodate a submersible pump set, in which case the upper fiberglass lining is placed under compression, and the lower one is freely suspended under its own weight. Vertical displacement of the fiberglass lining is elsewhere eased by an expansion spool and fiberglass centralizers (not by couplings as often contemplated in other centralizing designs). At Melun, due to exceptional reservoir performance, artificial lift was no longer required and, instead, self-flowing at high production rates prevails, a fact that led to the simplified design.

The well, put on line on late March 1995, demonstrated high productivity, producing about 70°C (158ºF) fluid at a rate of 200 m^3/hr at 2.5 bars wellhead over-pressure. It has been connected to two existing wells (one producer and one injector); the whole system operates according to the triplet array (two producers, one injector). The wellhead design achieves the required sealing and fixing (seat/receptacle) functions.

The concept of using wells with steel casings and removable fiberglass liners is seriously considered as an alternative in order to extend the lifetime and improve the reliability of existing installations. The following strategy would be used: a new production well would be drilled and completed, the two existing wells would be reconditioned/lined into injectors, exploitation would resume under a triplet configuration (one producer, two injectors). Total project costs, including work-over, are estimated at about 3.5 million ε (3.2 million US$)(Geoproduction Consultants, 2000). Another, less innovative but cheaper, alternative would consist of drilling/completing a large diameter vertical steel cased well securing high self-flowing rates according to the design and cost estimates analyzed in Geoproduction Consultants report (2000).

Heating Engineering Insight

Operation of Paris Basin geothermal district heating grids conform to a standard engineering rationale, parameter system analysis and in the generic doublet/heating grid modules, namely:

- A geothermal supply module (the so-called geothermal loop): geothermal reservoir, production and injection wells and related equipment (production/injection pumps, electric and hydraulic control devices),
- A demand module: heat load consisting of end users' consumption, i.e. heaters connected, via substations, to a distribution grid,
- A back up/relief module: fossil fuel fired boilers, an interface: geothermal heat exchanger.

The following items deserve a special comment.

Heat loads: retrofitting is the rule. Geothermal heating had to comply with existing buildings and heaters seldom designed for low temperature service. Residential dwellings compose the majority of the load, followed by public office buildings, schools, swimming pools and gymnasiums. Supply of domestic sanitary (tap) hot water (SHW) adds in many instances to proper heating. Centralized SHW represents a bonus, with a supply amounting to about 10 % of heating loads.

Heating devices: forced-air convectors are absent. Therefore, heat is diffused by conventional cast iron radiators requiring high (90/70°C – 194/158ºF) inlet/outlet temperatures and floor slabs (50/30°C temperature range 122/86ºF)--the latter more favorable to geothermal heat. As a result, many heating grids are conceived to adjust to those two contrasted heaters by means of high-temperature and low-temperature networks. High-inlet temperature heaters restrict temperature depletion and achievement of low rejection (at injection well head) temperatures which remain close to 40°C (104 ºF) and seldom attain 35°C (95ºF).

Regulation: it is indeed the vital segment of any combined geothermal/boiler heating management as it aims at minimizing the back-up boiler supply, thus upgrading the geothermal coverage ratio. District heating as opposed to industrial or agro-industrial process heat loads is subject to climatic charges and subsequent variable demand. Two temperature thresholds (besides the minimum reference outdoor temperature, set at - 7°C (19ºF) in the Paris Basin, to which is matched the installed heat capacity) are thus defined: the so-called transition (Θ*) and non-heating (Θnh) temperatures respectively. Below Θ*, the doublet is circulated at its maximum (nominal) flowrate and the complementary (peak) demand supplied by fossil fuel fired boilers. In the (Θ* - Θnh) temperature range, the whole demand of the (centralized) grid is supplied by geothermal heat. Above Θnh, whenever SHW supply is required, the doublet is operated at its minimum flowrate. Hence, the geothermal and grid flowrates are ascribed to variable-speed drive achieved by frequency converters. Depending upon local grid/heater characteristics, the transition temperature varies between 5 and 8°C (9 and 14°F); the non-heating temperature is set by law at 17°C (63 °F). In the (Θ* -Θnh) range, the geothermal flowrate decreases linearly. Practically, these simple regulation criteria are managed by an automaton which handles the grid/ geothermal loop interface by driving, via pressure/temperature sensors, the frequency converters and the safety (low/high pressure) instructions by closing the motor-actuated well head valves. The regulation suite usually conforms to the following sequence: the grid demand is transmitted, in terms of geothermal flowrate, to the injection pump frequency converter which adjusts the pump speed to the requested flowrate; the injection pump inlet pressure transducer signals to the production pump frequency converter the adequate flowrate instruction. Whenever the production pump outlet pressure exceeds the high pressure (heat exchanger/piping protection) instruction, the geothermal loop is shut down and relief boilers actuated accordingly; the same criterion applies to the low pressure (injection pumps inlet) instruction (pressure below bubble point).

Environmental Impact

Geothermal exploitation in the Paris Basin can be regarded, from an environmental point of view, as a risk as well as an asset. Hazards relate to the production of over-pressured (up to 11 bars well head pressures and over 200 m^3/h artesian free flow), hot and saline brines including toxic and flammable solution gases occurring in freshwater aquifer and densely populated urban environments. They are materialized by casing leaks and wellhead failures leading to (exposed) aquifer contamination and surface blowout damage. Work-overs represent another risk source with respect to waste disposal, gas escape and noise. In many instances, these risks remain under control and their consequences minimized. Fluid chemistry, well head pressures/temperatures and well deliverabilities are periodically monitored and casings inspected by wire-line logs easing detection of casing leakage/piercing and prompting relevant repair procedures.

Work-over technology and practice are adapted to services in a sensitive urban context by means of sound proof (diesel) engines, waste processing units and flexible working schedules (no night shifts), indeed a contrast with the earlier days common, oil and gas inherited, practice. Nevertheless, the industry is still awaiting the advent of silent, electrically driven, service rigs and pumps.

Since blowouts are unpredictable, the operators professional association -Agémo- initiated an emergency service in order to limit their magnitude. The contract awarded (after due bidding) to GPC specified to design, acquire, maintain and operate a wild well control facility, which should be mobilized in less than 6 hrs. Twenty geothermal operators subscribed to a five-year (renewable) contract whose effectiveness was checked on four blowouts recorded to date.

The progresses registered since the pioneer days of geothermal district heating contributed to upgrade its image among the public. Better social acceptance and growing clean air concerns should, therefore, turn geothermal district heating into an asset in consideration of saved greenhouse gas emissions. Such savings, with reference to natural gas- fueled heating, amount to ca 120,000 tonnes of carbon/yr. If an ad hoc ecotax were passed, the geothermal industry could benefit from an additional income of ca 23 FRF (3.5ε ~ 3.2 US$/) /MWht on a taxation basis of 250 FRF (38 ε ~ 34 US$/)/tonne of carbon (i.e., almost 10 % of the present heat selling price).

ECONOMY

Total geothermal investment costs amounted in the Paris Basin to ca 3.2 billion FRF (i.e., 500 million ε ~ 450 million US$) representing a unit investment cost of about 9,200 FRF(1,400 ε ~ 1,260 US$)/installed kWt. Investment costs split as follows (million FRF):

	Min.	Max.	Mean
• mining (well) costs	12	18	15
• heat plant/primary surface loop	4	7	5
• grid construction/ substation modifications	30	90	45

It is a generally accepted fact that, under normal feasibility conditions, total investment costs stand close to 65 million FRF (9.9 million ε ~ 8.9 million US$) to which the whole geothermal loop (wells, heat plant, surface piping and equipment) contribute 30 % and the grid proper 70 % respectively. From 80% to 90% of the investment was provided by (public) bank loans and the remaining 10 to 20% by public subsidies and grants.

Operation and maintenance costs include three main headings: (1) energy (electricity and back-up fossil fuels); (2) light maintenance/monitoring and heavy maintenance/ equipment warranty; and, (3) miscellaneous (provision for heavy duty works, overhead) costs.

The grid (primary and secondary networks) is operated permanently by a heating company with an assigned staff of three to five employees. The geothermal segment is monitored periodically and serviced occasionally by a geothermal engineering bureau. A thermal engineering bureau is usually appointed by the geothermal operator to assist the management in controlling grid operation and heat supplies.

Description of the various capital investments and OM cost items relevant to Paris Basin district heating systems may be found in a comprehensive economic review developed in Ungemach and Ventre (1997).

Revenues address heat sales to end users connected to the grid. These sales include both geothermal and boiler (back-up/relief) generated heat.

Global cash flow streams, selected on sites deemed representative of Paris Basin conditions, are displayed in Table 1. It emphasizes the dominant financial share of the debt repayment annuity which often nears 60% of total expenditure. This, added to back-up/relief boiler costs sensitive to natural gas prices and to the geothermal coverage ratio, exemplifies the structurally fragile economic and financial balance of Paris Basin geothermal operations. Actually, out of 34 doublets, 12 achieve profitability, 12 breakeven and 10 show a deficit. Prices close to 250 FRF (38 ε ~ 34 US$) could hardly compete in the past years with natural gas whose tariffs could afford a near 200 FRF (30 ε ~ 27 US$)/MWht figure. It is worth mentioning, however, that on several doublets (A, C and D in Table 1, among others), debt repayments will cease in year 2002.

To overcome these financial problems, two issues can be contemplated, in the short term, combined natural gas co-generation/geothermal grids and, in the medium term, enforcement of an ecotax applicable to greenhouse gas emissions. The latter would definitely secure a more attractive profit margin for the mutual benefit of geothermal producers and end users. Along this line, a typical example of a Paris Basin prospective balance sheet is given in Ungemach and Ventre (1997) and several revival scenarios of presently abandoned doublets are analyzed in Appendix 4 of that publication.

THE CO-GENERATION ISSUE

Co-generation appeared recently as a realistic survival alternative to geothermal operators facing severe competition from cheaper fossil fuels, firing conventional boilers, while negotiating renewal of end users heating contracts.

Gas co-generation on geothermal district heating grids raises growing interest, a financially and fiscally attractive issue. The simple reason is that the power required to produce the heat, which remains largely unused (hardly 10 % of the grid capacity), is sold to the utility at a price guaranteed over 12 years and indexed on gas market prices, with tax incentives added as a bonus. The interest is mutual. The gas company (Gdf) increases its market share and sells significant gas quantities to meet the demand of the grid (currently producing between 30,000 and 50,000 MWht/yr). The grid operator purchases cheap heat produced at marginal cost as a by-product of power generation.

Table 1. Balance Sheet for Various Doublet and Boiler/Geothermal Scenarios

Item/Doublet	A1 (1)	A2 (1) (2)	B	C	D1 (1)	D2 (1) (2)
Total heat supply (MWht/yr)	58,000	43,500	48,888	51,000	40,000	31,000
- geothermal	39,500	32,500	42,000	41,000	26,000	15,000
- back-up boilers	18,500	11,000	6,000	10,000	14,000	16,000
- geothermal coverage %	68	75	87.5	80	65	48
Heat selling price (FRF/MWht)	251	241	247	258	272	272
Revenues (10^3 FRF/yr)	13,980	10,480	11,860	13,160	10,800	8,430
Expenditure (10^3 FRF/yr)	13,520	10,540	11,570	12,370	9,790	8,850
- debt charge	7,100	6,800	6,900	7,600	4,300	3,200
- power	875	710	1,030	590	560	520
- back-up fuels	3,330	1;980	1,080	1,800	2,520	2,880
- maintenance	1,620	1,470	1,840	1,760	1,810	1,650
- heavy duty work-over provision	360	240	400	330	250	250
- overhead	240	240	320	290	350	350
Balance (10^3 FRF/yr)	+ 460	- 60	+ 290	+ 790	+ 1,010	- 420

(1) dual doublet management (2) co-generation on line in 2000 7.30 FRF = 1 US$

Table 2. Typical Co-Generation Grid Economics

	grid 1	grid 2
Generating unit	gas engine	gas turbine
Power rating (MWe)	4	5.5
Power production (MWhe)	13100	16,400
Gas consumption (MWht ; HCI)	39700	57,700
Heat production (MWht)	16400	21,600
Revenues (10^3 FRF)	10980	13,470
- power sales	6600	8,260
- heat sales	4380	5,210
Expenditures (10^3 FRF)	8580	11,510
- debt charge	2040	2,100
- gas costs	5160	7,160
- maintenance	1180	1,940
- miscellaneous	200	300
Balance	+ 2,400	+ 1,960

Practical candidate (combined cycle) systems consist of natural gas fired engines or turbines driving alternators. Heat is recovered (1) on engines on the cooling circuit and, at a lesser extent, on exhaust gases, and (2) on turbines via exhaust gases. Heat to power ratios stand around 1.1 (engines) and 1.35 (turbines) respectively.

The co-generator must comply to the following conditions:

- 50% minimum (global) energy efficiency,
- heat to power ratio higher than 0.5,
- use (self-utilization) of produced heat,
- conformity certified by the competent authority (Drire).

The contract is passed with the utility (Edf) for a duration of 12 years. The co-generator subscribes to a guaranteed installed power and a plant utilization factor (subject to bonus/penalty) of 95%. Co-generation extends over a 151 calendar-day (from November 1st to March 31st) heating period.

The foregoing have important implications on geothermal production. Power (and heat) is generated constantly, at nominal rating over 151 days (3,624 hours) to maximize electricity sales. Therefore, co-generated and geothermal heat grids are operated as base and back-up loads respectively during winter heating. This results in a somewhat drastic drop of geothermal heat supplies. Actually, in many instances artificial lift was abandoned and self-flowing production substituted instead.

On economic grounds, the following numbers (Table 2), borrowed from two typical co-generation grids, shape quite attractive with discounted pay back times nearing five years.

Increases in natural gas prices have a penalizing impact, mitigated though, thanks to the contract passed with the utility, which compensates about 75% of gas tariff rises. In the aforementioned examples, a 40% increase in gas prices would result in additional expenditures amounting to 510 (grid 1) and 730 x 10^3 FRF (grid 2) (78 and 111 x 10^3 ε ~ 70 and 100 x 10^3 US$) respectively.

Co-generation has become a reality on many operating doublets. At the start of the 2000/2001 heating season, twelve co-generation/geothermal heating plants were online. Five other doublets are already commissioned and due to operate in 2001. Three to five sites are projected. Summing up, within the next years only 10 to 12 doublets should be exploited via the conventional heat exchange/back-up relief boilers heating mode.

CONCLUSIONS

Based on an experience dating back to the mid 1970s, the following conclusions may be drawn as to the past, present and future of geothermal district heating in the Paris Basin.

The geothermal source proved dependable with respect to reservoir extent and performance allowing easy well completions and high yields. Drillings achieved a 95% success ratio and well productive capacities currently attain 250 m^3/h - 70°C (158°F) nominal ratings.

Large residential dwelling compounds of the Paris suburban belt favored the district heating development route as a result of suitable heat loads overlying the heat source.

The doublet concept of heat mining and retrofitting were the governing rationale in exploiting the resource and heating the end users connected to the heating grid downstream of the geothermal heat exchanger.

Developments benefitted from a strong involvement of the State, following the first and second oil shocks, in favor of alternative energy sources. Relevant supporting policies addressed the areas of legal/institutional (mining law), risk coverage (exploration and exploitation sinking funds), financial backing (fiscal incentives, subsidizing), project reviewing/commissioning (ad-hoc committees) and heat marketing.

In the mid-1980s, 54 doublets were online and exploitation targets set at 360 MWt (installed capacity) and 2,000 GWht/yr (heat production) respectively. Since then, recorded figures did not match expectations. As a matter of fact, actual figures, as of year 2000, stand at 34 operating doublets, 227 MWt installed capacity and 1,200 GWht/yr heat supply. This situation reflects the learning curve phases, infancy, teenage and maturity, inherent to any new technological development, particularly in the mining field.

Paris Basin geothermal development was soon confronted by three major problems:

- **Technical problems**: the thermo-chemically sensitive geothermal brine caused severe, corrosion/scaling induced, damage to well tubulars and production equipment; these problems had been clearly overlooked at design/implementation stages,
- **Financial problems**: deemed the most critical, they resulted from a massive debt charge (no equity) aggravated by a low price and depleted energy market in the aftermath of the second oil shock,
- **Managerial problems**: they related to the lack of experience and expertise of geothermal operators, the large majority belonging to the public/municipal sector, in handling industrial installations including a significant mining segment; consequently loose monitoring and maintenance policies were the rule.

This bleak outlook could be progressively overcome thanks to innovative, State supported, chemical inhibition and well restoration technologies, debt renegotiation and sound management of geothermal heating grids. These sharp progresses were however accompanied by the abandonment of the twenty or so poorly reliable doublets.

So, everything considered, in spite of a fairly hostile, competing, economic environment geothermal district heating scored well. It demonstrated so far, its technological and entrepreneurial maturity and gained wider social acceptance.

Still economic viability proves fragile and only gas co-generation could secure the survival of a number of geothermal district heating grids. Twelve co-generation systems are operating to date and it is likely this figure will reach the twenty mark in the near future.

Where to Go Next?

A major question arises on whether the future of geothermal district heating reduces to the sole gas co-generation survival scenario in which geothermal heat no longer supplies base load.

Recent climatic disasters attributed to global warming and greater sensitivity of the public to environmental, clean air concerns could challenge this trend and turn low-grade geothermal heat into a widely accepted asset. Taxation of greenhouse gas emissions, the so-called ecotax, would in this respect be decisive in giving geothermal heating a new chance.

Prospective developments could, in the short run, address realistically two objectives. First the extension of existing (co-generated and non co-generated) geothermal grids to new users. Second the reactivation of abandoned doublets according to a revival of triplet design combining two injectors (the old wells) and one, new generation, production well.

Note: The following conversions were used:

7.30 French Franc (FRF) - 1 US$

1 Euro (ε) = 0.90 US$

6.60 FRF = 1 Euro

REFERENCES

Geoproduction Consultants – GPC, 2000. "Restoration of An Abandoned Geothermal District Heating Well Doublet - A Case Study. GPC internal report AVV-PU-0038, 22 pages.

Ungemach, P., 1988. "Reservoir Engineering Assessment of Low Enthalpy Geothermal Reservoirs," in Geothermal reservoir engineering (E. Okadan editor). Kluwer Academic Publishers (pp. 241-281)

Ungemach, P., 1998. "A State of The Art Review of the Successful Geothermal Technologies Implemented at European Level. " Geoproduction Consultants (GPC) internal report no: 98285, 21 pages.

Ungemach, P., 2000. "Economics And Sustainability of Low Grade Geothermal Heat Sources – The Paris Basin Case History." Paper presented at the World Geothermal Congress 2000. Plenary session Japan, 6 June 2000.

Ungemach, P. and A. V. Ventre, 1997. "Economic, Legal and Institutional Insight into Geothermal District Heating." Paper presented at the International Course on District Heating Schemes. Cesme, Turkey, 19-25 October 1997. Proceedings pp. 23-1 to 23-20.