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The Evolution of Geothermal Energy in Spain - Country Update (2005-2009)

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ABSTRACT

There have been some significant changes in recent years in the status of the development of geothermal energy in Spain. In the field of high temperatures, research of potential was resumed in the Canary Islands and some interest was expressed in the possibility of the existence of EGS geothermal reservoir and/or medium temperature field (150-180ºC). In low temperatures (direct use of heat), there was renewed interest in some projects involving the geothermal area in Madrid that had been abandoned the decade before. High number of new projects were also initiated focusing on very low temperatures (geothermal heat pump – GHP). At this time, there are numerous facilities that have either been completed or are in the developmental stages. Many companies operating in the heat pump sector have entered the geothermal market.

There is also renewed institutional interest in geothermal development within the framework of renewable energies. Agencies of the central and regional governments are evaluating and distributing information on geothermal potential.

1. INTRODUCTION

From the seventies to the early nineties, intense investigative work was done into geothermal resources in Spain by the Geological Survey of Spain and major mining and power companies. For at least ten to twelve years after that, however, research slowed down significantly. Only four or five projects concerning geothermal resources remained active in Spain from 1994 to 2006, as opposed to the more-than-seventy projects run in the previous two decades.

This general panorama has changed drastically in recent years. Geothermal energy has become a new source of activity, although a hefty percentage of this new activity focuses on very low-temperature geothermal energy and the development of geothermal heat-pumping facilities.

But in the new, bracing environment, the conventional high-, medium- and low-temperature sectors too have evolved, and the amount of activity and the number of projects in the fields of exploration, evaluation and dissemination have increased significantly.

2. SUMMARY OF GEOTHERMAL ACTIVITY

The rise in geothermal activity in Spain in recent years has touched all sectors of geothermal resources. In the field of high-temperature geothermal resources, exploration activity has been resumed in the volcanic archipelago of the Canary Islands. In the field of medium-temperature geothermal resources, interest has focussed in recent years on areas of the Pyrenees (Jaca and Sabiñánigo) and the Madrid basin. The possibility of finding locations with favourable geological characteristics for the development of potential projects in enhanced geothermal systems (EGS) is being investigated in several areas of Spain, especially Cataluña and Galicia. Use of low-temperature geothermal resources for district heating and cooling is being studied for technical and economic feasibility in the northern area of the city of Madrid, in a set of public buildings including hospitals, schools and homes for the elderly.

Lastly, a large number of activities aimed at taking advantage of the heat existing in the more superficial areas of the Earth through use of geothermal heat pumps (GHPs) are being implemented all over Spanish territory.

3. ENHANCED GEOTHERMAL SYSTEMS (EGS)

3.1. Heat Flow in the Iberian Peninsula

Despite the fact that a multitude of Spanish subsoil temperature measurements had already been taken in different research projects, it was not until the mid-nineties when for the first time a project was conducted to evaluate the density of heat flow in the Iberian Peninsula.

Previously Spanish research teams had participated in the preparation of the Atlas of Geothermal Resources in Europe, as part of a European Union project in which quite reliable data were presented on the values of the geothermal gradient, temperatures at different depths, etc. The Atlas was quick to mark the areas of greater thermal anomaly and heat flow, including the Catalan Coastal system, the Baetic ranges, the Guadalquivir depression and Galicia.

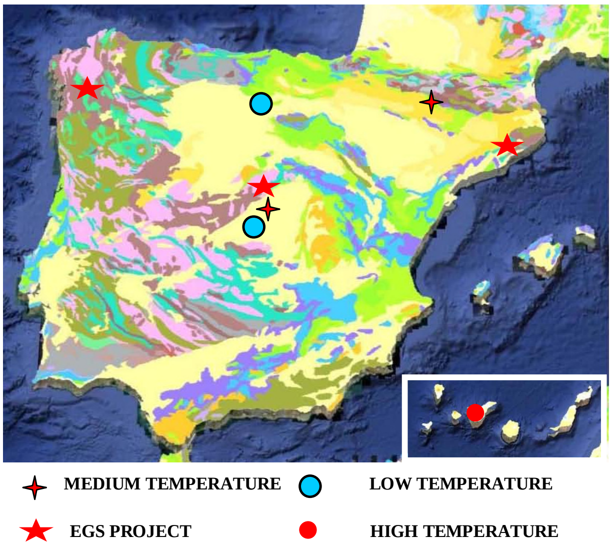

Figure 1: Location of the actually main geothermal project in Spain

However, in the nineties institutions in Spain and Portugal carried out campaigns to measure temperatures and gradients and to find the thermal conductivity of rocks, and with these data a flow map was drawn. The map had some limitations, because there were no bore holes with measurements for large swathes of peninsular territory. For mapping purposes, account was taken of two major sources of data: first, measurements taken in bore holes drilled for water, geothermal and mining purposes, and second, measurements taken in bore holes drilled for oil.

As the end result of this research, it was deduced that the average heat flow in the Iberian Peninsula could be estimated at 60 mW/m2, with the existence of anomalous areas of 90 to 150 mW/m2 in areas of Galicia, western Andalucía, Cataluña, the Baetic ranges and the Alborán area of the southern Mediterranean.

3.2 Enhanced Geothermal System (EGS) Technology. Area Screening. Progress in Research.

Action has been taken in recent decades in the field of hot dry rock, in research as well as in development and demonstration, in countries such as the USA, Great Britain, France and Germany in continental Europe, Japan and Australia. Thanks to this action, it has been possible to fine-tune technologies for the use of very deep geothermal resources, through deep fracture stimulation technology.

The sites where this work has been done are highly varied in terms of geology and structural conditions, from compact masses to masses of low-permeability fissured rock to areas of distension fractures.

Only two conditions are shared by all the geological situations involved: the hot rock reservoirs are made up of hard materials, of the crystalline or metamorphic basement type; and moreover there is always a thermal anomaly of greater or lesser size with respect to the average geothermal gradient of the Earth.

Based on this background, in 2005 to 2006 a power company, ENDESA, began work to explore areas with possibilities of deep geothermal resources in Spain, with a view to zone screening. The following screening criteria were set:

- Presence of masses of granitic or Precambrian rock, low matrix permeability.
- Existence of major fracturing, preferably distensive and affecting the deep rock mass.
- Existence, if possible, of a certain geothermal anomaly, such that temperatures on the order of 200 ºC are reached at depths no greater than six kilometres.

With these criteria, two of which are lithological/structural conditions (granitic masses and high-magnitude distension fractures) and the third of which is related with the internal structure of the Earth and heat flow, a rough selection of areas of interest was reached.

In this preliminary selection, the Iberian Hercynian massif was highly important, because it included the most favourable masses of rock (large pre-Hercynian, Hercynian and post-Hercynian granitic intrusions) and widespread distension fracturing, which took place during the Neogene period.

The most favourable areas were:

- Major north/south fractures in western Galicia.
- System of active fractures in southeastern and eastern Galicia: Ribadavia/Orense/Lugo.
- Borderline area between the Hercynian massif and the Guadalquivir basin, with major faults running west-northwest/east-southeast.
- System of rifts on the Mediterranean coast, especially in the northeast: Catalan Coastal ranges, whose basement is often granitic.
- Boundary faults in the Tagus graben.
- Rifts south of the Douro depression: Ciudad Rodrigo depression.

As a consequence of this screening, in later years (2007 to 2009) research has been done in two of the most promising areas, deep fracture zones in Galicia and rifts with a granitic basement in Cataluña.

In the first of these areas, in Galicia, explored by ENDESA, there is recent tectonic activity that gives rise to permeability due to fracturing in areas of major faults that affect granitic rocks with a high radiogenic capacity. This fracturing enables the deep circulation of water, which in turn causes a great abundance of hot springs. Associated with these major fractures there are also small Tertiary basins that reveal distensive Neogene activity overlying the Hercynian and Alpine fractures. This Neogene and current activity is especially reflected in eastern areas of Galicia and in the province of Orense, where there is a heavy concentration of seismic events and a great density of thermal water. Both geological phenomena are indicative of the great depth of the fracturing in that area.

The second area, made up of Catalunya's northeast/southwest system of basins, is being investigated by Petratherm España. There are several rifts in this geological area: Olot, Ampurdan, La Selva and El Vallés-Penedés. In all of them, post-Alpine distensive activity has created tectonic basins with a granitic Palaeozoic basement and fundamentally Neogene fill.

The entire area is the stage for intense seismic and neotectonic activity. In some cases (e.g., Olot), there is even heavy volcanic activity.

The most thoroughly studied of these rifts, and the location where research has reached its most advanced stage, is the El Vallés depression. This basin is bordered by two deep faults running northeast/southwest, whose vast depth reaches the zone's granitic basement. The deposits of Neogene materials that fill the rift lie as much as 3,000 metres thick. In the upper portion of these large faults, low-temperature (90-100 ºC) geothermal deposits have been located, with abundant surface manifestations of hot springs.

The El Vallés rift is one of the best-known geothermal areas of the Iberian Peninsula. It satisfies specific characteristics that make it very similar in all features to the area of Soultz-sous-Forêt, the location of the European hot rock project that has reached the most advanced stage and poses the best technical outlooks for obtaining a promising reservoir of geothermal energy from fractured, deep hot rock.

The verified data on El Vallés (90 ºC at a depth of 1,000 metres) resemble the data for the Soultz project. The geological structure is, as we have said, similar in both cases, since the rifts in the Catalan Coastal system are a southward prolongation of the Rhine/Rhone/Eastern Pyrenees rift system, all of which obey the same distensive mechanisms.

At this stage of understanding, Petratherm España, the Spanish subsidiary of the Australian company Petratherm, has begun research in the El Vallés area to locate an EGS reservoir. This same company is also engaged in studies investigating this same type of deposit on the southern edge of the Central System, where it borders with the Madrid Tertiary basin.

4. CONVENTIONAL HIGH-TEMPERATURE GEOTHERMAL RESERVOIRS

The Canary archipelago is the only area where high-temperature hydrothermal deposits might exist. The archipelago is a set of volcanic islands whose effusive activity has persisted throughout history from the Eocene to recent centuries.

Tenerife, because of its singular geological characteristics, can be selected as the island where high-temperature deposits are most likely to exist. The presence of a great volcanic edifice with a huge quantity of both basic and acidic lava output is consistent with the prediction that there is deep steam to be found. The geochemical study of the existing gaseous emissions in the centre of the island and in areas outside the central edifice confirm this prediction.

From the seventies to the nineties the IGME (Geological Survey of Spain) investigated the entire island by means of geological prospecting, volcanological prospecting, geochemical prospecting, geophysical prospecting, etc. Subsequent investigations sponsored by the European Union, under its R&D programmes, uncovered the existence of favourable areas in the eastern zone as well as the northwestern zone of the island. In the east, northeast/southwest fractures are allowing gases and volatile fluids from possible high-temperature deep reservoirs to escape. Isotopic geothermometers give estimates of deep temperatures on the order of 200 ºC. In the northwestern zone, the fractures run northwest/southeast, and isotopic geothermometers give estimates of deep temperatures on the order of 180 to 190 ºC. The geophysical (magnetotelluric and electromagnetic) prospecting that has been done reveals the northwestern area as the more favourable geological context, due to the possible presence of shallower magmatic bodies than in the eastern zone. Thermal gradient studies in exploratory boring give estimates of the depth of the possible high-temperature reservoir in the northwestern zone as approximately 2,500 to 3,000 metres, that is, 1,000 to 1,300 metres below sea level, in fractured basaltic materials of what is termed the “Old Basaltic Series”.

Since 2007/2008 Petratherm España, S.L., has been running a new research programme. The latest data (on isotopic gas and water composition) seem to confirm the existence of deep reservoirs. An extensive, heavy flow of endogenous CO2 supports this theory. The volatile leakage from these possible deep reservoirs is partially masked by the heavy, shallow circulation of cold meteoric water.

5. MEDIUM-TEMPERATURE (150-180 ºC) GEOTHERMAL DEPOSITS

The existence of deep carbonate geological layers in areas of the Pyrenean and Baetic mountain ranges allows medium-temperature geothermal reservoirs to form. Drilling for hydrocarbon research purposes has detected this type of store in the following areas:

Pyrenees. Jaca/Sabiñánigo area. Geothermal flows at a temperature of 150 to 170 ºC in Eocene and Palaeocene carbonate reservoirs at a depth of 2,800 to 3,500 metres.

Baetic ranges. Borderline area between Sevilla and Cádiz. Geothermal flows at 150 to 160 ºC in Jurassic carbonate reservoirs at a depth of 3,200 to 3,500 metres.

Baetic ranges. Area in southern Almería province. Geothermal flows at 170 to 180 ºC in Triassic carbonate reservoirs at depths of 2,500 to 2,700 metres.

Tertiary Madrid basin. Area north of the city of Madrid. Geothermal flows at 140 to 160 ºC in Cretaceous carbonate reservoirs at a depth of 3,400 metres.

The Pyrenean and Madrid areas are currently being investigated by different firms that have geothermal interests.

6. LOW-TEMPERATURE (60-90 ºC) GEOTHERMAL DEPOSITS

A large number of low-temperature geothermal deposits were discovered by drilling in the eighties. These deposits were mainly in areas of the southeast (Granada, Almería and Murcia), northeast (Barcelona, Gerona and Tarragona), northwest (Orense) and central peninsula (Madrid). Other isolated locations were found in Albacete, Burgos, Mallorca, etc. Some of these areas were then tapped at a very small scale for heating use in residential areas, hotels, schools and fundamentally agricultural facilities, the latter especially in areas of heavy protected-crop activity (greenhouses) in the southeastern Iberian Peninsula.

However, the rekindling of interest has reached this type of geothermal use as well. At present economic feasibility studies are being conducted for two large-scale, low-temperature (70-80 ºC) geothermal operations in Madrid and Burgos.

In Madrid, the firm we mentioned before, Petratherm España, is engaged in a study on tapping the geothermal resources of the Tertiary basin. Boring has proved there is a 75- to 80-ºC geothermal resource beneath the city of Madrid at a depth of 1,500 to 2,100 metres. An old geothermal operation undertaken in the late eighties by the Regional Government of Madrid and called to a halt for financial reasons in the early nineties has been restarted by Petratherm España, which is currently looking into the economic feasibility of the project. Hospital buildings, schools and universities, homes for the elderly and technological research centres will be the future consumers of the energy. With an estimated thermal output of 10 to 12 MW(th) and a final power supply on the order of 40,000 to 50,000 MW.h (th) per year, this project will be a good demonstration of how to put a geothermal resource to tertiary-sector district-heating uses. The project calls for the joint use of heating in winter and cooling/air conditioning in summer. Diverse institutions are interested in participating in the project, including the Regional Government of Madrid and the Institute for the Diversification and Energy Savings (IDAE).

The second project currently under study for economic feasibility is in the city of Burgos. In 1980/1981 a 2,500 metre deep borehole was drilled in the vicinity of Burgos, locating low-temperature, 80 to 82 ºC resources in a Cretaceous sandy reservoir. The project came to a halt after its early feasibility studies due to a lack of likely consumers in the industrial park where the deposit lies.

After 25 years of evolution, the zone's industrial development has increased and there is a larger consumer population. An important cosmetics company, L'Oreal, which consumes a great deal of power (hot water for industrial processes and facility heating) decided in 2008 to undertake a new feasibility study, which is currently under way. With a thermal output of 9.3 MW(th) and a power supply potential on the order of 35,000 to 40,000 MW.h (th) per year, this project will be a fine demonstration of low-temperature geothermal use in industrial district heating. This project is supported by diverse institutions as well, such as the Regional Government of Castilla y León, the Burgos City Council and the Chamber of Commerce and Industry.

7. VERY LOW TEMPERATURE (15-25 ºC) GEOTHERMAL HEAT-PUMP

During the past few years an important economic sector related to very low temperature, shallow geothermal, requiring the use of heat pumps has been developed. The work scenarios are diverse and, depending on the geographic zone, it has been implemented on different systems of use. There has been implemented with closed systems -vertical or horizontals- as well as open systems using with ground water.

The resources are being used not only for heating and sanitary hot water but also for air conditioning, being this one a very important factor of the development of this kind of systems. From year 2007 the workshops, courses and sessions have been numerous dedicated to geothermal and fundamentally to shallow geothermal with a very numerous presence of interested people that demonstrate the increasing inte in this technology. The enterprise sector is very diverse and accuses the logical problems of a very premature development.

On the one hand it is appraised the existence of numerous companies of the sector of heating facilities and air conditioning with very little knowledge of the subsoil.

On the other hand, the subsoil tasks are entrusted to companies of perforation that come from the sector of geotechnical and ground waters, with no formation in geothermal resources and without having specialists of the subsoil working together with them. Finally the nonexistence of a suitable regulatory frame for this type of resources makes very difficult the management of the projects.

Although previously some projects using this kind of resources were developed, is at the beginning of XXI century when appear the first projects of certain sight. Cataluña is one of the first areas in which this kind of resource was used, as well as Valencia. A very significant case is the one that is developed in the urban surroundings of Zaragoza where the ground water of the alluvial of Ebro River is pumped for a lot of geothermal open circuits, basically for air conditioning; the origin of these projects is due to a bud of legionella in an important hospital.

Although the data of use are very poor and not specific and still they offer many doubts on their precision, can be estimated in about 120Mwt in different zones; projects on Murcia, Castilla-LaMancha , Cataluña, Andalucía and Madrid are the most relevant.

8. INSTITUTIONAL ACTIVITIES

In the South of Spain the Andalusian Energy Agency has started in 2009 with a study for the evaluation of the geothermal resources and reserves in the territory of the Autonomous Community of Andalucia. This study includes all the types of resources: EGS, medium temperature, low temperature and very low temperature (geothermal heat pump).

On the other hand, through an institutional collaboration of several public organizations as Institute for the Diversification and Saving of the Energy (IDAE), Geological and Mining Institute of Spain (IGME), Energy Institute of Catalunya (ICAEN), Geological Institute of Catalunyia (IGC) and the Earth's Sciences Institute of Jaume Almera (ICTJA), in which is important the participation of the different administrations -state and autonomic-, is carrying out a wide task of summary, adjustment of ancient cartographies to digital support and valuation of the geothermal potential of orientated Catalonia not only to the geothermal conventional resources but fundamentally to the possible deep reservois (EGS).

The transformation of former cartographies in format paper with different information to digital systems has supposed a great of integrating effort, but it allows to verify the overlapping and agreement of information of different origin in a unique format and to corroborate the raised hypotheses of work.

The work of summary is already carried out by the IGC and as short-term task there appears the publication of an Atlas of geothermal resources of Catalunya in the year 2010.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009	-	-	41895	155937	17034	21428	7728	58975	28105 Wind, Byomass, wastes and solar	85107	94762	321447
Under construction in December 2009												
Funds committed, but not yet under construction in December 2009												
Total projected use by 2015												

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

[1)] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

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

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

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

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

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate (kg/s)	Temperature (^oC) Inlet	Temperature (^oC) Outlet	Enthalpy[2)] (kJ/kg) Inlet	Enthalpy[2)] (kJ/kg) Outlet	(MWt)	Ave. Flow (kg/s)	Energy[4)] (TJ/yr)	Capacity Factor[5)]
Arnedillo	H+B	11	50	30			0,92	8	21,10	0,73
Fitero	H+B	8	52	30			0,73	5	14,50	0,63
Lugo	H+B	4	44	25			0,32	2	5,01	0,50
Orense	H	5	75	30			0,94	4	23,74	0,80
Archena	H+B	10	48	25			0,96	6	18,20	0,60
Sierra Alamilla	H+B	8	52	30			0,74	5	14,51	0,62
Montbrió	H+B	15	42	18			1,50	10	31,65	0,67
Montbrió	G	6	78	25			1,33	3	20,97	0,50
Cartagena	G	150	38	18			12,55	60	58,26	0,15
Zújar	G	10	45	20			1,05	4	13,19	0,40
TOTAL							21,04		221,13	0,33

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

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

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

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

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	6,11	128,71	0,67
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating	14,93	92,42	0,20
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]			
Other Uses (specify)			
Subtotal	21,04	221,13	0,33
Geothermal Heat Pumps			
TOTAL			

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

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

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	1		1			3
2006	1		1			4
2007	1		1			7
2008	1		1			10-12
2009	1		1			12-15
Total	5		5			36-41

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0,15	0,1	0,05		70	30
2000-2004	0,4	--	--		--	100
2005-2009	1,5	--	--		95	5