

Technical and Economic Appraisal of Geothermal District Heating Projects in North Madrid (Spain)

Raul Hidalgo¹, Carlo Piemonte² and Pierre Ungemach³

¹ PETRATHERM ESPAÑA, Avenida Doctor Arce n°14, 28002 MADRID ESPAÑA.

² STUDIO ASSOCIATO DE INGEGNERIA (SAI) - Via Juvara 9, I - 20129, MILANO ITALY.

³ GPC INSTRUMENTATION & PROCESS (GPC IP) - Paris-Nord 2 - Immeuble Business Park - Bât. 4A - 165, rue de la Belle Etoile - BP 55030 - 95946 ROISSY CDG CEDEX - FRANCE;

¹ r_hidalgo@petratherm.es, ² carlo.piemonte@studio.ai.191.it, ³ pierre.ungemach@geoproduction.fr

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ABSTRACT

The Madrid area, located at the Northern part of the Tajo sedimentary basin, benefits from a dependable geothermal resource, evidenced thanks to previous hydrocarbon and geothermal exploration. Four (one hydrocarbon, three geothermal) deep exploratory wells enabled to assess the geothermal potential of the area. It may be summarized in terms of well deliverabilities and wellhead temperatures standing within the 200-250 m³/h; 75-90°C ranges respectively i.e. installed capacities of heat from 7 to 12 MWt depending on rejection temperatures.

Two development targets have been selected for geothermal district heating purposes which display contrasted utilization trends, wholly public (a total of twelve - educational: school, university and medical: hospital, nursing homes - buildings) and private (shopping malls, warehouses, office buildings and hotels) users respectively, which require specific technological designs and grid operating procedures, bearing in mind that retrofitting is the rule. Due to the existence of a nearby well (Geomadrid 1) whose integrity could be checked by logging, a feasibility survey concentrated on the first mentioned Cantoblanco/Valdelatas district. Its outcome proved rewarding from both technical design and economic viability stand points. As a result, the advent of the first geothermal district heating grid ever achieved in Spain could soon become a reality.

1. INTRODUCTION

The Madrid northern suburban areas enjoy one of the most favourable geothermal environments identified to date in Metropolitan Spain. This statement is supported by the four exploratory wells drilled in the area (see locations in Figure 1 map) namely:

- El Pradillo 1 (Shell, 1980) 3400 m
- Tres Cantos (IGME, 1981) 2400 m
- San Sebastian de los Reyes (ENADIMSA, 1982) 2100 m
- Geomadrid 1 (ENADIMSA, 1990) 2000 m

The information provided by well logs and flow tests together with previous geophysical investigations (mainly seismic lines), enabled to assess the local geothermal potential, portrayed in Figure 1 and 2, the latter mapping the features of the tertiary clastic deposits set as a priority development target, given (i) its higher than normal subsurface temperatures (75 – 90°C at ca 1800 to 2400 m depths), and (ii) its dependable reservoir properties (more than 100 m net thickness, 20 to 45 dm transmissivities) (see

Figure 3) eligible to 200 – 250 m³/h well productive capacities.

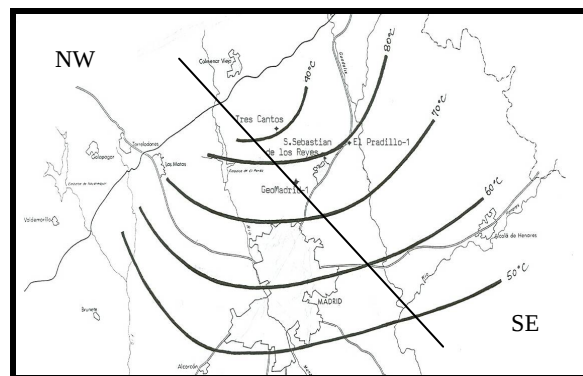


Figure 1: Geothermal well locations. North Madrid area.

2. GEOLOGY

Geologically, the Tertiary sandstone reservoir belongs to the Tajo sedimentary basin, of which it occupies its uppermost northern part. The main hot aquifer unit consists of a thick multilayered sequence of tertiary detritic, consolidated, sandstones overlying a Mesozoic basement hosting radiogenic granitic rocks. The area is bound to the North by crystalline rocks delineating the North Madrid Sierras, marked by deep parallel faults trending SSW-NNE. Elsewhere its limits correspond to the thinning of the sandstone aquifer (see Figure 2 and 3).

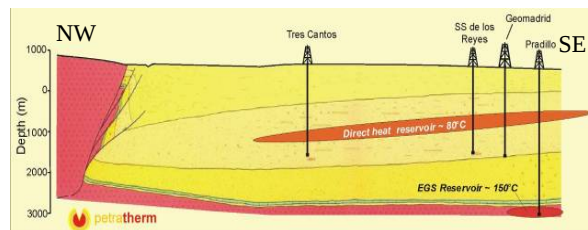


Figure 2: NW-SE cross section showing the position of the wells and vertical extent of the geothermal reservoir in the Madrid Basin.

As a result of these promising resource premises, matching a significant energy demand in such densely populated areas, Petratherm applied for geothermal mining rights over the most promising development area. Those were awarded, in year 2007, under the form of an exploration lease, the so-called Cayena tenement, 300 km² in area, over the perimeter mapped in Figure 3.

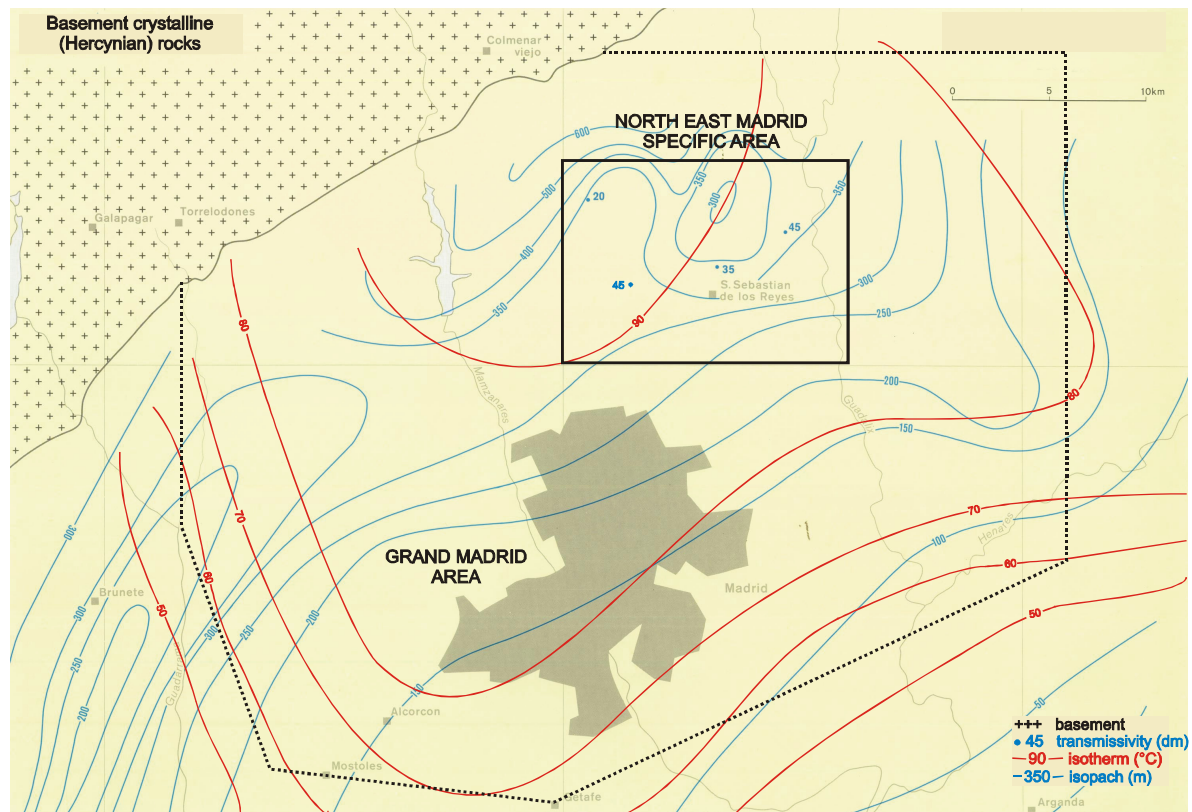


Figure 3: Geothermal resource base map Madrid area (adapted from European Geothermal Atlas 2002).

3. PREFEASIBILITY STUDY

A thorough prefeasibility study was further undertaken, in early 2008, in order to evaluate the geothermal resource, existing well deliverabilities and the heat demand structure within the vicinities of the existing wells. Detailed evaluations focused on the San Sebastian de los Reyes and Geomadrid areas due to the compatibility between a proven dependable, resource (see table 1) combined with the preliminary heat and cold load estimates (see table 2).

Table 1: Madrid geothermal well salient features

Well	Tested interval (mbgl)	Transmissivity (dm)	Bottomhole temperature (°C)	Well deliverability (m ³ /h)
Pradillo	At 1600 - 1800 m	46.6	70°-80°	150
Tres Cantos	1600 - 2400 m	20.3	70°-90°	150
San Sebastian de los Reyes	1600 - 2100 m	35.3	75°-90°	250
Geomadrid 1	1550 - 2000 m	44.4	70°-78°	200

Table 2: Early estimates of heat & cold loads. Cantoblanco and San Sebastian de los Reyes areas.

Project	Heat load (MWht/yr)	Cold load (MWht/yr)	SHW supply (MWht/yr)	Total load (MWht/yr)
Cantoblanco (Geomadrid)	38400,00	5050,00	13430,00	56880,00
San Sebastian de los Reyes	44785,00		7353,20	52138,20

Finally, the prefeasibility analysis led to select the Cantoblanco/Valdelatas district nearby the Geomadrid1 well which exhibits a 8 to 10 MWt installed capacity, as the best candidate. A detailed feasibility survey was further commissioned in order to assess whether the local resource to heat & cold (H&C)/sanitary hot water (SHW) demand adequacy would be met at technically feasible, economically viable and environmentally safe conditions, given the important H&C/SHW load (institutional, educational, medical and old people residence buildings) existing nearby the Geomadrid 1 well.

Simultaneously to the foregoing, inspection logging of well Geomadrid1 was carried out, via CIC (casing inspection caliper), CBL/VDL (cement bond/variable density log) and CCL (casing collar locator) tools, in late July 2008. It confirmed the pressure and temperature pattern measured in 1990. It elsewhere showed a good casing status, liner and cementing status, suggesting Geomadrid 1 well could be reliably recovered as an injector well serving the needs of a future geothermal district heating and cooling (GDHC) doublet scheme.

4. FEASIBILITY STUDY

It was commissioned with a view to assess precisely the amount of geothermal heat marketable to local end users and to design accordingly a relevant distribution grid and surface heat exchange/production facilities.

It should be stressed here that local heating systems fuels and practice may differ drastically from one user (and within one user entity) to another.

4.1 Geothermal Resource Features

According to the conclusions of the well data compilation exercise, two geothermal production scenarios were retained respective to flowrate and heat exchanger outlet temperatures 200/250 m³/h and 73°C respectively.

4.2 Heat Demand Appraisal

It was undertaken to confirm in detail the possibility of exploiting Geomadrid geothermal reservoir for direct uses in order to feed a district heating system for some important users located in the vicinity of the geothermal source.

Users demand and heating/SHW characteristics have been thoroughly investigated by Energesis Ingeniera S.L. (University of Valencia) within the framework of the connecting grid/users location display mapped in Figure 4 (SAI 2009).

As a result the following eligible loads were identified:

Total installed thermal power 36.209 kW

Net thermal power demand (90%) 32.588 kW

Yearly energy consumption

- space heating 35.600 MWh/year

- SHW production 2.394 MWh/year

Total 37.994 MWh/year

and their seasonal distribution illustrated in Figure 5 load duration curve. The latter reflects the heterogeneity in local heating practices, with heating periods varying yearly from 2200 (educational) to 4500 h (medical), and daily from 12 to 24 hours.

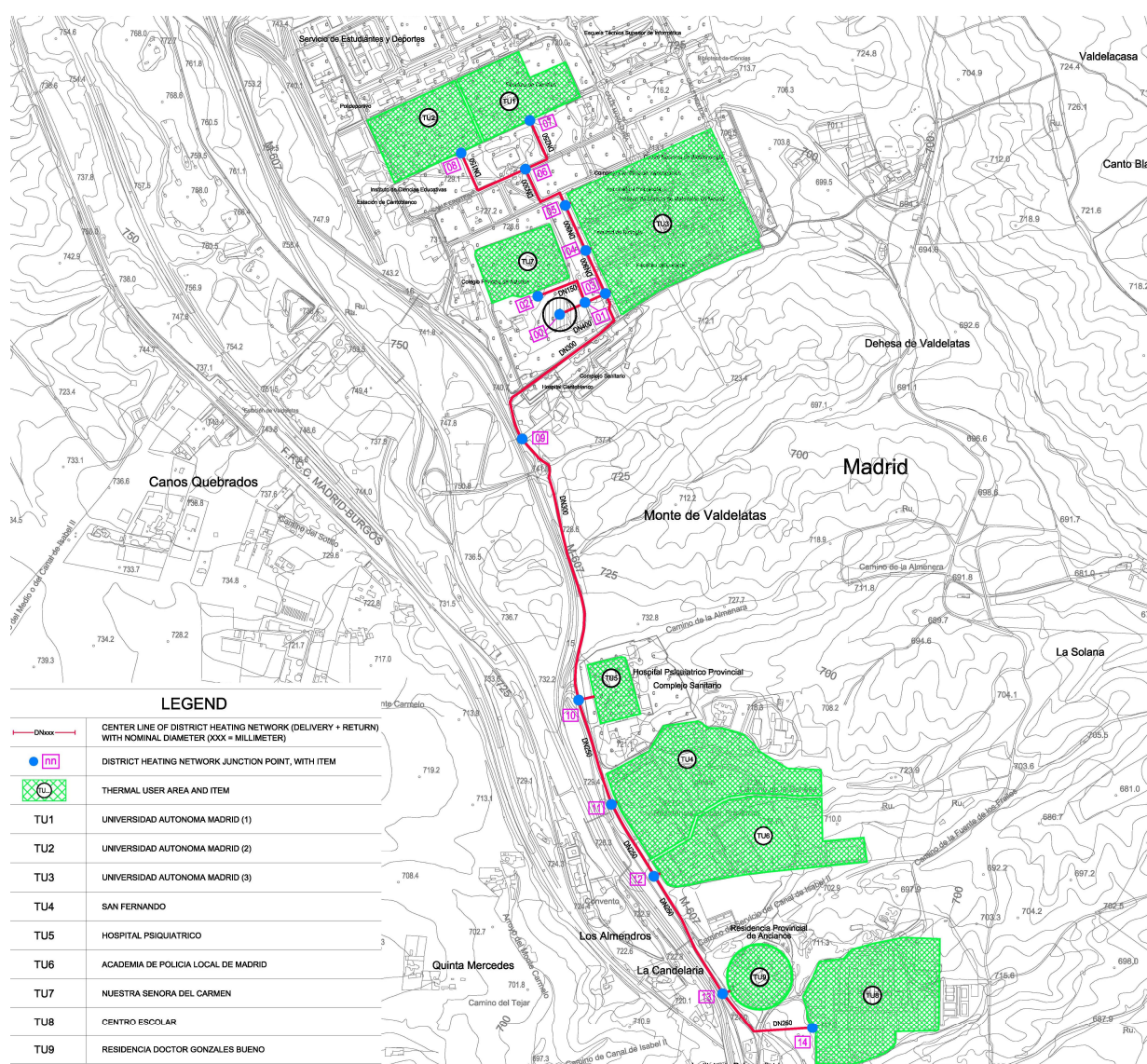


Figure 4: Grid location map (source:SAI).

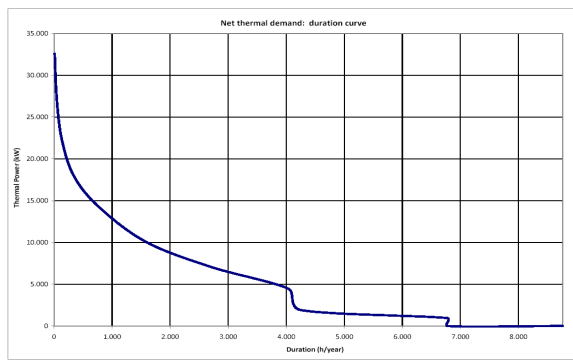


Figure 5: Heat load duration curve.

4.3 Operating Temperatures

All systems are based on fossil fuel (either domestic fuel oil or natural gas) fired boilers and cast iron (90/70°C

inlet/outlet temperatures) radiators and medium temperature convectors (80/60, 70/50°C). Reference outdoor and non heating temperatures are set at -5°C and 23°C respectively.

Clearly, meeting the needs of such diversified users, from a 73°C, 200/250 m³/h geothermal source and a single plant/distribution grid design, was a true retrofitting challenge.

Initially, the inlet peak demand temperature was set at 90°C, thus requiring turbocompressor driven heat pumps to boost the geothermal well head temperature. In order to deplete users rejection temperatures and increase accordingly the geothermal coverage ratio, cascading schemes were contemplated whenever possible, particularly in the southern fraction of the grid. Ultimately, an option limiting to 80°C the, heat pump boosted, geothermal inlet temperature, was considered bearing in mind that the 90°C design temperature would be required less than 150 hrs/yr.

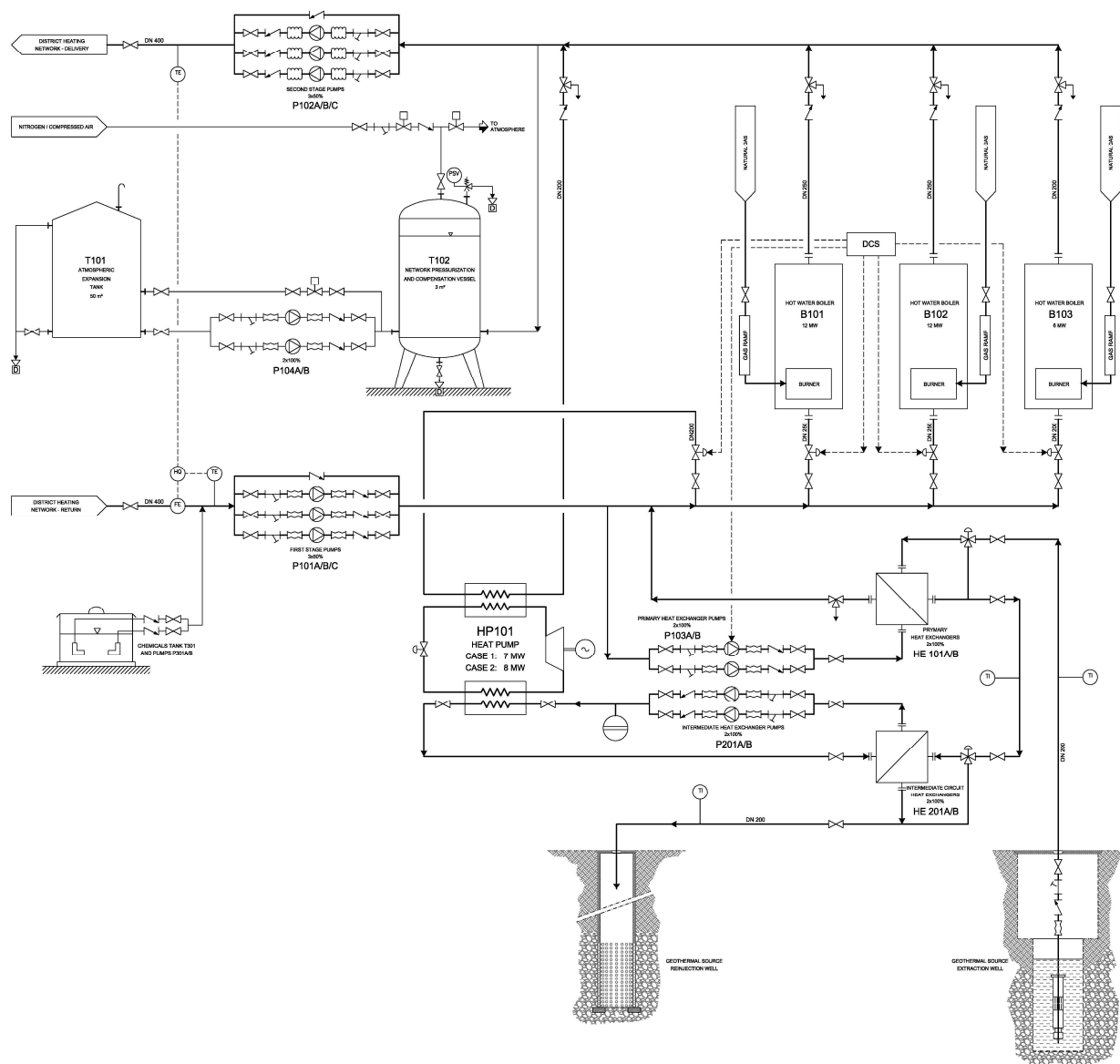


Figure 6: Geothermal loop and heat plant lay out (source: SAI).

4.4 System Design

The rationale behind the district heating concept aimed at:

- Achieving centralised production from a single heat plant hosting (i) the geothermal heat exchanger(s), (ii) a large capacity heat pump designed to boost the sole heat exchange contribution to the heat demand, and (iii) peak-back up-relief, natural gas fired, boilers, a design summarised in Figure 6 layout.
- Piping the heat to end users via an appropriate distribution grid (Figure 5).

Initially designed features stand as follows:

4.4.1 Geothermal Source

- Maximum production/injection flow rate(s): 200; 250 m³/h
- Production temperature: 73 °C
- Minimum rejection (injection) temperature: 40°C
- Nominal installed geothermal power: 7.7 (200 m³/h) MWt / 9.6 (250 m³/h) MWt

4.4.2 District Heating

- Installed capacity : 33 MWt
- Grid inlet (delivery) temperature(s): 90/80°C
- Grid outlet (rejection) temperature(s): 65/55°C
- Grid demand
 - Heating: 35600 MWht/yr
 - SHW: 2400 MWht/yr
 - Total: 38000 MWht/yr
- Maximum hot water circulation rate: # 1150 m³/h

4.4.3 Distribution Grid

- Twin, polyurethane foam, preinsulated pipe
- Minimum jacket/pipe diameters (mm): 250/150
- Maximum jacket/pipe diameters (mm): 560/400
- Total pipe length: 3600 m
- Maximum velocity: 2.5 m/s
- Maximum head loss: 10⁻³ m/m
- Heat losses: # 3000 MWt/yr

4.4.4 Heat plant (see layout in Figure 6, and table 3 below)

Table 3: Production units ratings

Geothermal flow rate (m ³ /h)	200		250	
Temperature range (°C)	90-65	80-55	90-65	80-55
Heat exchanger	1.4	3.7	1.75	4.6
Heat pump condenser	6.8	4.2	7.7	5.3
NG Boiler 1	12	12	12	12
NG Boiler 2	12	12	12	12
NG Boiler 3	6	6	6	6

The layout sketched in Figure 6 addresses a three staged geothermal preheating/heat pump boosting/boiler peak load design, for the 90-65°C temperature depletion case. Three operating regimes are considered, (i) winter (all three stages operate simultaneously), (ii) interseason (geothermal heat exchange and heat pump operate simultaneously, boilers switched off) and (iii) summer (geothermal heat exchange alone, heat pump and boilers disconnected). According to this set up, two heat exchangers, one primary (geothermal

interfacing) and one intermediate (heat pump interfacing), are assembled in parallel mode and controlled by three-way valves. Note (i) that the heat pump may be switched off from the heating grid via a three-way valve, (ii) that, owing to similar outlet temperatures (90°C) the heat pump and three peak – back up – relief boilers are mounted in parallel, and (iii) that whatever the temperature depletion (90/65°C vs 80/55°C) and flow rate (200 vs 250 m³/h) contrasts heat pump coefficients of performance (COPs) do not vary significantly, nearing 4.5 as COP yearly average.

4.4.5 Energy Balance

Summing up, the overall energy budget shapes as displayed in table 4 balance sheet.

Table 4: Energy balance sheet

Geothermal flow rate (m ³ /h)	200		250	
Temperature depletion (°C)	90-65	80-55	90-65	80-55
A. GRID DEMAND (MWht/yr)				
Net users' consumption	38000			
Grid losses	3100			
Total	41100			
B. GRID SUPPLY (MWht/yr - %)				
Geothermal heat exchangers	13900/34	17200/42	15900/38	19600/48
Heat pump condenser	13650/33	13800/33	13800/34	12200/30
Peak load – back up – relief boilers	13550/33	10100/25	11400/28	9300/22

4.5 Economic Feasibility

It is assumed that heat production, distribution and sales are managed by a private operator, subject to taxation, in the form of a joint venture associating a miner (the geothermal concession holder) and a heating service company (the exploitation licensee).

The economic feasibility of the project may be assessed from the figures and ratios listed in table 5 summary sheet.

Table 5: Project economic feasibility highlights

Project life (yrs)	25
CAPEX (10 ³ €)	11750 – 12250
OPEX (10 ³ €/yr)	1250 – 1450
SUBSIDIES (% CAPEX)	10 – 30
DEBT/EQUITY	1
REVENUES (10 ³ €)	2100 – 2500
NPV (10 ³ €)	2500 – 5200
ROR (%)	9 – 15
DPBT (yrs)	12 – 8

5. CONCLUSIONS

The Geomadrid GDH feasibility appraisal carried out North of Madrid in the Cantoblanco/Valdelatas district leads to the following conclusions.

5.1 The Resource

The area benefits from a dependable geothermal resource, hosted at ca 1500-2000 m depths in a sandstone reservoir, exhibiting bottomhole temperatures and well deliverabilities standing within the 75-77°C and 200-250 m³/h ranges respectively and subsequent 8 to 10 MWt heat installed capacities. It could be exploited at attractive production costs by drilling a new production well in deviation from the existing drilling pad, the well Geomadrid 1, drilled in 1990, being converted into an injector.

5.2 The Market

All users identified nearby belong to public, either educational, medical, administrative or old people residential, entities totalizing a net heat demand load of ca 38000 MWt/yr, supplied by fossil fuel fired boilers and conventional, high temperature, heaters.

5.3 GDH Design

Adjusting the geothermal resource to the eligible heat load represented a true retrofitting challenge. The selected scheme consists of accessing end users' demand from a central heat plant via a ca 3.6 km distribution grid. Given a 33 MWt peak power and 90°C inlet temperature requirements, the new plant design combines, natural gas fired, peak load/back up/relief boilers, a primary geothermal heat exchanger and a thermocentrifugal heat pump. An optimum design would enable geothermal, heat pump sustained, heat to supply ultimately ca 75% of the total grid demand.

5.4 Economic Viability

Provided a 50/50 debt/equity and substantial, up to 25-30%, grants and incentives a less than ten year return on

investment (CAPEX estimated at # 12 mio €) and 12% rate of return could be realistically attained.

Summing up there is a good chance for the Geomadrid project to complete the first GDH grid ever achieved in Spain.

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