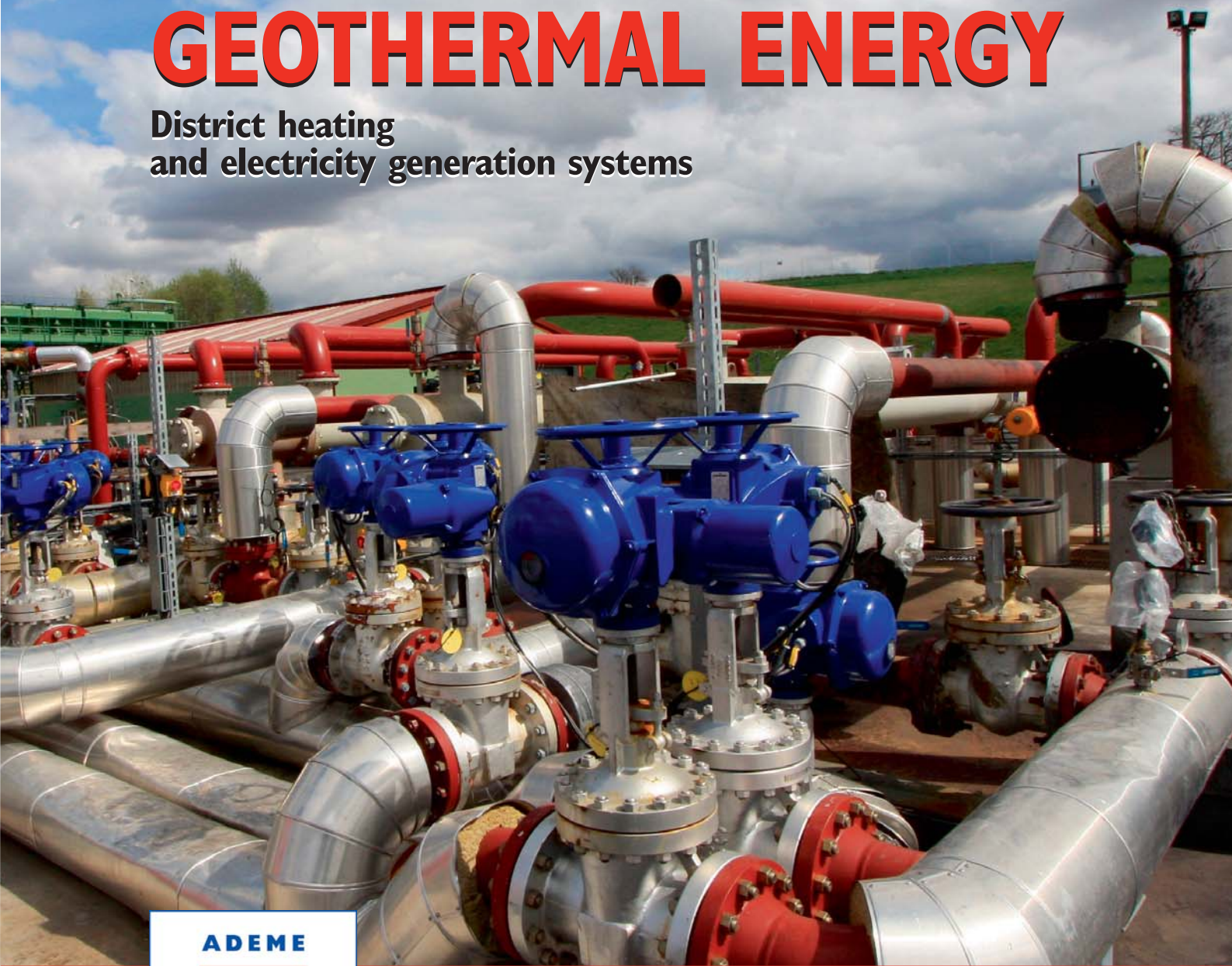


French know-how
in the field of

GEOHERMAL ENERGY

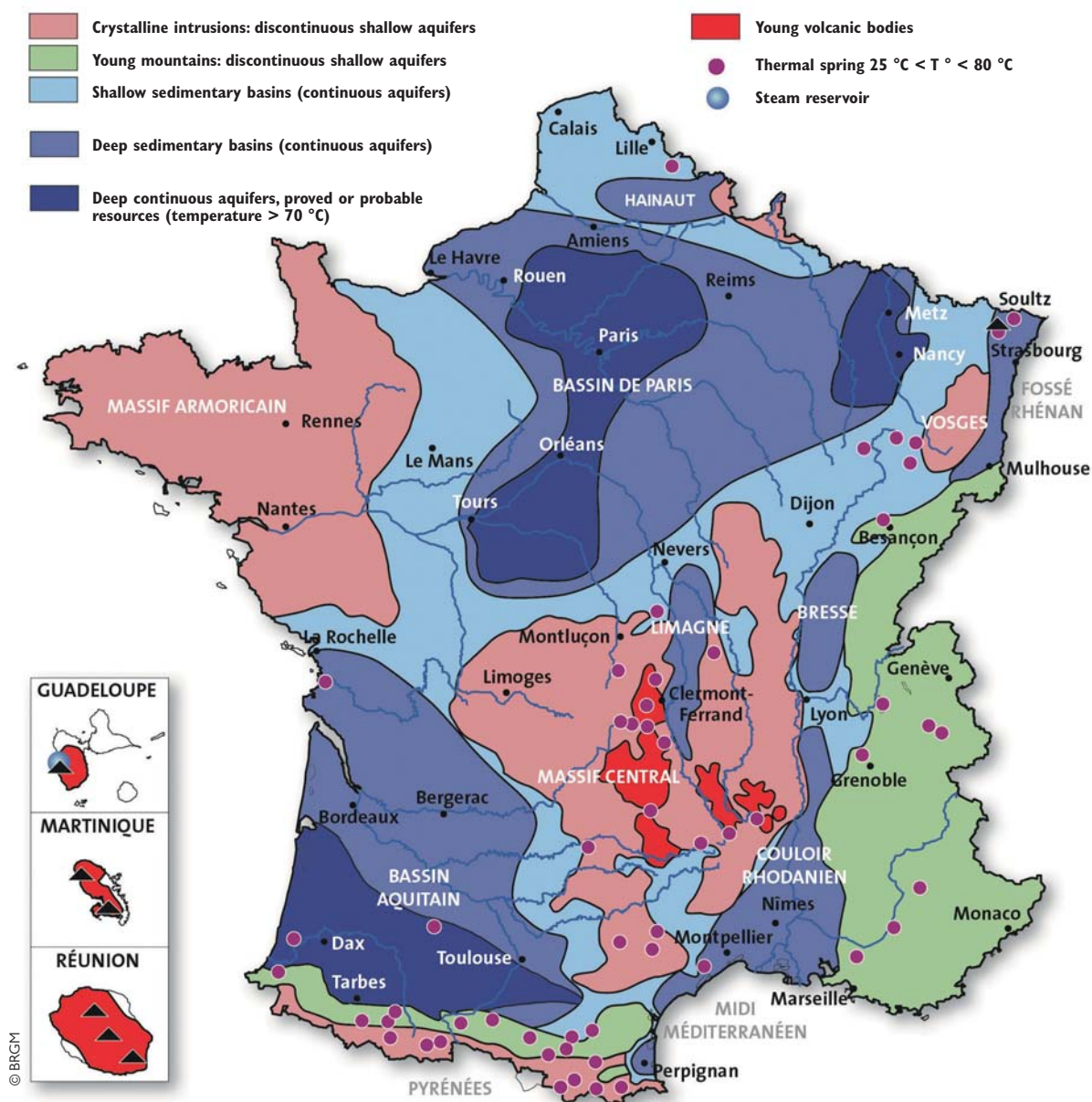
District heating
and electricity generation systems



ADEME



French Environment &
Energy Management Agency



Map of geothermal resources in France (see map of prospective geothermal sites).

Cover page

Heat exchangers – Pilot deep geothermal energy site at Soultz-sous-Forêts.
© Christian WEISS – ADEME

This brochure is aimed at presenting the French expertise, public and private, at international level in the field of geothermal energy (district heating and electricity generation systems).

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French expertise in the renewable energies field
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Context

From the Greek “geo” (earth) and “thermos” (hot), the term “geothermal” covers both the science that studies the earth’s internal phenomena and the industrial processes that seek to exploit it to generate electricity and/or heat.

Geothermal energy is based on exploiting the heat that is found at subsurface levels. This heat mainly originates from the disintegration of the radioactive elements that constitute the earth’s crust and from the dissipation of primitive energy. Its most visible surface manifestations are well known (volcanoes, geysers, hot springs, etc.) and its presence can be easily understood by applying the geothermal gradient concept, meaning that the temperature increases with depth.

Globally, the geothermal gradient averages 33 °C per kilometre, as occurs in France for example, but its value may be significantly higher, particularly in areas of active or recent volcanism in which it may reach several tens of °C per 100 metres.

At shallow levels, the subsurface heat can be exploited to generate heat or cold if it is assisted by a heat pump. At depths below several hundred metres, the heat can be used directly for thermal uses (heating of buildings, use in industrial processes, agricultural applications, etc.) or for generating electricity.

An environmentally friendly, renewable and universally available energy source

More than 35 countries currently use geothermal energy to produce electricity, with a global installed power amounting to 11 GW. Heat is produced by geothermal energy in 79 countries, with a total installed power of 43 GW.

Within Europe, France is ranked in 3rd place in terms of capacity and is playing an important role in the development of this energy. The Grenelle Environmental round table plans multiplying the amount of geothermal heat in the French energy mix by 6 between 2006 and 2020, which represents the replacement of 1.3 million tonnes of oil equivalent. For France, the generation of geothermal energy must increase from 15 to 80 MW, with the long-term potential estimated at 200 MW.

Acknowledged French expertise

After a major development phase at the start of the 1980s, due to high fuel prices, followed by a downturn in the 1990s, the geothermal energy market is currently booming again in France, due to policies which are favourable to renewable energies.

In particular, the French industry can rely on the experience acquired in the Paris basin, which has **the world’s largest concentration of low-energy geothermal applications in operation, exploiting the same aquifer.**

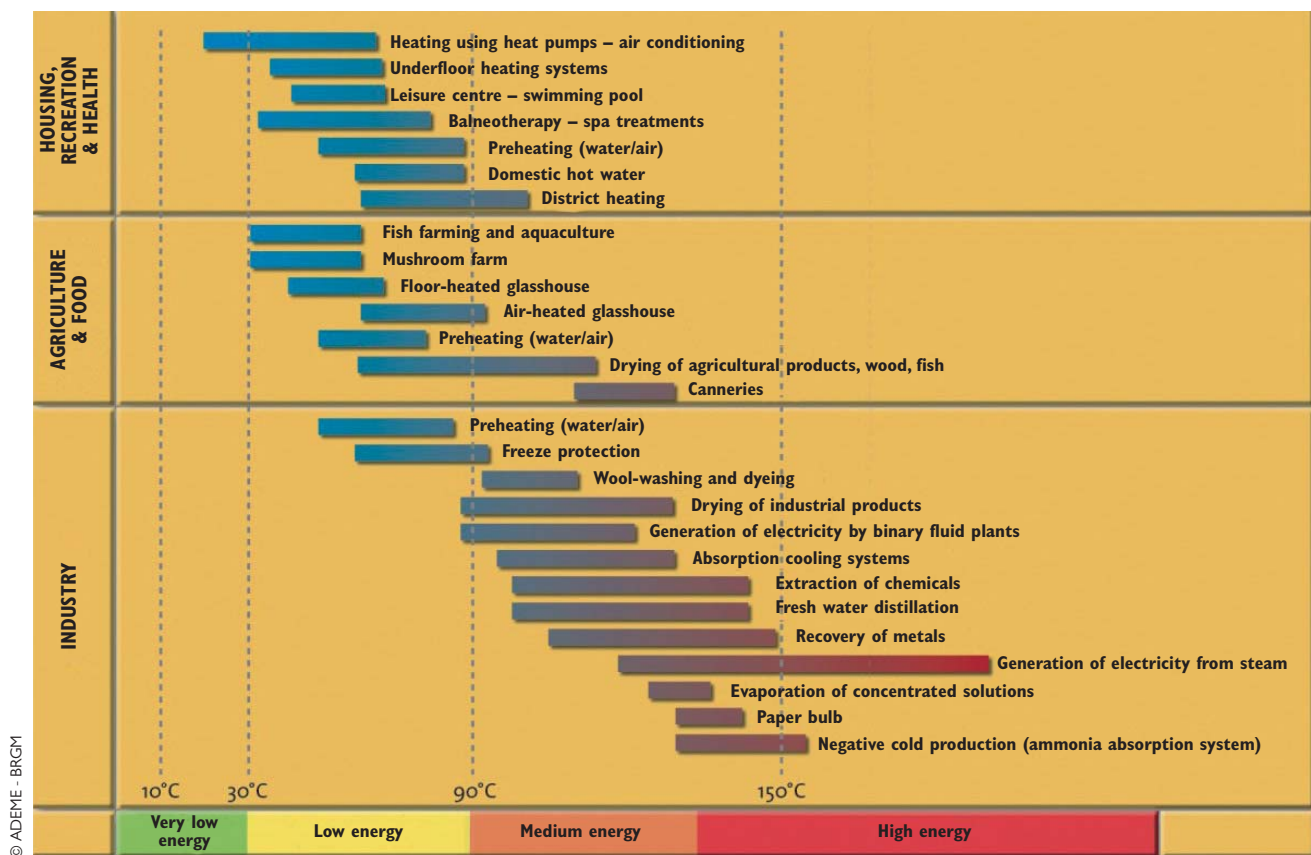
This dynamism can be attributed in large part to the support policy employed by the public authorities for the past few years and the presence of a broad range of companies specialised in the field of geothermal energy.

Indeed, France possesses the complete industrial fabric required for producing the components of geothermal loops and surface installations (boring pipes, exchangers, valves, turbines, alternators, regulation systems, corrosion treatment systems, binary plants, etc.) for the production of electricity or heat.

To this can be added highly developed skills in the exploitation of energy installations and subsurface engineering, in addition to the recognised expertise of companies capable of performing the most complex drilling operations at great depth.

Deep geothermal borehole in Paris – CPCU.





Main uses of geothermal energy according to temperatures.

Mature technologies

The main target use for **medium and high-energy geothermal energy** (at temperatures of above 90 °C) is electricity generation. The deposits are generally encountered at depths of between 500 and 1,500 m in areas of active or recent volcanism, along the boundaries of tectonic plates. In France, resources are found in insular Overseas Départements (Guadeloupe, Martinique, Réunion and Mayotte).

In the case of high-energy deposits, electricity is generated in steam power plants; geothermal steam at over 150 °C emerging directly from geothermal boreholes is fed into a turbine connected to an alternator.

In the case of medium-energy deposits (temperature of between 100 °C and 150 °C), binary plants are used, operating in a closed circuit (Organic Rankine Cycle technology) using a volatile organic fluid (isobutene, isopentane, etc.).

These plants may also operate as combined heat and power (electricity) plants for heating or cooling applications.

This is also the case for EGS (Enhanced Geothermal Systems) geothermal power plants which are intended for reservoirs with low permeability (fault basins and areas on the periphery of high-energy geothermal fields), that have natural fissures located several thousands of metres deep and whose permeability must be increased by hydraulic or chemical stimulation.

Low-energy geothermal resources (at temperatures of 30 to 100 °C) directly exploit the heat of resources found in deep, highly porous and permeable sedimentary formations, situated at depths of 500 to 2,500 metres.

These types of resources are found in France – in the Paris or Aquitaine basins, for example. They are often exploited for urban heating purposes, the heating of

glasshouses, swimming pools and spa establishments, aquaculture and drying operations. Heat pumps may also be added to optimise the exploitation of the geothermal resource.

Very low-energy geothermal resources (at temperatures of below 30 °C) require the use of heat pumps to raise the temperature of the heat extracted from the subsurface layers to a level that is compatible with the intended use (usually the heating of buildings). The main target uses for this type of geothermal energy are the heating and cooling of single-family dwellings, tertiary and collective residential buildings.



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Innovative schemes in support of the geothermal energy industry

Ambitious development targets for geothermal energy

In recent years, France has set itself the target of multiplying the contribution of geothermal heat to the French energy mix by 6, representing a total of 1.3 million tonnes of oil equivalent by 2020, while the production of geothermal electricity in France should increase from 15 to 80 MW.

These targets are consistent with one of the general objectives for France, defined in the framework of the European Union-level negotiations, which aims to increase the share of renewable energies in final energy consumption to 23% by 2020 (50% for the French Overseas *Départements*).

These targets were set during the Grenelle environmental round table, a vast consultation process initiated in 2007 that aims to prepare long-term environmental and sustainable development decisions in France.

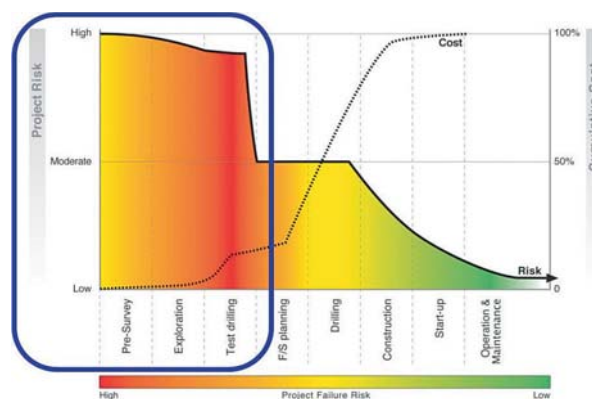
France – pioneering the coverage of geological risks in geothermal energy

One of the major obstacles to the development of geothermal energy projects is what is referred to as the **geological risk**.



ADEME Advertisement for the Renewable Heat Fund.

This risk is linked to the fact that the exploitable geothermal energy resource can only be precisely known after the drilling of boreholes – a costly operation which may result in failure (e.g. due for instance to a lack of resources, to insufficient temperature or exploitable capacity in relation to the forecasts or to the inability to exploit the geothermal fluid due to excessive acidity).



“Geological risk” in geothermal energy.

Since the 1980s, to hedge this type of risk and allow for the effective execution of geothermal energy projects, France has implemented an innovative solution consisting of an insurance system that covers the geological risk, managed by ADEME and SAF Environnement (a subsidiary of the French Consignments and Loans Fund [*Caisse des Dépôts et Consignations*]), and financial aid for the implementation of projects.

This scheme has allowed for the execution of several dozen geothermal heat installation systems in mainland France, which provide heating for over 200,000 dwelling equivalents, mainly in the Paris and Aquitaine regions.

In keeping with this experiment, steps were taken since 2011 to create an export support scheme that focuses on both financial aspects and the coverage of geological risk for the international projects of the French geothermal energy industry.

Renewable Heat Fund (*Fonds chaleur renouvelable*)

The Renewable Heat Fund, with a budget of 1.2 billion euros for the 2009-2013 period, is dedicated to the funding of projects using renewable heat in the collective housing, tertiary and industrial sectors. It allows installations that produce heat from renewable energies to be economically competitive in relation to instal-

lations that cover the same energy needs but operate using conventional energy sources. ADEME has been appointed to manage this scheme.

With regard to geothermal energy, the eligible operations are deep geothermal energy installations with or without heating networks, installations with heat pumps on surface water bodies or on probe fields, in addition to installations that recover energy from wastewater or seawater.

The Heat Fund may be approached for aid in the upstream phase of projects for the implementation of feasibility studies, thermal response tests or experimental drilling.

182 geothermal energy projects, allowing for the exploitation of more than 50,000 TOE/year, have been funded in France by the heat fund since the scheme was created in 2009.

It should also be noted that in France, in addition to the aid granted by the Renewable Heat Fund, heat networks exploiting more than 50% of renewable and recovered energy sources, including geothermal energy, benefit from a reduced VAT rate (5.5%) applied to the heat that they distribute.

Supporting R&D and innovation

French stakeholders in geothermal energy are involved in numerous projects that seek to improve current technologies or develop new technologies.

R&D and innovation for geothermal energy may benefit from different research support schemes implemented at the French or European levels, examples of which include:

- **European financing (FP7, Intelligent Energy for Europe Programme, etc.)**
- **The single inter-ministry fund (FUI) for competitive clusters (cf. paragraph below)**
- **Funding from the French National Research Agency (Agence nationale de la recherche - ANR), ADEME, OSEO, etc.**
- **Regional funding and other associated financing (European Regional Development Fund).**

European Deep Geothermal Energy Programme at Soultz-sous-Forêts (Alsace)

The “Enhanced Geothermal Systems” (EGS) concept envisages the extraction of hot water at great depths, in naturally fractured areas in which the permeability is locally increased, thus allowing geothermal salt water to circulate in convection loops.

International research in this field began in Los Alamos in the 1970s. Since 1987, it has focused on the site of Soultz-sous-Forêts in Alsace, France, where a scientific pilot project jointly funded by Europe, Germany and France, has been operating for three years.

This scientific pilot project, which remains the world’s most advanced scheme in terms of feasibility and the scientific and technological knowledge acquired, consists of four wells drilled to depths of between 3,600 and 5,000 m.

Geothermal water is circulated between the wells by a pumping system, which allows for the collection of approximately 40 litres of water per second at 200 °C at the bottom of the well and the generation of approximately 1.5 MW of electricity thanks to an ORC (Organic Rankine Cycle) type thermo-electrical conversion unit.

Development of demonstration projects

In the context of a major national loan that aims to relaunch French industry (“Investments for the future” – *Investissements d’avenir*), a vast programme costing 1.35 billion euros has been dedicated to the implementation of “demonstration” projects concerning renewable and carbon-free energies. This programme will run from 2010 to 2014.

Demonstration projects – be they “demonstrators” or technological platforms – are intended to promote pre-industrial experimentation with “breakthrough” technologies. In particular, they allow companies to take a technological and financial risk between the research phase and the mass-production of new eco-technologies.

Based on the needs identified by “Strategic Roadmaps”, Calls for Expressions of Interest (CDI’s) are then launched and the best of the proposed projects are selected.

A CDI for geothermal energy was issued at the end of 2011. It has several components:

1. Generation of EGS-type electricity or via conventional reservoirs, with the creation of: demonstrators and action programmes concerning the components, technologies and knowledge of geothermal resources and their exploitation,

2. Production of heat with:

- The implementation of technological platforms for very-low-energy geothermal power;
- Production of deep geothermal demonstrators.

Financial support takes the form of subsidies, reimbursable advances and equity holdings in companies. ADEME has been appointed to manage this programme.

Competitive clusters: french clusters for growth and employment

Competitive clusters are cornerstones of French public policy for innovation and R&D. They bring together companies (SMEs/SMLs and large groups), research laboratories and higher education institu-

Geothermal plant of Soucy-en-Brie – Boiler room



Avenia competitive cluster

Based in the Aquitaine region of France, Avenia's goal is to develop innovative projects that bring together stakeholders from research and industry in the field of geosciences (industrial geothermal energy, underground storage of intermittent energy sources, responsible development of fossil energy sources and the geological storage of CO₂).

Avenia's geothermal energy activities focus on the geothermal aspects of heating networks in particular.

tions on a single site and cover the entire value chain, thus uniting public and private innovation capacities on projects of high potential.

To stimulate the emergence of projects, invitations to tender are issued by the public authorities. These represented €1.5 billion of funding for the 2009-2011 period. In addition, the French local authorities provide support and the clusters benefit from a special tax regime.

France has around ten clusters operating in the renewable energies field, including the Avenia cluster, dedicated to geosciences.

Institutes and laboratories of excellence

In addition to the aforementioned demonstrators, R&D and innovation in geothermal energy are also supported in the framework of the Investments for the future (*Investissements d'avenir*) scheme via other mechanisms, such as the Institutes and Laboratories of Excellence (*Instituts et Laboratoires d'excellence*).

Geodenergies Institute of Excellence (Orléans)

Institutes of Excellence for Carbon-Free Energies (*Instituts d'excellence dans le domaine des énergies décarbonées – IEED*) are field specific institutes which, through a strategic public-private partnership, conduct research programmes associated with technological platforms, carry out experimental research and development activities focusing on market requirements, contribute to the engineering of initial and continuing training courses and ensure the socio-economic exploitation of the results obtained.

The Geodenergies IEED (Geotechnologies for producing carbon-free energies) was awarded its official quality label in March 2012. It aims to produce technological "bricks" to facilitate the emergence of three industrial sectors associated with subsurface levels: CO₂ storage, energy storage and geothermal energy (heat and electricity). Coordinated by the BRGM in Orléans, Geodenergies associates 22 companies and 11 public research bodies.

"G-eau-thermie profonde" deep geothermal Laboratory of Excellence (Strasbourg)

Through the Laboratory of Excellence (*Laboratoire d'Excellence – LabEx*) call for projects launched in 2011, laboratories with an international profile have the opportunity to receive significant resources that will allow them to compete on equal terms with their foreign counterparts,

attract researchers and teaching and research staff of international renown, and develop a high-level integrated research, training and exploitation policy. 171 Laboratories of Excellence have thus been selected for funding over a long enough period to allow them to deploy a large-scale scientific strategy.

Situated in the Alsace region, the G-eau-thermie profonde laboratory received its official quality label in March 2012. It seeks to develop the use of deep geothermal energy by improving the knowledge of deep geothermal reservoirs and through the development of new technologies allowing for their exploitation. It combines the academic skills of the University of Strasbourg with the industrial skills of the Electricité de Strasbourg group. This medium-term programme (8 years) has received government funding of €3 million.

Examples of R&D/innovation projects

Development of an Organic Rankine Cycle machine designed for geothermal energy – Enertime

Through its ORCHID® range, Enertime has developed expertise in the design, manufacturing and implementation of industrial-sized Organic Rankine Cycle (ORC) modules (500 kW to 5 MW range), using non-toxic, non-flammable fluids for temperatures of above 120 °C. The company is also developing new modules capable of exploiting geothermal resources starting at 80 °C.

Enertime manages the entire design process for its modules and can thus offer optimised solutions for projects for which the company is consulted.

Enertime raised €1.5 M of capital at the start of 2011 from investment funds and obtained €1.8 M in aid from TOTAL to complete the development of the 1 MW ORCHID® module. Such a module is operating since septembre 2012 for an industrial heat recovery application in the Pays de Loire region of France.

GEOSTOCAL project: inter-seasonal storage of excess heat in deep aquifers

The ANR GEOSTOCAL project (2008 – 2011), coordinated by the BRGM, and funded by the French national agency for research (ANR), brought together several academic and industrial partners. It demonstrated, the theoretical technical and economic feasibility of the inter-seasonal storage of high-power heat in deep aquifers, connected to an urban heating network and exploiting the excess free heat produced during the summer season.

The technical, economic and ecological aspects of different storage configurations have been studied, some of which – being particular innovative – offer a flexible combination of conventional, mining-type geothermal energy, and heat storage.

Convinced by these results, CPCU – the industrial partner of the ANR project – is currently bringing an industrial demonstration project for one of these configurations. The scientific support for this project, if it should materialise, should provide new information about the Dogger deep aquifer that will be of direct benefit to current conventional geothermal operations and to future storage operations.



Technologies and industrial development

LOW AND MEDIUM GEOTHERMAL ENERGY FOR SUPPLYING DISTRICT HEATING

Deep-aquifer geothermal energy, referred to as “low-energy”, concerns the exploitation of aquifers at depths of more than several hundred metres. Given the size of the sub-surface investments required for the exploitation of very deep aquifers, this type of energy is generally associated with heating networks: systems capable of supplying several thousand dwellings, thus spreading the sub-surface investments in geothermal energy over a larger number of points of consumption.

Proven technology

Supplied mainly via a borehole or a geothermal doublet, geothermal heating networks transport heat in the form of hot water in buried pipes for the heating of dwellings, public and industrial buildings and domestic hot water supply.

The resources exploited must be hot enough to be used (between 30 and 90 °C). Depending on the situation, production may be carried out via a single well connected to a heat exchanger or, more frequently, via a “geothermal doublet” linked to an exchanger.

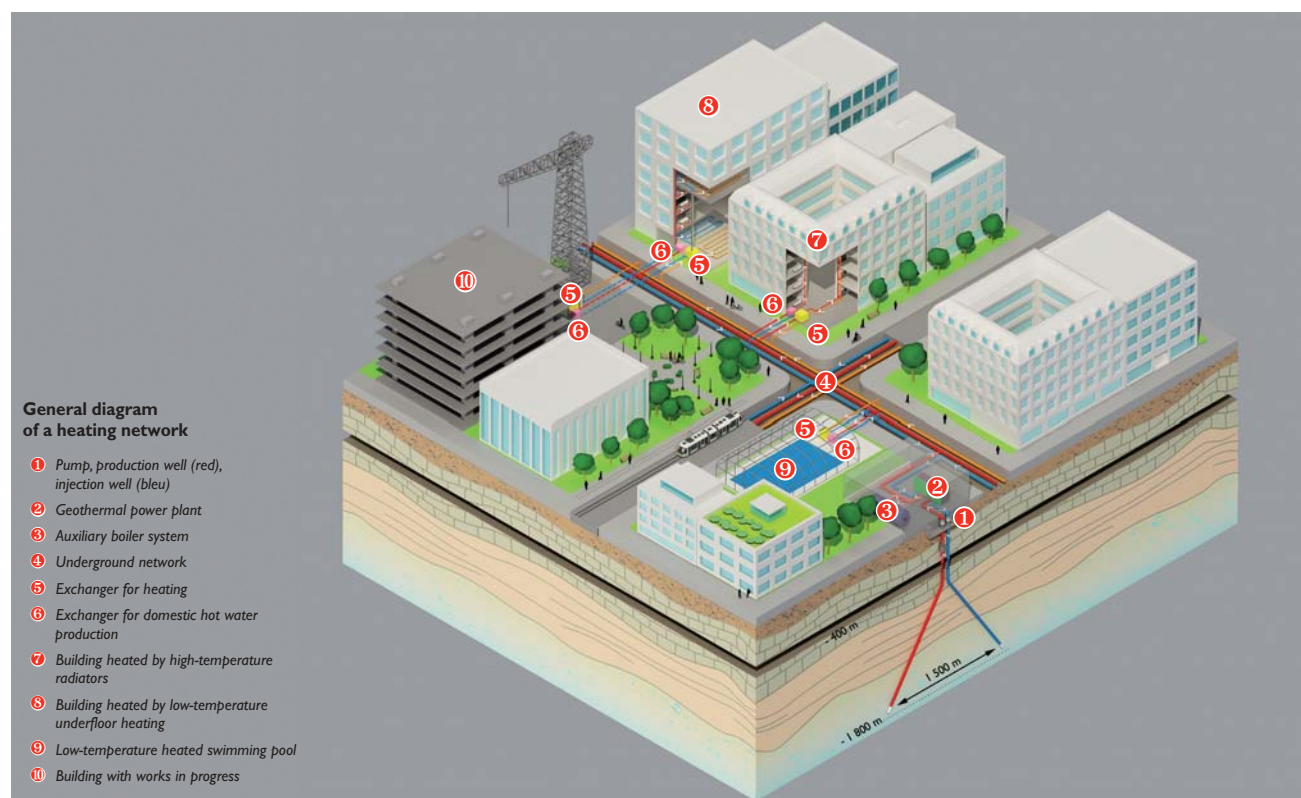
A geothermal doublet consists of one production borehole and one reinjection borehole. Geothermal water is brought to the surface by a production pump. After water has released its heat energy, it is reinjected into its aquifer of origin via an identical borehole.

The two boreholes are far enough away from one another so that the cooled water reinjected doesn't impact the production borehole. Reinjecting the water after the removal of the calories prevents surface-level pollution if the water is salty or prevents waste if it is only slightly mi-

neralised and thus suitable for domestic or industrial use. This configuration offers several advantages: lack of discharge into the environment (closed-loop circuit), sustainability of the hydraulic flow rate and stability of the operating pressures.

In France, the creation of a heating network requires numerous partners: public authorities, building and infrastructure managers, users and residents of the district in addition to geothermal energy professionals, consisting of operating companies and service companies (subsurface and surface).

To ensure the profitability of the cost of boring and the surface investments, the energy produced must be capable of supplying 3,000 to 4,000 dwelling equivalents, if possible situated within a radius of 3 to 4 km. This generates a total power of 40,000 to 45,000 MWhr/year.





Thermal waters, public baths in Budapest.

Paris basin: an operating model for low-energy geothermal power

The Paris Basin has the special characteristic of offering a strong link between the geothermal resources and the demand for heating, as numerous conurbations are situated directly above continuous aquifers. Out of the approximately 200,000 dwelling equivalents in France heated by geothermal heating networks, approximately 170,000 are situated in the Paris region.

This sedimentary basin has five large aquifers, including the Dogger which has the largest number of low-energy geothermal operations in the world, with 36 operations currently recorded, which are used for collective heating applications. Putting this into context, a typical operation in the Paris region allows for the heating of approximately 4,000 to 5,000 homes.

The Dogger covers an area of over 150,000 km² with the temperature measured directly below the Paris region varying between 56 °C and 85 °C according to the depth of the reservoir (between 1,600 and 1,800 m).

The district heating networks supplied by the Dogger geothermal resource, which

Paris-Orly airport is heated by geothermal energy ADP / CFG Services

Since the end of 2010, the Southern and Western terminals of Paris-Orly airport have been partly heated by geothermal energy. One-third of the heat supplied is indeed of geothermal origin and originates from a borehole doublet that collects naturally hot (74 °C) water at a depth of 1,750 metres in the Dogger.

Aéroports de Paris invested 12.7 million euros in this installation, for which ADEME and the Île-de-France region provided subsidies amounting to 30% of the total investment cost. The Aéroports de Paris' technical teams supervised this project, supported by the external skills of CFG Services for subsoil operations (studies, drilling and implementation of the dual geothermal system). In addition to offering major savings in gas consumption, geothermal energy will also prevent Aéroports de Paris from emitting 9,000 tonnes of CO₂ per year into the atmosphere.

Extension of the Sucy-en-Brie heat distribution network – Cofely GDF Suez

Sucy-en-Brie is a perfect example of the mastery acquired by Cofely GDF Suez in the field of renewable energies. It shows that it is possible to develop the use of geothermal resources while guaranteeing their sustainability and increasing the number of beneficiaries via an extension of the heating distribution network.

By drilling a new production well and converting the two existing wells into reinjection wells, Cofely GDF Suez has created the first geothermal "triplet" in the Île-de-France region. The works, rounded off by the extension of the heating distribution network (from 3 to 4 km), have increased the power of the new production plant (from 7 to 11 MW) and the number of dwelling equivalents supplied (from 2,350 to 2,900).

are mainly exploited by private companies such as **Dalkia**, **Cofely**, **IDEX Energie** and **Coriance a2a**, but also by local public-private ventures (*sociétés d'économie mixte* – SEM), have been operated for nearly thirty years and have thus been fully

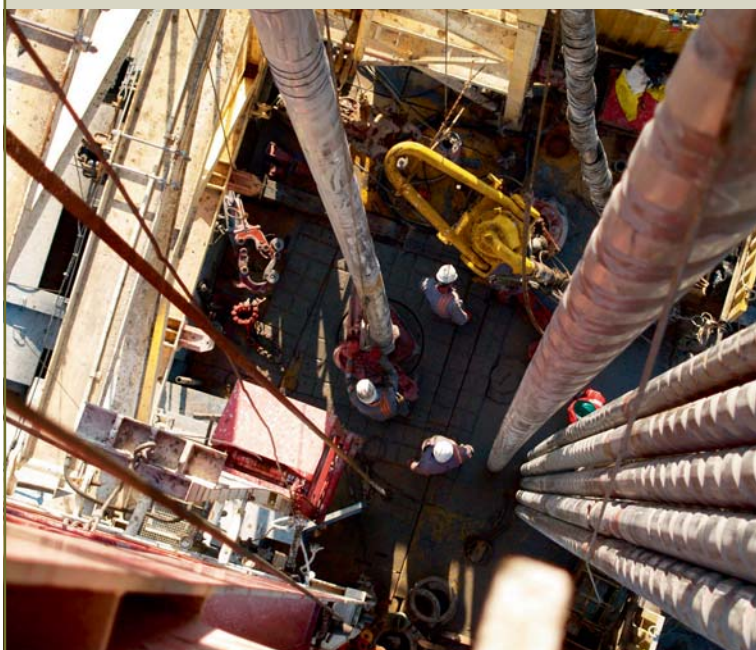
amortised, with their average availability rate still approaching 95%. The oldest of these installations is situated at Melun l'Almont. Commissioned in 1969, it is still operating today.



Geothermal extractor
Geothermal energy plant
in Melun.



© Antea



The Orly Choisy operation: the drill pipes are assembled one after the other as the drilling progresses.

A new geothermal doublet for the town of Orly – Antea / COFOR

Since 2008, Valophis Habitat has benefitted from a new doublet of geothermal boreholes connected to its Orly – Choisy-le-Roi heating network. This deep-aquifer geothermal doublet (1,700 metres) produces over 300 m³/hr of water at 76 °C. With these volumes of hot water collected, Valophis can guarantee an 86% coverage rate of its heating network by geothermal energy. Covering a distance of 18 km both ways, the associated heating network allows for the heating of 8,000 dwelling equivalents, including the municipal buildings of the town of Orly (secondary schools, etc.).

Antea Group has been appointed as project manager for the design and execution of this project, accompanied by COFOR as the main contractor.

This operation prevents the emission of 15,000 tonnes of CO₂ each year, compared to a gas-powered solution, and allows for significant savings. One MW costs 27 euros instead of 35 to 40 euros for gas. This amounts to annual savings of 150 to 200 euros for a family of four people living in a four-roomed apartment.

Development of geothermal energy in the town of Meaux – Coriance

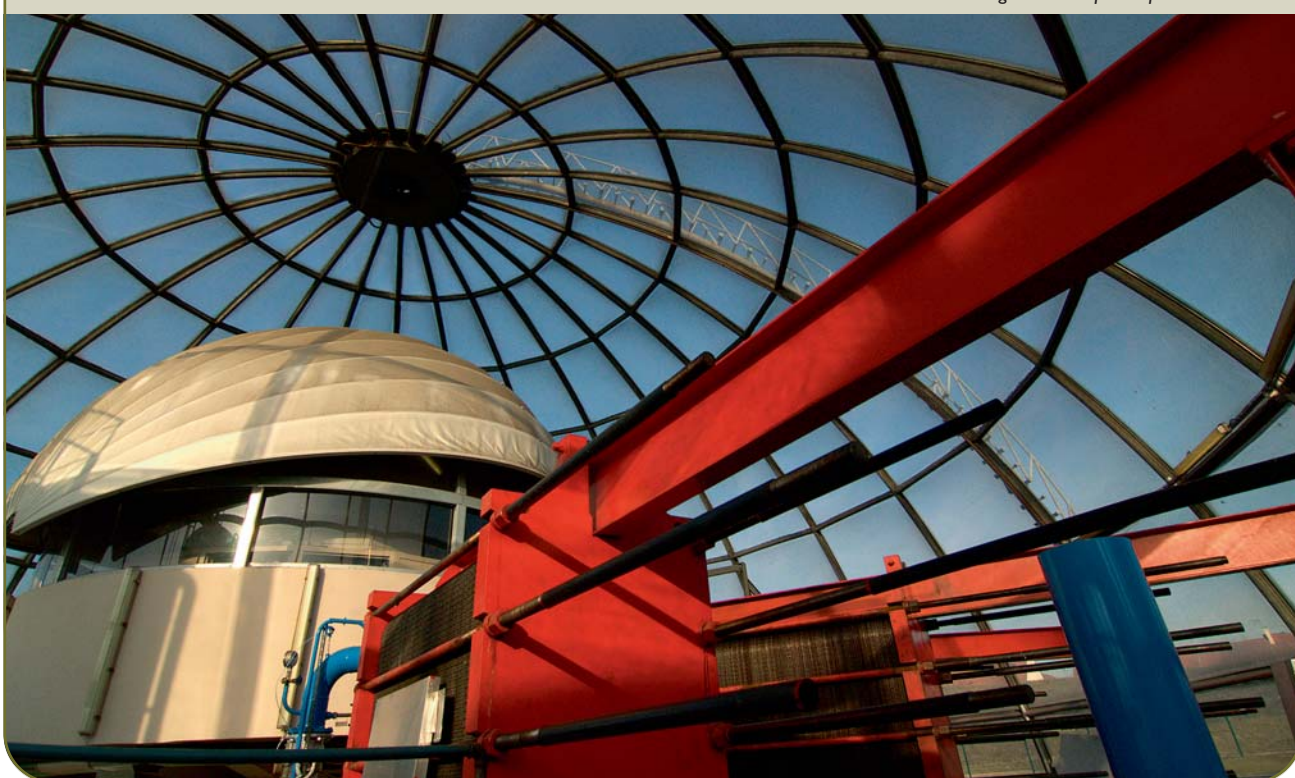
According to the wishes of the Meaux town council, the Syndicat Mixte de Géothermie de Meaux and its delegate Energie Meaux, a subsidiary of Coriance, have entered into an agreement concerning the development of geothermal energy: 26 million euros of investments are envisaged.

Three existing doublets will be converted into triplets: new production wells will be drilled, while the current wells will be relined and then reused for the reinjection process. The fourth doublet will be retained. The installation of extraction pumps will produce a total flow rate of 885 m³/hr. A heat pump (4 MW) will optimise the recovery of subsurface energy.

The geothermal capacity of Meaux will thus be doubled: 60% of the heat for the networks will be produced from this safe, local and renewable resource. Eventually, nearly 12,000 dwelling equivalents will be supplied, preventing the emission of 30,000 tonnes of CO₂ per year!

Meaux geothermal power plant - Coriance.

© Cédric Helsly – Photothèque Coriance





Renewal of operations

The sustainability of the oldest geothermal heating networks now involves the renewal of the systems. Depending on the situation, the existing systems operate as a borehole triplet (drilling of a production well after renovation of the two existing boreholes, in the form of an injection well with a smaller diameter), or are abandoned and replaced by a new doublet. Since 2007, four operations have been renewed in this way for the municipalities of Orly, Sucy-en-Brie, La Courmeuve and Coulommiers. At the same time, 3 new operations (doublets) have been created: North-eastern Paris, the Orly airport site and Lagnes.

These recent operations bear witness to the renaissance of deep geothermal energy in the Île-de-France region, which will continue in the coming years (7 renewals planned for 2012 / 2013).

Significant development potential

There are numerous development prospects for low-temperature geothermal energy in mainland France. In the Paris Basin, the attention is focused on the Albian/Neocomian, Lusitanian and Trias aquifers which have significant potentials, especially where the Dogger is less favourable or is already highly exploited.

In the Aquitaine Basin, the geothermal resources have been exploited for around thirty years via a dozen boreholes, mainly located in the Gironde département. The context is clearly different from the Paris Basin insofar as all of the sites operate on a single-well basis, i.e. without the reinjection of fluid.

Alsace and the Upper Rhine Plain offer a geothermal potential that is already exploited in Germany (Bruschaal site to the north-east of Karlsruhe). A deep borehole (approximately 2,000 metres) in the Rittershoffen region near Strasbourg, will be used to verify this potential over the national territory.

At the international level, the successful operating procedures employed in the Dogger in the Paris Basin could be used as an example for Central and Eastern European countries, which are well endowed with low and medium-temperature geothermal resources. The Pannonian Basin, the Podhale Basin and the Carpathian Basin all come to mind.

Geothermal energy for an eco-district – Dalkia

Dalkia - a world leader in energy services - funds, designs and operates numerous geothermal installations over dry probes or aquifers at depths of several metres to several thousand metres. For example, Dalkia manages 17 geothermal doublets out of the 36 installations operating in the Ile-de-France region.

At Fort d'Issy-Les-Moulineaux, Dalkia is constructing the first geothermal heating network that will supply an eco-district, using a warm-water loop. Dalkia will operate this system for a period of 25 years. From 1 January 2013, two geothermal wells drilled to a depth of 600 m to reach the Albien aquifer (28 °C) will supply heating and domestic hot water to 1,600 dwellings, 2 schools, one swimming pool and shops. Heat pumps installed on the ground floor of buildings will be used for the heating and cooling of accommodation and shops.

Latest project to be launched: the design, execution and 25-year funding of a doublet in the Dogger (2,000 m at 71 °C), which supplies the Lagnes heating network (Île-de-France region). Other projects underway: Arcus in Norway (90 dry probes at a depth of 300 m), Le Plessis-Robinson in Île-de-France (two boreholes at a depth of 900 m in the Neocomian: 38 °C), projects in China, etc.

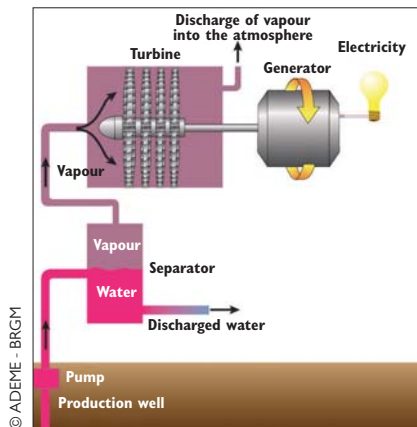
Mapping of "cold bubbles" in the départements of Seine-Saint-Denis and Val-de-Marne after thirty years of geothermal exploitation

Following the resurgence of deep geothermal energy in the Île-de-France region at the start of the 2000s, ADEME and the BRGM realised the need to efficiently manage the "cold bubbles" that have appeared around injection wells since the start of operations – mainly between 1980 and 1985.

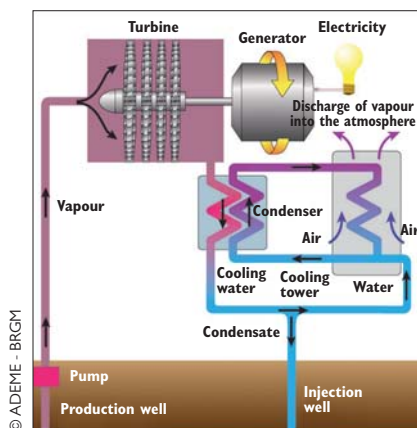
Of the 36 doublets currently in operation in the Paris region, 27 are located in Val-de-Marne and Seine-Saint-Denis. Since 2009, a resource management model has been implemented throughout these départements, firstly to improve our knowledge of the size of these cooled areas with a view to optimising the siting of new boreholes in the context of new operations or renovations and secondly, to predict the start of cooling at the production boreholes. Data for this model, implemented by the BRGM, are provided by the DOGGER database, created in 2001 in association with subsurface design offices, which stores all information relating to the operations.



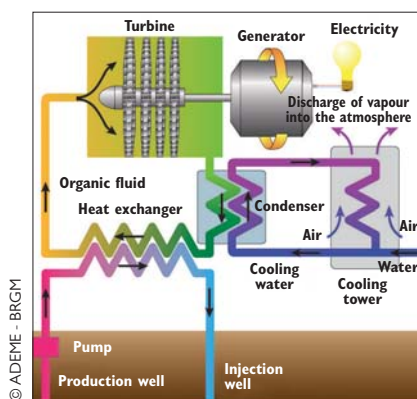
Filter of the Lagnes geothermal plant (DALKIA)



Back-pressure power plant: after separation of the vapour phase, the vapour obtained expands in a turbine and released into the atmosphere.



Condensation power plant: the vapour obtained at the head of the production borehole powers the turbine. It is then condensed at the turbine outlet.



Binary fluid geothermal power plant: the geothermal fluid transfers its heat inside an exchanger using an organic fluid which is vaporised at low temperature and expands in the turbine.

HIGH-ENERGY GEOTHERMAL POWER FOR ELECTRICITY GENERATION

Discovered a century ago, electricity generation using geothermal energy grew significantly in the 1970s and today accounts for 11,000 MW of power worldwide. The current technologies allow for electricity generation at lower and lower temperatures. Furthermore, there is a promising outlook for stimulated geothermal (“EGS”) systems.

Electricity generation in volcanic Areas

Geothermal electricity generation is based on the exploitation of deposits containing resources at temperatures of 100 to 350 °C in regions of active volcanism.

On these sites, the vapour produced at the head of the borehole powers a turbine and an alternator which generates electricity. The condensed fluid is then reinjected into the deposit to optimise the operating period.

Los Azufres II geothermal power plant in Mexico – Alstom

Alstom is a global leader in the world of power generation, power transmission and rail infrastructure and sets the benchmark for innovative and environmentally friendly technologies. Pioneer in the exploitation of geothermal energy, Alstom supplies the engineering, the equipment and the construction of geothermal solutions, since the supply of turbines until the construction and the maintenance of the power plant.

The group has installed more than 380 MW of geothermal electricity capacity worldwide. Alstom's projects include the plants of Los Humeros (Mexico 2009), Los Azufres (Mexico 2000), Las Tres Virgenes (Mexico 1998), Lahendong (Indonesia 1995), Bouillante (French West Indies 1980) and Wairakei (New Zealand 1958).

Appointed in 2000 by the Mexican Government, the geothermal power plant of Los Azufres II is one of the most cost-effective sources of energy available in Mexico. Through a turnkey project, Alstom provided all of the engineering, services, the construction of the site, supply of the steam turbine as well as the system of control for the four 25 MW units.

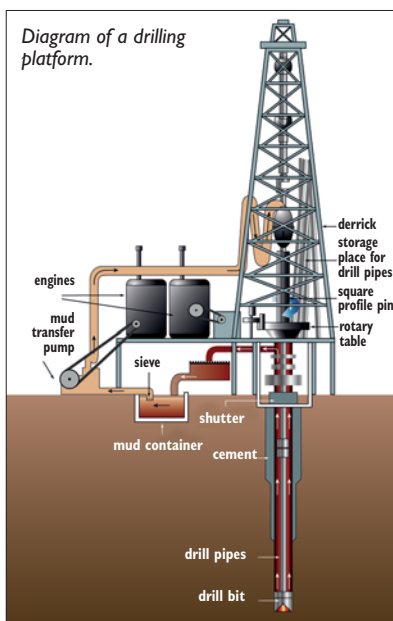
Los Azufres II plant makes use of drilled wells to extract steam from a depth of up to 4500 meters where the geothermal reservoir is located. The power plant began commercial operations in 2003, all the combined units feeds the nation's electrical distribution grid, with more than 800 GW of electricity a year of clean and reliable electricity.

Los Azufres geothermal power plant in Mexico – Alstom.





Diagram of a drilling platform.



© ADEME - BRGM

Electricity can also be generated using resources at temperatures of between 100 °C and 160 °C. In this case, the geothermal fluid transfers its calories inside an exchanger containing an organic liquid that has a low flashpoint and in which the vapour activates a turbine; the organic liquid circulates in a closed circuit between the geothermal exchanger and a condenser. This technology is referred to as binary fluid or ORC (Organic Rankine Cycle) technology.

Project Development stages

The implementation of a generic project to develop a geothermal resource for the generation of electricity consists of the following stages:

1 - Preliminary reconnaissance: this stage involves using geological data to select areas propitious to the existence of geothermal resources within a given territory.

2 - Execution of pre-feasibility studies: the purpose of these studies is to reveal the existence of geothermal resources within areas identified as being potentially favourable.

3 - Drilling of exploratory boreholes: exploratory boreholes are intended to

Geothermal development project on Dominica – BRGM/CFG Services

The island of Dominica in the West Indies possesses a significant geothermal potential for the generation of electricity, which was recognised during the first explorations of the Wotten-Waven field carried out by BRGM in the 1980s.

In the framework of projects funded by the Organisation of American States ("Geo-Caribbean" Project) and by the European Union (Caribbean Geothermal" project, coordinated by the Guadeloupe Region) between 2005 and 2010, CFG Services and the BRGM, associated with ADEME, carried out the pre-feasibility study for a geothermal power plant project with a capacity of 120 MW, which aims to cover the electricity needs of Dominica and to export any surplus to Guadeloupe and Martinique via undersea cables.

The study included geological exploration, geochemical and geophysical activities, the creation of a preliminary field model and the selection of sites conducive to the drilling of three exploratory boreholes, the preliminary design of the production units, updating of the economic assessment, including the interconnection cost and an environmental pre-feasibility assessment.

The prospects for this project are remarkable from an environmental point of view. It is also promising in terms of regional cooperation and economic development for these Caribbean islands, all the more so given that the three exploratory boreholes drilled at the end of 2011 and at the start of 2012 under the management of the AFD confirmed the findings of previous studies and the presence of a high-temperature resource.

A new project entitled "*Géothermie Caraïbe – Phase 2*" (Caribbean Geothermal – Phase 2), coordinated by the Guadeloupe Region and ADEME in association with the Martinique Region, BRGM, AFD, the French Consignments and Loans Fund and Électricité de Strasbourg, is currently being launched. Its aim is to prepare a development plan for geothermal energy with the appropriate tools on a Caribbean scale in order to create the required cumulative effect.

Adapting the most recent oil exploration techniques to high-energy geothermal power – Teranov

Since the end of 2010, Teranov has undertaken an operational research program that consists in adapting the most recent oil exploration techniques to high geothermal energy. The aim is to propose a range of services for public or private developers by developing an integrated tool that optimizes exploration costs and allows the related financial risk to be assessed more accurately. The format and accuracy of this tool should be equal to those of tools commonly used by investors in mines and industries.

To complete this research programme successfully, Teranov is working in close collaboration with the most reputable para-petroleum service companies. This service offering should allow Teranov to access the flourishing high-energy geothermal power markets in the Caribbean region and Latin America.

confirm the existence of a geothermal reservoir and to assess its characteristics (depth, extent, permeability and properties of the existing geothermal fluid). In the absence of positive results, the project may be abandoned at this stage.

4 - Exploitation of the geothermal reservoir with the execution of the complete electricity generation project (feasibility study, drilling of exploratory boreholes and construction of surface facilities including the power plant).



Expert appraisal of the “Joint Geophysical Imaging” project for high-energy geothermal power in Kenya – CabENR

Amongst its regular missions, the Cabinet Alain Boisdet conducted an expert appraisal of the “Joint Geophysical Imaging” (JGI) project in Kenya on behalf of the PNUE. JGI seeks to increase the effectiveness of geothermal prospection by optimising the location of wells.

It is used in Kenya in the context of increasing the installed power from 115 MW to over 1,000 MW by 2020. It will constitute a benchmark process for the other countries in the ARGEO programme. JGI integrates an innovative 3D imaging methodology for data collected from different geophysical sensors.

Alain Boisdet performed a technical and organisational appraisal of the project in order to identify its strengths and weaknesses and issue recommendations for improvements. This mission illustrates CabENR's recognised international expertise, based on its excellent knowledge of the geothermal sector and the pertinence of its analyses.



Olkaria 2 geothermal power plant (Kenya).

High-enthalpy pilot project in mainland France – Fonroche Géothermie

Fonroche Géothermie, aware of the key issues in the sector, is actively working to implement a high-enthalpy pilot project in the municipality of Lons in the Pyrénées Atlantiques département of France. The innovative technology developed by the consortium of companies which are experts in the field could allow for the exploitation of geothermal resources that have so far remained unusable. Linked to innovative, high-performance custom-designed thermodynamic systems, one thermodynamic combined heat and power unit will allow for the generation of 5.5 MW of electricity and up to 20 MW of heat exploited using heat distribution networks, in the form of steam, hot water and iced water; for the heating and cooling of residential and tertiary buildings situated close to the plant.

Fonroche Géothermie is investing heavily in the social, societal and environmental impacts of its activity, especially by implementing wide-ranging communication campaigns.

Bouillante geothermal power plant in Guadeloupe – BRGM / EDF

This plant, situated in the West Indies, has France's biggest conventional geothermal electricity generating capacity. Consisting initially of one unit – Bouillante 1 – delivering a power of 4 MW, which was commissioned by EDF in the 1980s, a second unit – Bouillante 2 – was subsequently added, delivering a power of 11 MW after the thermal stimulation of an existing well by the BRGM group in 1988 and the drilling of three new wells at the start of the 2000s.

Géothermie Bouillante, a subsidiary of the BRGM and EDF groups, operates the plant and develops new projects at the scale of the geothermal concession that it holds. The engineering and maintenance of the sub-surface loop is carried out by CFG Services, and the concession constitutes the focus of the R&D activities carried out by BRGM and the University of Antilles-Guyane.

Bouillante geothermal power plant in Bouillante, Guadeloupe.

© Bernard Sanjuan – BRGM





A dynamic french sector

In France, the resources for producing geothermal electricity (high-energy sources) are situated in the Overseas *Départements*, particularly in the West Indies (Guadeloupe and Martinique) and in the Indian Ocean (Réunion Island and Mayotte).

The Bouillante power station is a pioneering site in the Caribbean, supplying 6% of the electricity consumed in Guadeloupe. In addition, surface exploration programmes have been launched in Martinique and are being created for Réunion and Guadeloupe. On each occasion, they are associated with a steering committee involving all stakeholders in order to take account of the expectations of all parties.

Numerous French companies operate in the field of geothermal electricity generation, from SMEs to major groups. **Alstom** thus has several major references to its credit, including in Indonesia, Mexico and New Zealand. **GDF Suez** is involved in the launch of several power plants in Indonesia via its subsidiary **International Power**.

French oil operators and specialist engineering firms also possess skills that allow them to ensure the execution of projects, from feasibility studies through to exploitation and including the drilling of complex boreholes to great depths. Those companies are members of the AFPG, the French association of geothermal energy professionals (www.afpg.asso.fr).

*Lahendong geothermal energy power plant (electricity production) in Indonesia
CFG Services, commissioned in
2001- 20 MW of power.*

Supply of equipment and ORC for geothermal power generation – Cryostar

Cryostar is a global manufacturer of rotating machinery such as: pumps, compressors, turbines, turbo-compressors, turbo-generators, vaporisation units, liquefaction units. Cryostar also designs ORCs (Organic Rankine Cycle). Since 2000, Cryostar has been developing specific solutions dedicated to geothermal energy.

In 2007, Cryostar provided turbo-generators to equip geothermal power plants in Soultz-sous-Forêts in France (2.5 MWel power) and Unterhaching in Germany (3.7 MWel power).



*Geothermy Unterhaching GmbH & Co KG
3.7 MW Cryostar turbo generator.*

will be operational in 2013. It will be the first commercial, geothermal, supercritical ORC project in Europe.

Soultz-sous-Forêts is the first EGS project in the world. Unterhaching is at the moment the only operating Kalina cycle geothermal power plant in the world. More recently, Cryostar has been chosen to supply a turn-key power plant for the Kirchweidach site in Germany. The ORC designed and developed by Cryostar is spercritical and has a nominal power of 8 MW. It is under construction and



Soultz-sous-Forêts: a leading pilot site for experimentation with EGS technology

The GEIE-EMC operates an EGS (Enhanced Geothermal System)-type deep geothermal energy site, situated at Soultz-sous-Forêts/Kutzenhausenn in the Upper Rhine Plain. It is managed by a consortium of Franco-German energy companies (ES, EDF, EnBW, Plazwerke, Steag and Bestec).

The site comprises four geothermal wells at depths of between 3,600 and 5,000 m, which cut through fractured granite. The ORC-type power plant with a net output capacity of 1.5 MWe is powered by a geothermal fluid (salt water – 100 g/L) at ~ 170 °C and ~ 40 L/s overall.

The site benefits from scientific support (50 PhDs, 235 publications, 700 conferences and 400 technical reports) and a technical infrastructure that allows for the performance of tests/experiments in the fields of surface facilities (production pumps, exchangers, sludge and corrosion prevention) and provides knowledge of sub-surface levels (reservoir modelling, plotting, etc.).

www.geothermie-soultz.fr

Soultz drilling rig – GEIE EMC.



ELECTRICITY GENERATION BY EGS TECHNOLOGY

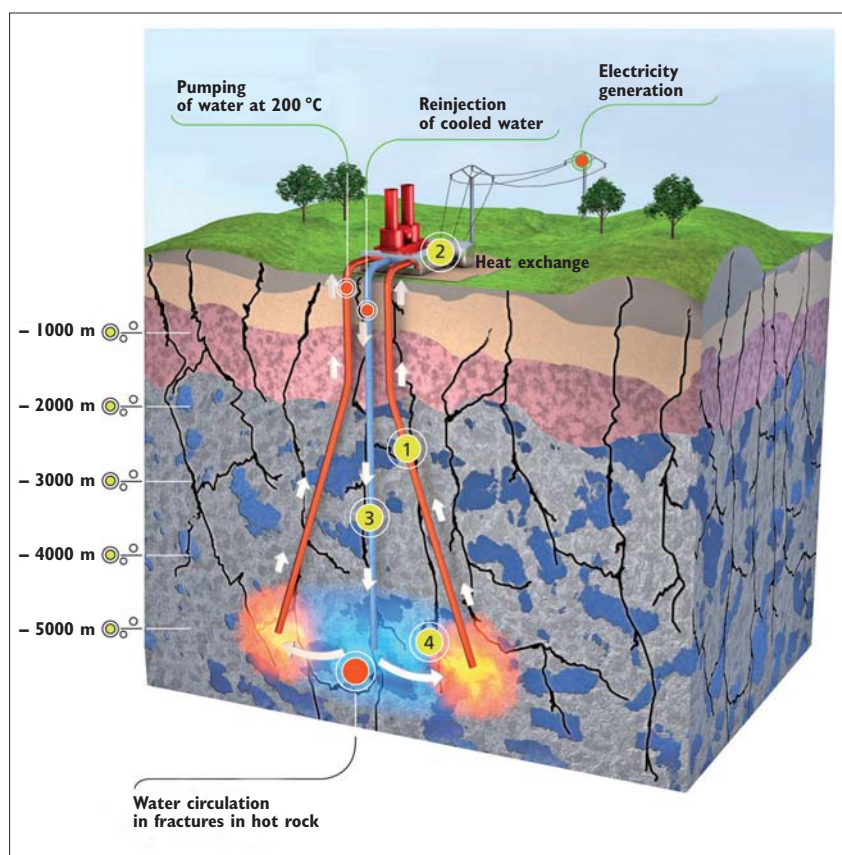
Throughout the world, several projects are currently being carried out in order to develop geothermal power plants based on the “Enhanced Geothermal Systems” (EGS) technology, relying on the stimulation of hot, naturally fractured rocks. France pioneered this field with its scientific pilot project at Soultz-sous-Forêts.

Cutting-edge technology

Conventional geothermal operations are carried out on highly permeable reservoirs capable of providing high outputs of geothermal fluid production. EGS-type technologies seek to improve the hydraulic performances of environments that are fractured to varying extents (basement rock or sedimentary rock in compact basins) and are not porous or permeable enough to be exploited using traditional methods.

The extraction of heat from these formations thus becomes possible provided that these environments are stimulated (hydraulically or chemically) in order to facilitate the circulation of the fluid and thermal exchanges.

"Principle of EGS systems
diagram of the Soultz-sous-Forêts power plant.





Volcanic eruption of the Piton de la Fournaise (Réunion island).

These technologies allow for the more complete exploitation of traditional hydrothermal fields and the execution of geothermal production in areas without any volcanic context.

There is a particularly high number of potential targets on the different continents, consisting of deep granites underneath a thick sedimentary covering layer.

The most advanced project in terms of EGS technology began in France in 1987, in the framework of a Franco-German collaboration with the support of the European Union. Based in the French *département* of Bas-Rhin at Soultz-sous-Forêts, this project has overcome numerous obstacles, allowing for the eventual deployment of this technology on a larger scale.

Pre-feasibility studies of deep geothermal energy in a fractured environment – ES Géothermie

In line with the innovations and pilot projects carried out concerning EGS technology in France, ES-Géothermie has conducted several pre-feasibility studies in the Alsace region on the topic of hot fractured rocks. Carried out on behalf of manufacturers (Cristal Union sugar plant at Erstein, Kronenbourg brewery at Obernai) and local authorities (the municipality of Illkirch-Graffenstaden, of Wissembourg), the aim of these studies was to examine the extent to which the deep geothermal potential suitable for exploitation in a fractured environment may be economically exploitable and under what conditions.

ECOGI project: the first industrial geothermal exploitation of a resource in a fractured environment – ES-Géothermie

ECOGI (*Exploitation de la Chaleur d'Origine Géothermique pour l'Industrie* – Exploitation of Heat of Geothermal Origin for Industry) is a joint-venture involving the ES Group, Roquette Frères and the French National Consignment and Loans Fund in a project to produce heat energy via deep geothermal resources in order to power the Roquette industrial site situated in Beinheim.

Designed to produce 24 thermal MW out of the 90 MW consumed by the Roquette site via two wells (at depths of 2.5 to 3 km), this plant will be an ambitious project using a renewable energy source to power the Roquette industrial site situated 15 km away from the wells, thus providing a sustainable and responsible response to the energy needs of industrial groups. ES Géothermie is providing assistance to the project holder for this undertaking.

Geothermal power plant, Soultz-sous-Forêts.



© GBE Exploitation minière de la chaleur

French aid and expertise worldwide

Through initiatives and dedicated financial instruments, France provides international support for numerous development projects and technology transfers in the renewable energies sector.

FASEP fund – Studies and Green Innovation for emerging countries

FASEP is a donation scheme for local beneficiaries (central government, provincial government, municipality, technical agency, etc.) with average sums of approximately 400,000 euros. It allows for the financing of services which meet the local beneficiary's need, are situated upstream of development projects and are likely to call upon the expertise of French companies (engineering, equipment manufacturers and operators), for which the financing has been identified (public or private, bilateral or multilateral).

Renewable energies are one of the sectors covered by FASEP. The following types of intervention are supported in particular: preparatory studies for infrastructure construction and/or operation projects; feasibility studies; preliminary design projects and tender designs, etc.; technical support for project preparation or execu-

tion; institutional cooperation for economic purposes.

FASEP "Green Innovation" allows for the financing of pilot demonstration projects for French green and innovative technology in emerging countries.

Reserve for Emerging Countries (Réserve Pays Émergents – RPE)

The RPE is an intergovernmental loan scheme with a sovereign guarantee, for the financing of projects (mainly infrastructures) that correspond to the beneficiary country's development targets. The funding of projects is considered on a project-by-project basis and mainly applies to the financing of French goods and services.

Renewable energies and projects forming part of the mechanisms set out in the Kyoto Protocol are amongst the priorities targeted by the RPE. The scheme is limited to a certain number of countries and the funding conditions are governed by the rules of the OECD.

French Global Environment Fund (FGEF)

The FGEF is a bilateral public fund created by the French government in 1994 following the Rio Summit. The FGEF's joint funding programmes are an instrument of the French cooperation and development policy. It is aimed at supporting multi-stakeholder partnerships and forms part of the strategic priorities of French aid. Its role is to associate global environmental protection with local development via sustainable development projects on the following topics: biodiversity, the fight against climate change, management of international waters, the fight against land degradation, handling of persistent organic pollutants, etc.

French export programme: expanding on export markets

With its partners in the French export team, UBIFRANCE uses its network of Energy-Environment experts deployed in 60 countries to offer French companies a programme of actions aimed at markets with high growth potential. In 2012, this programme is conducting around sixty actions, especially with regard to developing countries. These actions range from participation in a professional trade fair and the organisation of tailor-made "B-to-B" appointment programmes to promotional seminars on French expertise and the organisation of "Selling to..." events involving foreign ordering customers. Furthermore, UBIFRANCE offers a wide range of information and consultancy services, which also include arranging contacts with foreign decision-makers, in order to help French companies break into export markets.

Projects of the French Development Agency (Agence Française de Développement – AFD)

With an on-site presence in more than 50 countries, the AFD finances economic and social development projects in numerous countries as the pivotal operator in the French public development aid system. Through a wide range of financial instruments (loans, subsidies, guarantees, etc.), the AFD supports the public authorities, the private sector and local associative networks for the implementation of a wide variety of economic and social projects. The AFD is also involved in environmental protection and energy management topics. In 2010, the sums committed by the AFD in developing countries prevented the emission of 5 million tonnes of CO₂ (i.e. equal to the emissions produced by 1.8 million vehicles).

Steam turbine – Los Humeros power station (Mexico) – Alstom



Contacts

PUBLIC INSTITUTIONS

French Ministry of Ecology, Sustainable Development and Energy

This ministry prepares and implements the Government's policy in the sustainable development, environment, climate and energy fields. It is notably responsible for preparing and implementing the Government's policy on renewable energies and reducing energy consumption.

www.developpement-durable.gouv.fr

ADEME French Environment and Energy Management Agency

ADEME is France's main public institution for implementing public environment and energy management policies. The agency encourages, organises, coordinates, facilitates and carries out operations in the following fields: waste management, soil preservation, energy efficiency and renewable energies, air quality and noise prevention. The agency proposes its expertise and consultancy services to companies, local authorities, public authorities and the general public. In the geothermal energy field, ADEME plays an important role in bringing together all French stakeholders, defining and guiding support and innovation policies (Renewable Heat Fund, Geothermal Road Map, Geothermal Call for Expressions of Interest, R&D programmes, etc.).

www.ademe.fr

Club ADEME International

The Club ADEME International is a network of around one hundred innovative French eco-companies which are active on the global sustainable development market. The club supports its members in the development of innovative projects and international partnerships.

www.clubinternational.ademe.fr

"Géothermie perspectives" (Geothermal prospects) website

ADEME, in partnership with BRGM, has developed a website dedicated to geothermal energy:

www.geothermie-perspectives.fr

AFD - French Development Agency

A pivotal operator for public development aid, the AFD is a public institution responsible for financing economic and social development projects in numerous developing countries. The AFD is involved in the geothermal energy field in several countries (Kenya, Indonesia, Dominica, etc.).

www.afd.fr

BRGM

BRGM is the leading French public institution in the application of Earth sciences for managing the resources and risks relating to soils and subsurface levels. Its actions revolve around three missions: scientific research, support for public policies and international cooperation. The BRGM's Geothermal Energy division participates in the development and promotion of this energy source, in France and worldwide in partnership with ADEME. The BRGM's research in this field concerns all forms of geothermal energy and is divided into the following areas: increasing knowledge of shallow and deep geothermal resources, optimising its exploitation procedures and integrating geothermal energy into buildings (heat pumps and heating networks).

www.brgm.fr

Ubifrance and the French trade commissions

UBIFRANCE, the French agency for international business development, comes under the aegis of France's Ministry for Economy and Finance and of Ministry for Foreign Trade. UBIFRANCE lies at the heart of France's public-sector export-support framework. With 80 offices in 60 countries, UBIFRANCE offers a comprehensive range of products and services aimed at accompanying French-based companies in their development on export markets: knowledge-based products and services, from business information to consultancy and monitoring services, in order to help companies elaborate a strategy for international expansion; promotional operations in order to foster partnerships with companies outside France.

www.ubifrance.fr

PRIVATE INSTITUTIONS

AFPG - French Association of Geothermal Energy Professionals

The AFPG brings together around 85 members representing the different trades in the French geothermal energy industry: drillers, heat pump manufacturers and installers, turbine manufacturers, heating network managers, design offices, etc. It is organised into three main sectors: high energy, direct uses of heat and heat pump-assisted geothermal energy. Its missions concern three major areas:

- Representing and uniting professionals working in the industry in France.
- Informing local authorities, manufacturers and private citizens about the resources and the variety of geothermal solutions.
- Supporting the public authorities with regard to regulations, legislation and quality strategy.

www.afpg.asso.fr

SER – Syndicat des Énergies Renouvelables (French Renewable Energies Union)

Created in 1993, the SER is the French industrial organisation for renewable energies. Its action covers the different sectors of renewable energies: biomass (France Biomasse Énergie), wood energy, biofuels, marine energies, wind energy, geothermal energy, hydroelectricity, heat pumps, solar photovoltaic (SOLER), solar thermal and thermodynamic.

The SER's mission is to promote the interests of manufacturers and professionals in renewable energies to the public authorities, the French Parliament and any bodies responsible for energy, industry, employment and research.

www.enr.fr

PEXE

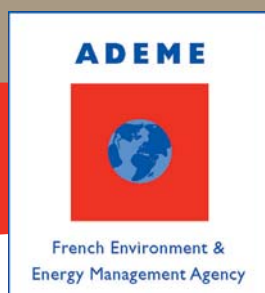
The Association for the promotion and international development of French eco-companies – aims to increase the individual and collective competitiveness of eco-companies and create a sector of excellence in the field of eco-activities. The association brings together 40 French eco-companies networks and represents over 5,000 eco-enterprises.

www.pexe.fr

ABOUT ADEME

The French Environment and Energy Management Agency (ADEME) is a public agency under the joint authority of the Ministry of Ecology, Sustainable Development and Energy, and the Ministry for Higher Education and Research. The agency is active in the implementation of public policy in the areas of the environment, energy and sustainable development.

ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large, to enable them to establish and consolidate their environmental action. As part of this work the agency helps finance projects, from research to implementation, in the areas of waste management, soil conservation, energy efficiency and renewable energy, air quality and noise abatement.



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