Research Activities of Enel Green Power in Geothermal

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October 2014

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Geothermal technologies

Past, present and future

Past 5-10 years	Medium term outlook 5-10 years	Long-term outlook 10+ years

Today

Conventional

- **Dry steam** (~3 GW of capacity today)
- **Flash steam** (~8,4 GW of capacity today)

Binary cycle (~1,7 GW of capacity today)

Binary cycle

- **Mostly proven** and cost-effective technologies
- **Incremental plant technological advances** going forward
- **Binary only** as an **ancillary** application due to infancy stage of technological development (i.e., higher costs)

- **Binary** proven to be a **self-standing technology**, increasing overall installable potential
- **Economics** not yet in line with steam technologies (dry and flash), **expected to improve in the long term**

Breakthrough

EGS (Pilot project in France)

Supercritical Fluid (Pilot project I n Iceland, Italy, Japan)

Hybridization; Cascade utilization

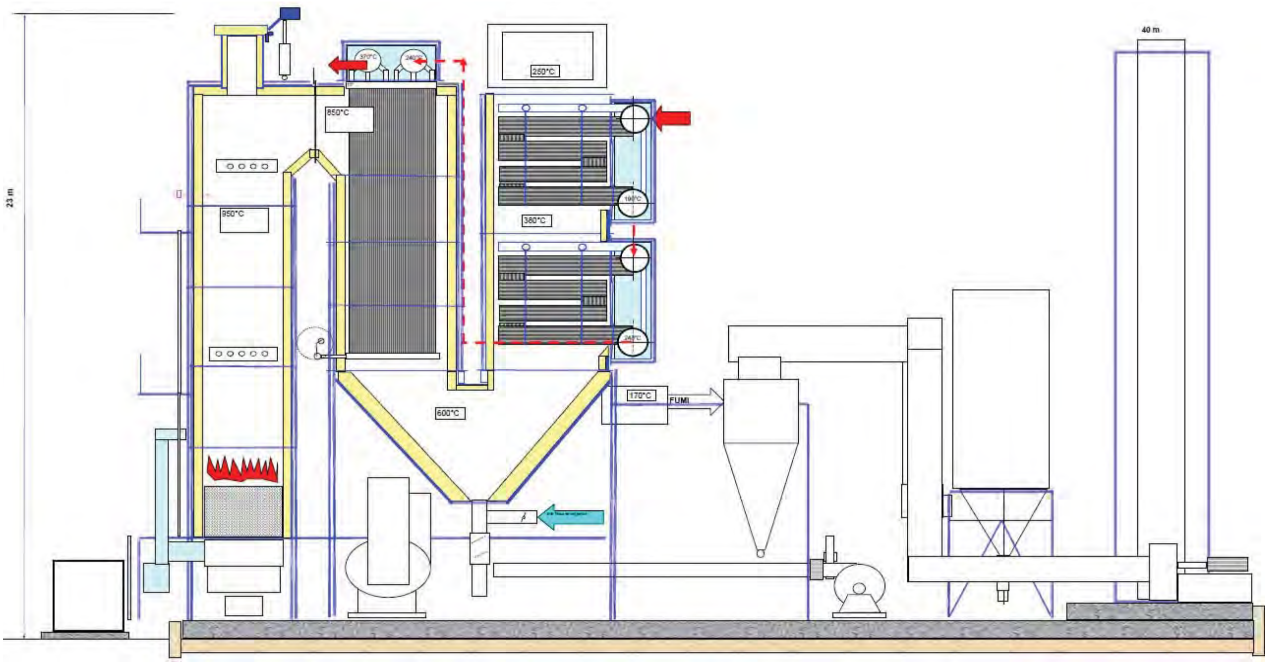
Cascade utilization

- **Technology still in "development"** phase
- **Under certain technological development outlook** (i.e., fast decrease in technology costs), expected to **increase installable potential**
- **Cascade utilization are already present in the market**

Background & description

- Previous studies showed the benefits of steam superheating
- Coupling of biomass and geothermal generation is unique
- Cornia 2 is a 20 MW nameplate “standardized” geothermal power plant, currently operating at around 14 MW_e of gross output, due to the poor characteristics of the steam feed: 110 t/h saturated @ 5.2 bar and 153°C (steam saturation is due to chloride scrubbing)
- The project consists in repowering by means of steam superheating from 153°C to 370°C, with heat supplied by solid biomass combustion. Expected power increase: around 5 MW_e, with optimum utilization of existing installation and grid connection
- Favorable site characteristics (flat nearby terrain, availability of an industrial site for biomass storage and “boiler” installation, plenty of woods and agricultural lands around)
- Entirely renewable power generation, with lower unit CapEx and higher biomass utilization efficiency (around 35% vs. 20-25%) than a stand-alone biomass power plant (biomass-geo synergy)
- Authorization was obtained in Sept. 2011

Hybrid Plants: Biomass



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Hybrid Plants: Biomass

Site	Technology	Biomass type	Biomass need [kt/y]	Capacity [MWe]
Cornia 2	Geothermal steam superheater with biomass firing by combustion grate	Forest & agricultural residues, power crops	43	4.8

Cornia 2 biomass repowering

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Hybrid Plants: Biomass

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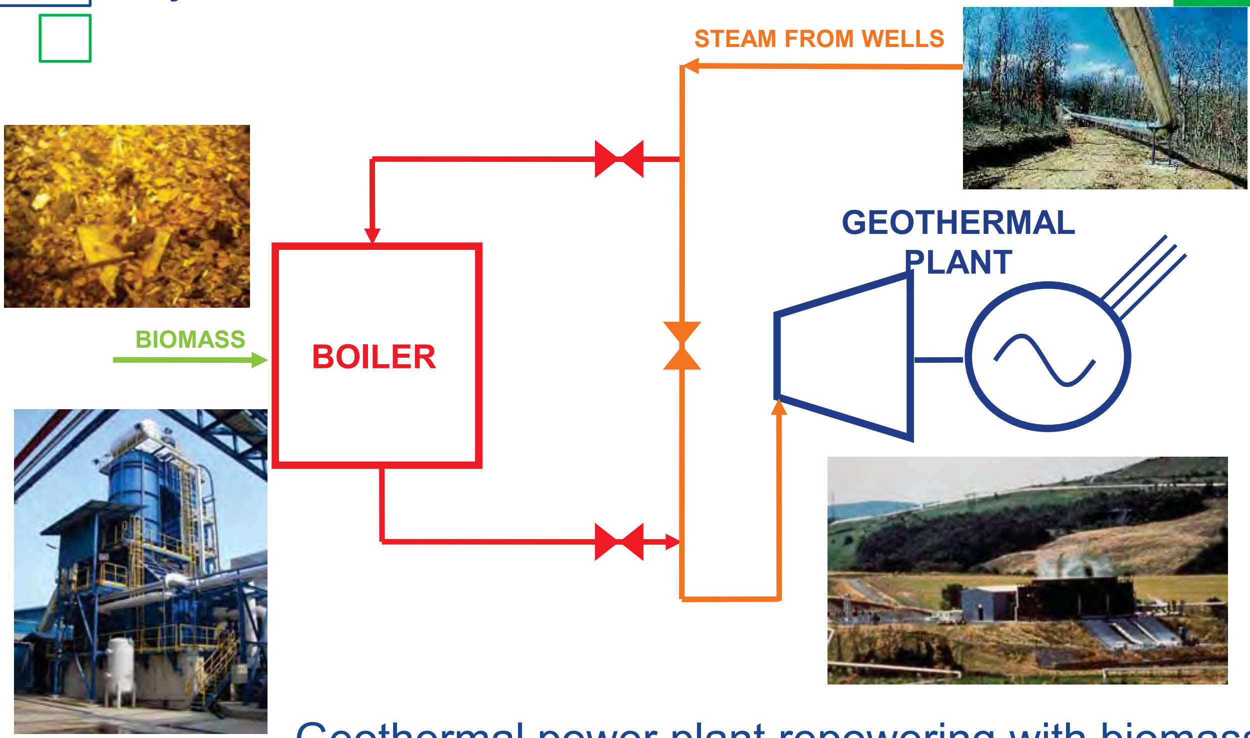
Hybrid Plants: Biomass



Geothermal power plant repowering with biomass

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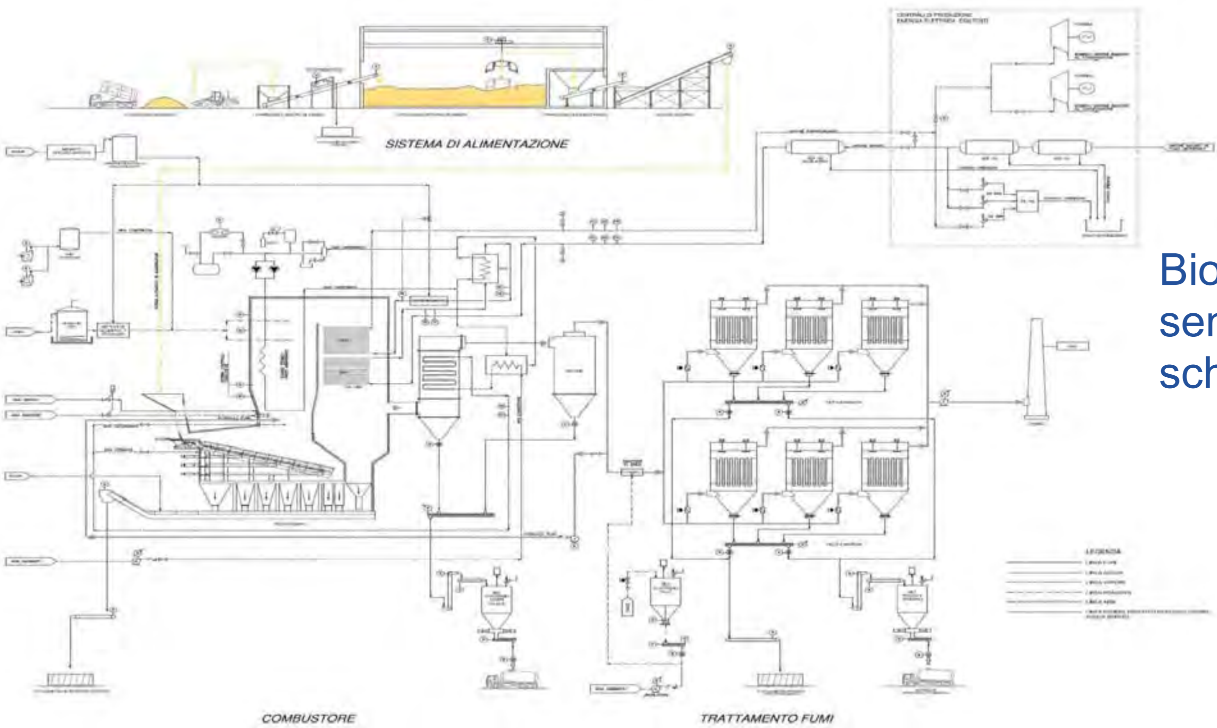
Hybrid Plants: Biomass



Biomass semplified scheme

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Hybrid Plants: Biomass

Project description and main data

Location	Cornia 2 geothermal power plant – Castelnuovo Val di Cecina (PI)
Plant data	Thermal capacity: 16 MWt Increased net electric capacity: 4.8 MWe
Plant description	Biomass storage and handling system Combustion grate for biomass Superheater boiler for geothermal steam Flue gas treatment (including bag filters) Existing steam turbine (to be refurbished) and generator Existing cooling towers Geothermal superheated steam – 110 t/h @ 4.7 bar, 370°C
Biomass	43 kt/yr at 10.5 MJ/kg 100% short range forest and agricultural residues as well as powercrops
Equivalent operating hours at full load	7,800 hr/y
Total Net Energy production	37,440 GWh/yr
Grid connection & Area	Currently operating geothermal power plant Cornia 2

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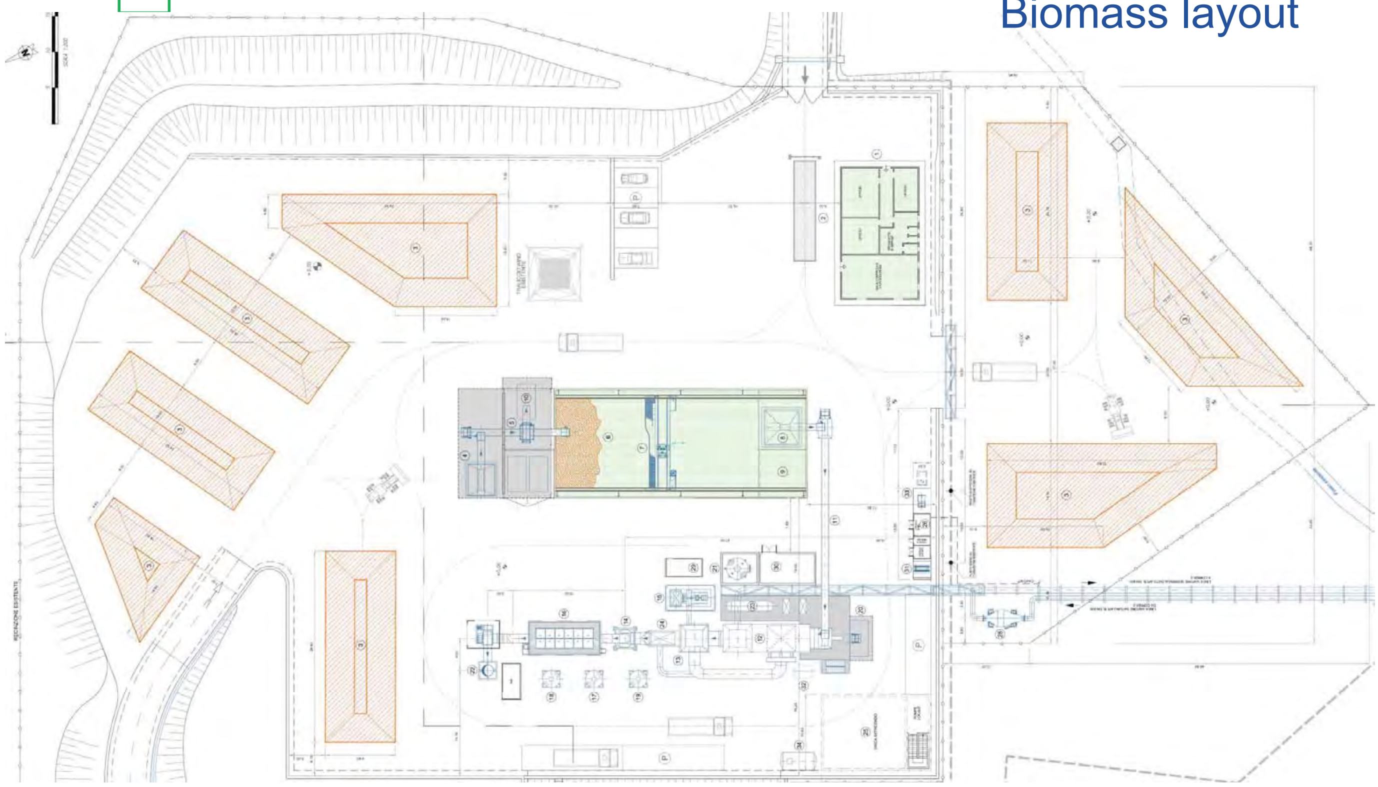
Hybrid Plants: Biomass

Biomass layout



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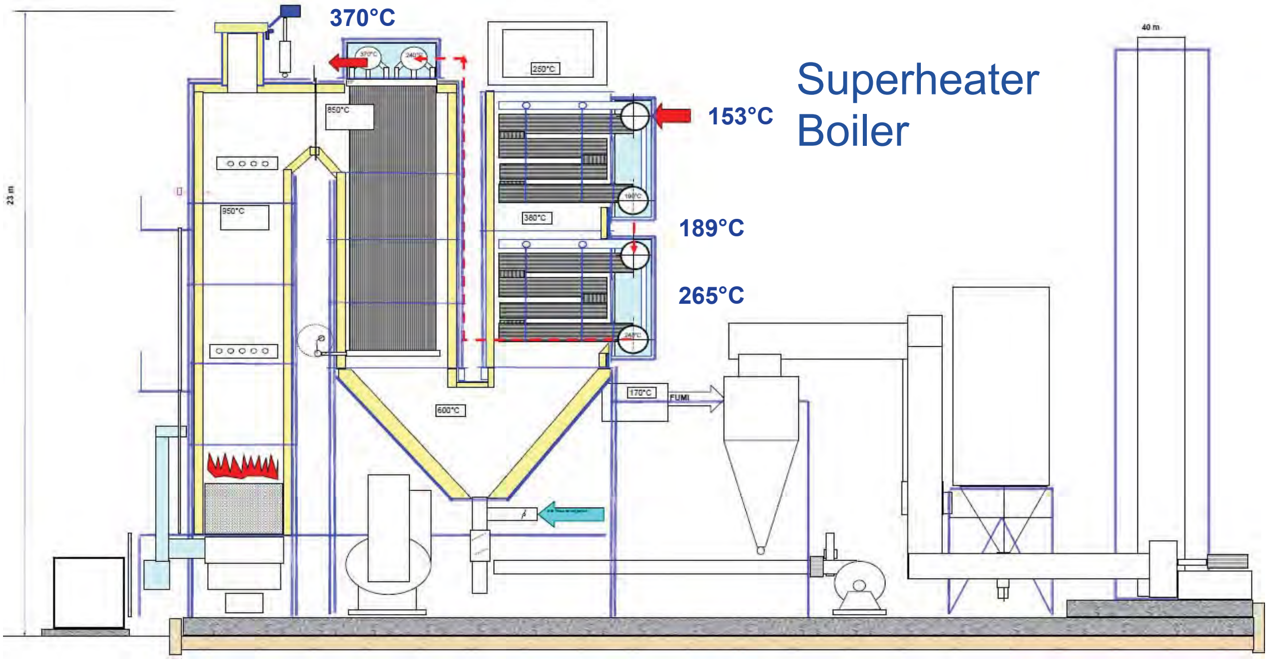
Hybrid Plants: Biomass



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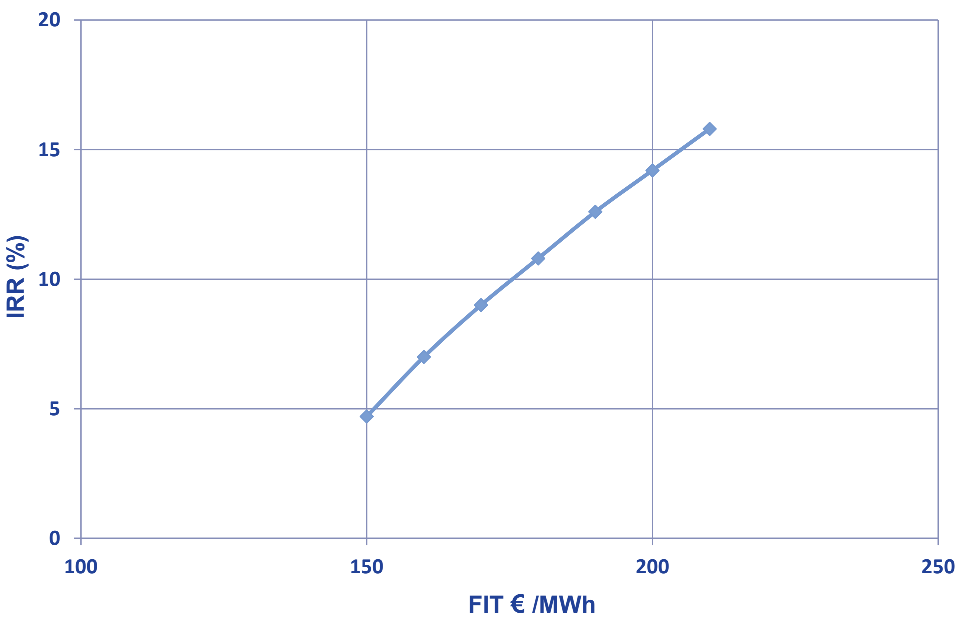
Hybrid Plants: Biomass



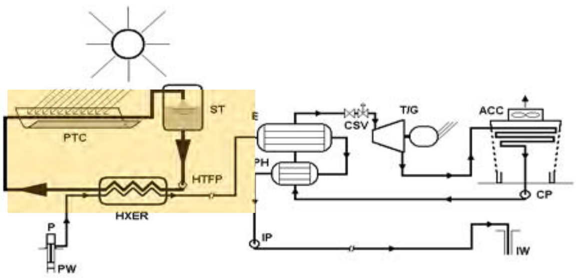
Investment profitability

Biomass repowering

- The boiler – superheater is a non-standard equipment (low pressure steam requires large tube area to minimize steam pressure drop; high metal surface temperatures must be avoided using low flue gas velocities, notwithstanding the low heat exchange rate of the steam)
- Possible schemes with diathermal oil heat exchange and final superheating in the boiler or with total heat exchange in the boiler; the latter was chosen on the basis of CapEx and O&M considerations
- Turbine maximum rated temperature was 280°C; however, the manufacturer stated that operating temperatures up to 380°C can be reached with minor modifications (including removal of the first reaction stage and substitution of the impulse control stage)
- Optimization of the existing assets entailed the transformation of the existing powerhouse of the dismissed Cornia 1 plant in a short term biomass storage facility (with a high speed bridge crane for loading and unloading)
- The Italian RES incentive scheme was changed in July 2012, reducing the FIT from the range 190÷280 €/MWh to 125 €/MWh, thus making the investment less profitable

Hybrid Plants: Solar

Stillwater Geothermal Binary cycle plant (33MW)



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Hybrid Plants: Solar

Hybrid Geothermal – PV

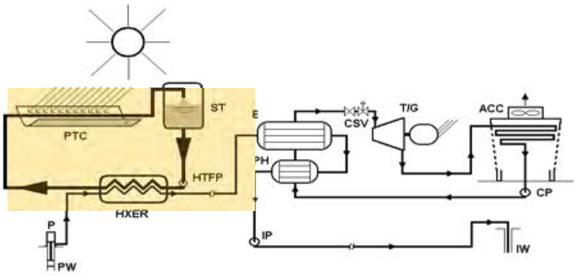
Stillwater Geothermal Binary cycle plant (33MW)

Stillwater Solar PV plant (26MW)

✓It is the first hybrid PV solar - geothermal application in the world combining the continuous generation capacity of binary-cycle, medium-enthalpy geo power, with the peak capacity of solar power;

✓Still Water (33 MW) geo plant is one of the world largest binary cycle plants with "Closed-loop" system;

Hybrid Geothermal – CSP



✓World's first plant integrating CSP with a Geo binary plant will be developed in Nevada;

✓CSP will integrate Geothermal gross capacity in order to maintain appropriate thermodynamic range of operation of isobutane;

✓Hybrid Geo-CSP plant aimed to flatten hourly variations and increase production;

PV hybridization project already operational in the US

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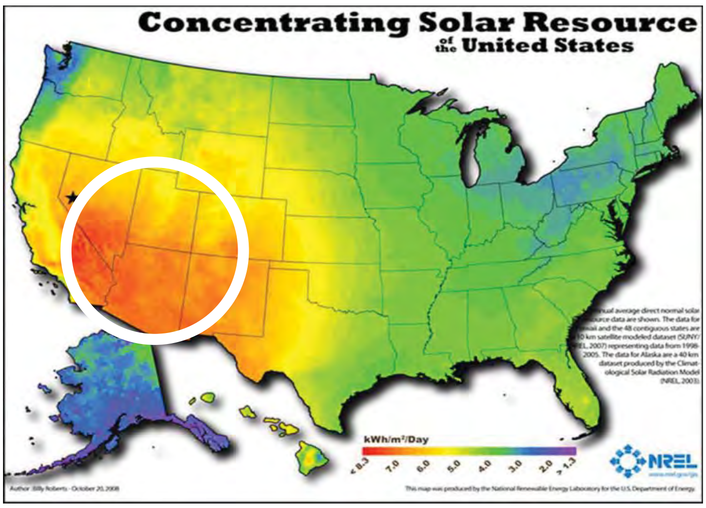
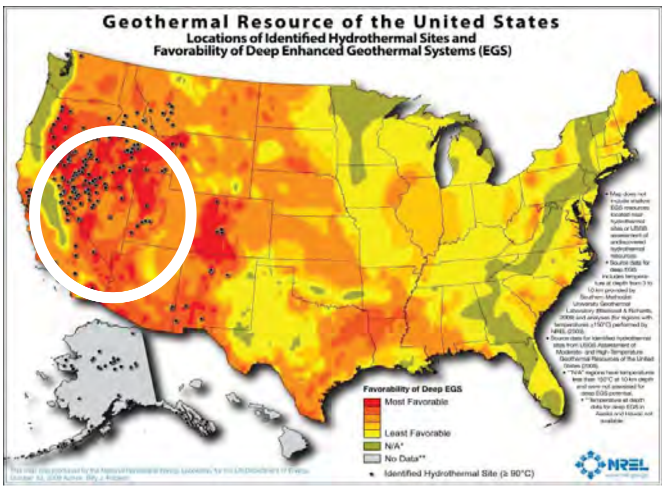
Hybrid Plants: Solar

In western USA, plentiful solar radiation & geothermal





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Hybrid Plants: Solar

Salt Wells and Still Water are the world largest binary cycle plants
They are the benchmark in binary geothermal energy generation

- A binary system with two fluids, **hot water from underground** wells heats **an organic fluid** and turns it into a vapor that makes the turbine generate power.
- **They are "Closed-loop" systems** that continually replenishe the geothermal resource used in the power generation process, without use of other Natural Resources (water)
- They will also be **the first hybrid solar-geothermal applications** in the world.

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Hybrid Plants: Solar

STILLWATER PLANT

EGP Innovation
Hybrid Plants: Solar

STILLWATER PLANT

Working fluid = isobutane
Active production wells = 7
Units = 2, each with 2 turbo-generators
Cooling = air cooled condenser

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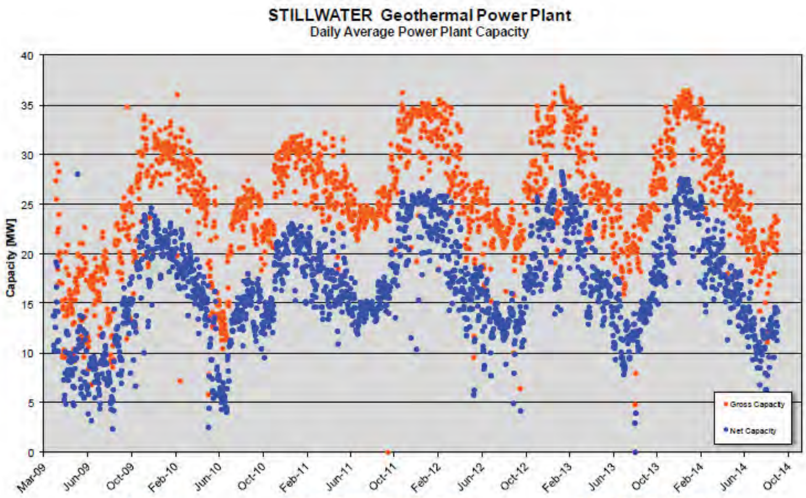
Hybrid Plants: Solar



Years	Total Gross Generation [GWh]	Total Net Generation [GWh]
2009	124.323	71.815
2010	217.458	130.461
2011	242.086	159.271
2012	235.711	155.553
2013	236.881	157.975
2014 (Jan – Aug)	149.164	95.343

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Hybrid Plants: Solar

STILLWATER PLANT

- 2009 – began w/ nominal capacity 33.1 MW.
- 2012 – 26 MW of photovoltaic capacity added.
- Production impaired during warm weather, because of dry cooling.
- Geothermal brine temperature lower than design, so power island underutilized.
- Integration with Solar designed to increase the power output.

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Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project PV

- World's first solar/geothermal hybrid project combines the continuous generation capacity of the medium enthalpy geothermal binary cycle with the peak capacity of solar power thus allowing for synergies to be explored.
- Integrates 26 MW of solar photovoltaic capacity to EGPNA's operating 33 MW Stillwater Geothermal Project
- Consists of over 89,000 polycrystalline silicon PV panels built on 240 acres. It will generate enough energy to meet the needs of 16,000 American households.
- In 2012, this state-of-the art plant won EGPNA the Geothermal Energy Association Honor Award for Technology Advancement which recognizes companies that develop innovative or pioneering technology to further geothermal development.

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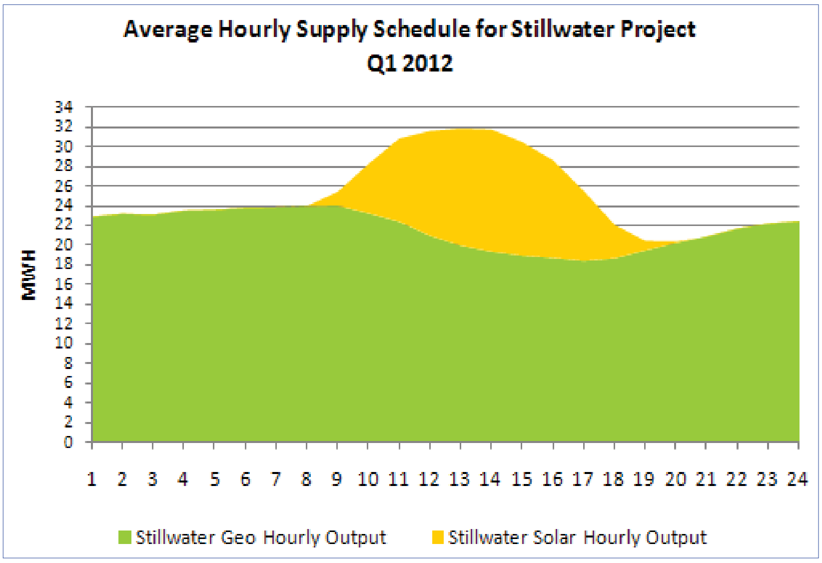
Hybrid Plants: Solar
Stillwater Solar Geothermal Hybrid Project PV

Addressing key risks

- Thermal efficiency in a geothermal unit lowest during the hottest & sunniest times of the day - when solar PV is most productive
- The result, stabilized production
- Successful application of this concept paves way to address key risks including resource risk and generation intermittency



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Hybrid Plants: Solar

Development

Stillwater Solar Geothermal Hybrid Project PV

- July 2011: Construction begins
- December 2011: Construction completed on 24 MW
- March 2012: 26 MW fully commissioned
- More than 150 construction workers employed onsite
- Created new opportunities for suppliers

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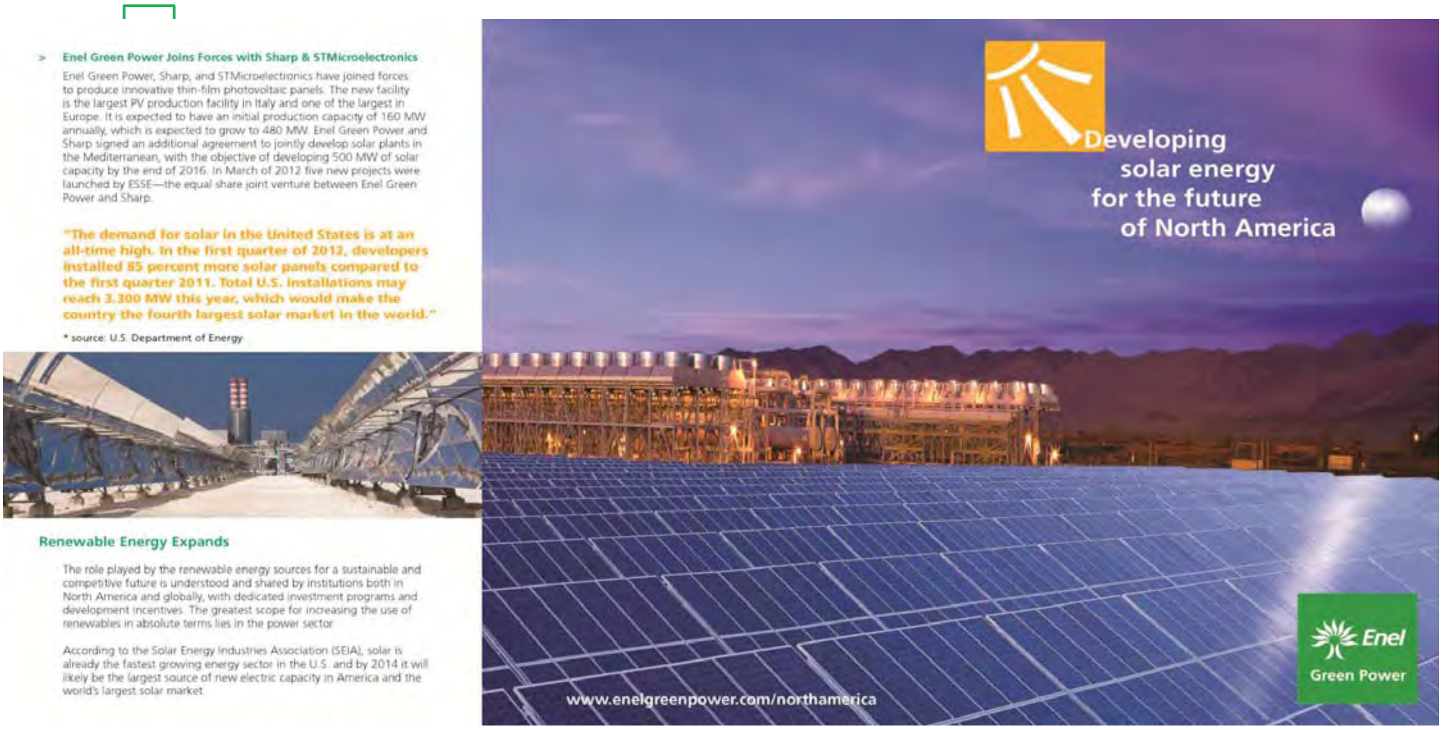
Hybrid Plants: Solar



> Enel Green Power Joins Forces with Sharp & STMicroelectronics

Enel Green Power, Sharp, and STMicroelectronics have joined forces to produce innovative thin-film photovoltaic panels. The new facility is the largest PV production facility in Italy and one of the largest in Europe. It is expected to have an initial production capacity of 160 MW annually, which is expected to grow to 480 MW. Enel Green Power and Sharp signed an additional agreement to jointly develop solar plants in the Mediterranean, with the objective of developing 500 MW of solar capacity by the end of 2016. In March of 2012 five new projects were launched by ESSE—the equal share joint venture between Enel Green Power and Sharp.

"The demand for solar in the United States is at an all-time high. In the first quarter of 2012, developers installed 85 percent more solar panels compared to the first quarter 2011. Total U.S. installations may reach 3,300 MW this year, which would make the country the fourth largest solar market in the world."

* source: U.S. Department of Energy

Renewable Energy Expands

The role played by the renewable energy sources for a sustainable and competitive future is understood and shared by institutions both in North America and globally, with dedicated investment programs and development incentives. The greatest scope for increasing the use of renewables in absolute terms lies in the power sector.

According to the Solar Energy Industries Association (SEIA), solar is already the fastest growing energy sector in the U.S. and by 2014 it will likely be the largest source of new electric capacity in America and the world's largest solar market.

Stillwater Solar Geothermal Hybrid Project PV

EGP Innovation
Hybrid Plants: Solar

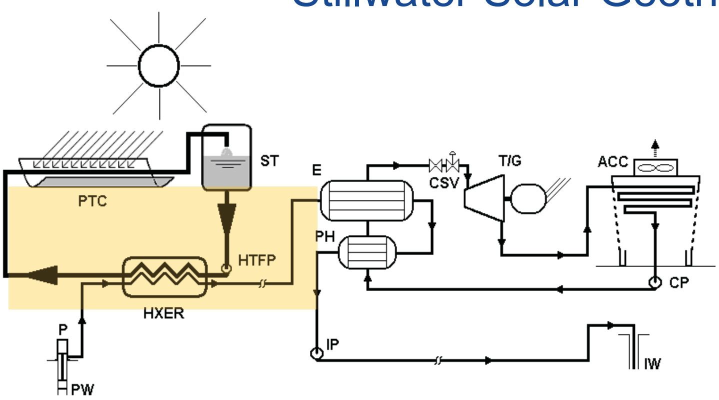
Stillwater Solar Geothermal Hybrid Project PV

- The solar plant not only sits next to the geothermal plant, it is integrated with the geothermal plant and provides the energy to run the geothermal plants auxiliary loads.
- The integration also includes the Control System, Electrical Protection and Island Mode capability, Fire Detection/Protection Schemes, Electrical Interconnection, and the use of a common Operations and Maintenance staff.
- Alternatively, the geothermal plant provides auxiliary power to the solar plant when there is no sunlight thus eliminating the need for back feeding power from the utility.
- The implications for the renewable industry are major. This first-ever geothermal-solar hybrid power plant demonstrated that the concept works to combine the strengths of different renewable technologies and create a better whole.

Stillwater Solar Geothermal Hybrid Project PV

- Minimize geothermal technology problems and produce more electricity without expanding the use of the geo-resource
- Improve performance over a pure geothermal system
- More cost-effective than standalone solar facilities, also thanks to medium temperature and low-cost solar collectors
- Enhancing the thermal efficiency in the geothermal unit during the hottest and sunniest times of the day or year, through the solar plant
- Stabilizing production during the day, enabling a more load-following production profile, thanks to geothermal

Stillwater Solar Geothermal Hybrid Project CSP



	Condizioni nominali di funzionamento	Prestazioni annuali
DNI	900 W/m2	2460 kWh/m2/yr
Input Solare	28.8 MW	78,930 MWh
Input termico addizionale al ciclo	17 MW	32,250 MWh
Output elettrico incrementale[4]	2 MW	3960 MWh
Efficienza campo solare	59 %	41 %
Efficienza incrementale ORC	12 %	12 %
Efficienza incrementale globale[Errore. Il segnalibro non è definito.]	7 %	5 %

Tabella 2 – Prestazioni incrementali della configurazione ibrida geo-solare.

- Solar Field Area: 20 acres
- Collectors' Area: 32,000 sqm
- HTF temp at heat exchanger inlet: 400°F (205°C)

5-10% of Geothermal project gross capacity in order to maintain appropriate thermodynanmic range of operation of isobutane

Hybridization CSP + Geothermal

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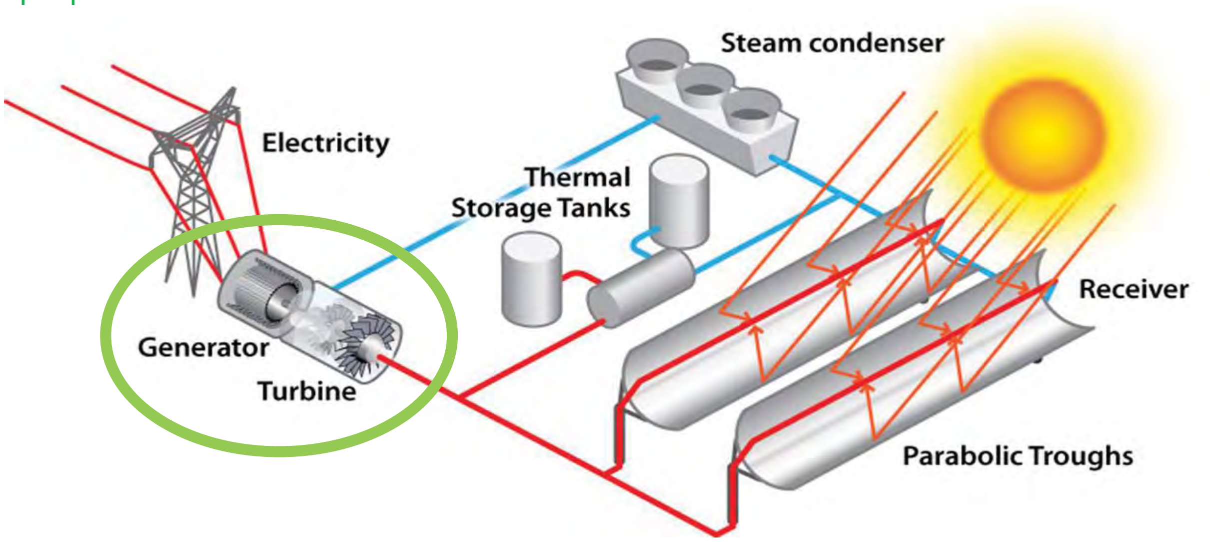
Hybrid Plants: Solar



Two Issues:

1. Intermittent (no power at night or on cloudy days)
2. Requires power block which is expensive

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Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP

Advantages of Integration

Relative to Geothermal ORC:

- Increase the maximum temperature of the working fluid, resulting in a higher efficiency of the ORC;
- Stabilize production during the day, when the air cooled ORC suffers from a higher ambient temperature, by increasing thermal input;
- Compensate reservoir temperature depletion during the years (adding solar collectors) without reducing power production;
- Reduce investment risk from uncertainty of the geothermal resource.

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Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP

Advantages of Integration

Relative to Concentrating Solar Power (CSP):

- Stabilize power generation without using thermal storage or a back-up fuel source;
- Reduce capital costs because the power island is shared, thermal storage is not strictly required, the low ORC operating temperature allows use of less expensive lower temperature (400°F/ 204°C rather than the typical 750°F/ 400°C) solar collectors;
- Reduce thermal losses (increase efficiency) of the solar collectors due to the low working temperature.

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Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP

Under Construction

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Hybrid Plants: Solar

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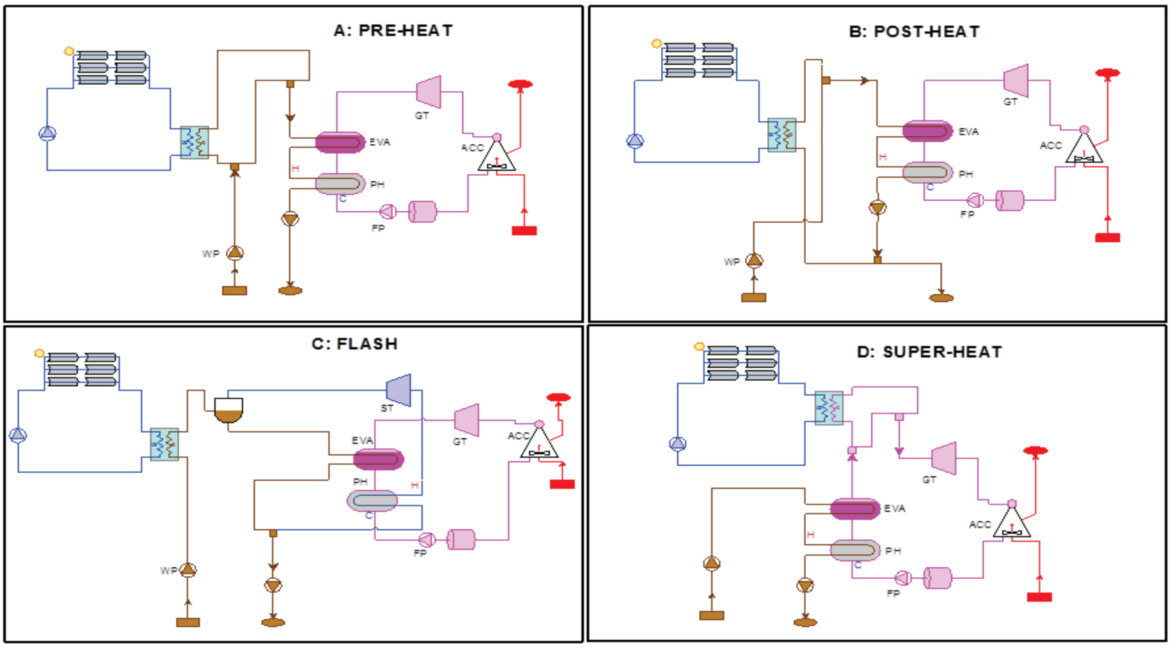
Stillwater Solar Geothermal Hybrid Project CSP



Integration 4 Ways

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Hybrid Plants: Solar

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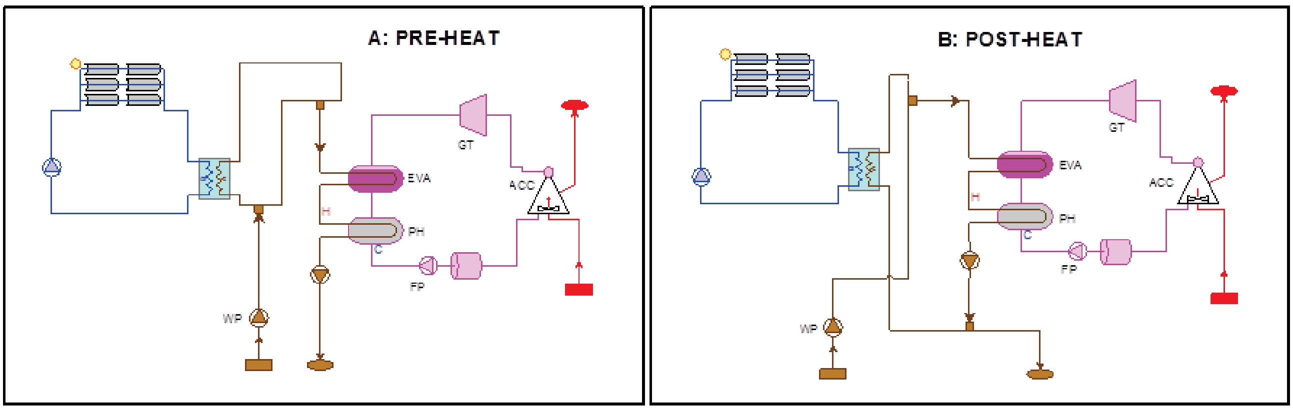
Stillwater Solar Geothermal Hybrid Project CSP



Options A and B do not interfere with the existing power block.

Stillwater Solar Geothermal Hybrid Project CSP

Comparison Assumptions

Design Conditions:

- Aperture Direct Normal Irradiance = 900 W/m^2;
- Ambient temperature = 21°C;
- Useful heat from solar source at design conditions = 17 MW-th.

Annual Conditions:

- Average daily Direct Normal Irradiance (DNI) = 5.92 kWh/m2-d;
- Average Ambient Temperature = 10.7°C.

Hybrid operating strategies - how many turbines are in operation at a given ambient temperature.

Stillwater Solar Geothermal Hybrid Project CSP

Parameters of Comparison

Case	Ambient Temp	Net Thermal Input (% of 17 MW-th)	Turbine Expanders in Service
1	40°F (4.4°C)	25	4
2	53°F (11.7°C)	50	3
3	63°F (17.2°C)	75	3
4	70°F (21.1°C)	100	2

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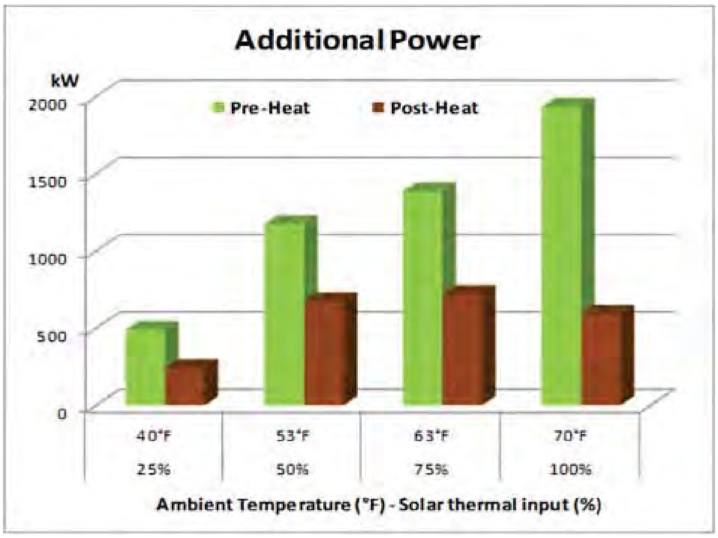
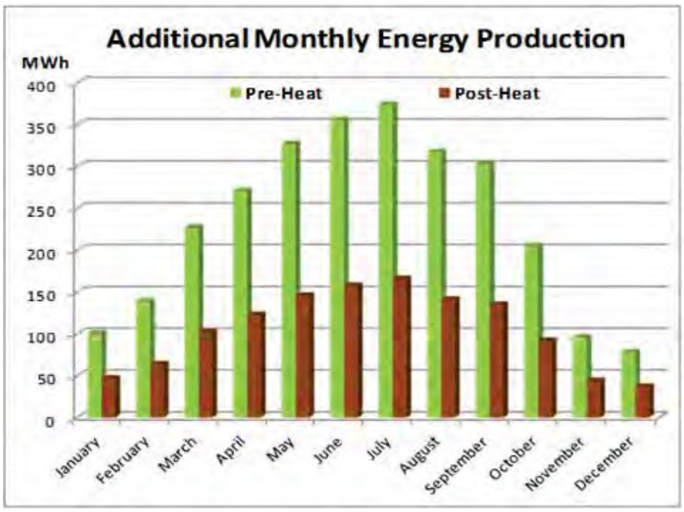
Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP





Results of Comparison

- Pre-Heat produces about 2x the incremental power and energy as Post-Heat.
- Pre-Heat selected for CSP integration.

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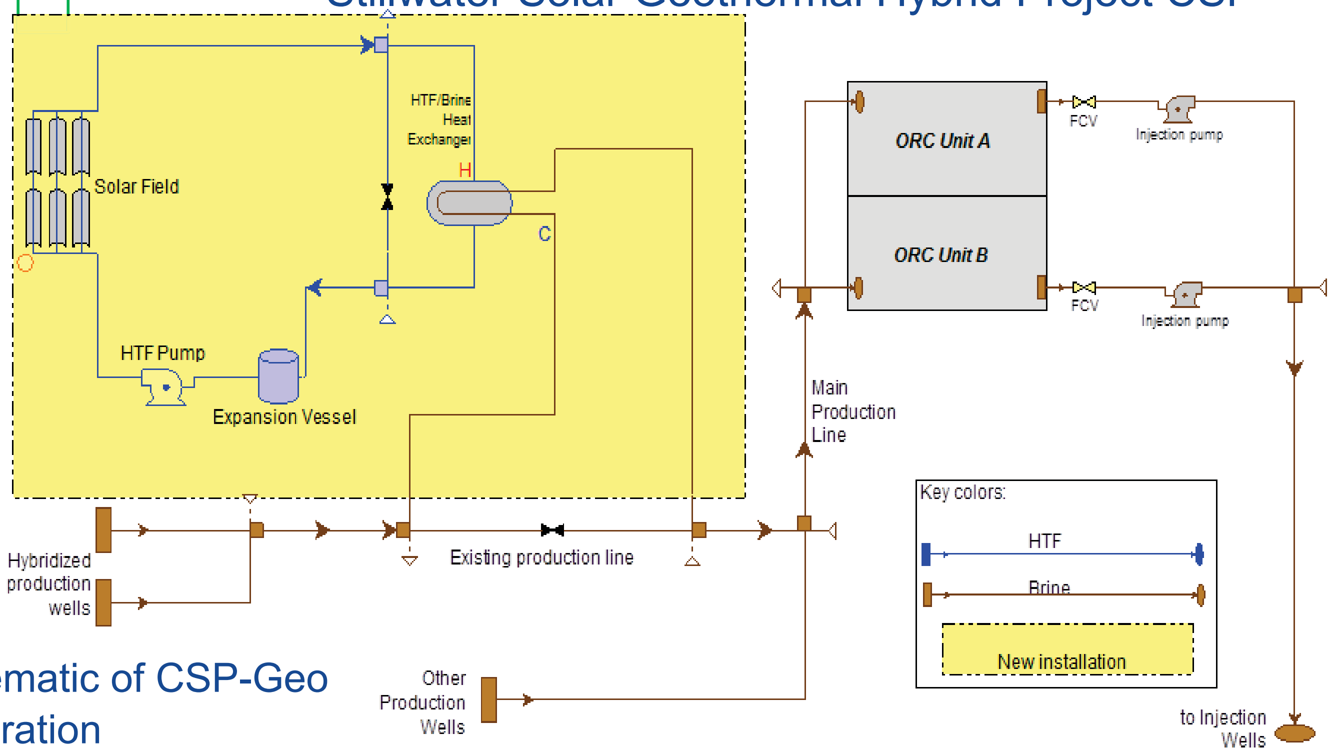
Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP



Schematic of CSP-Geo Integration

Stillwater Solar Geothermal Hybrid Project CSP

CSP Solar Field

- 17 MWth
- 24,000 m^2 of parabolic trough collectors
- 11 parallel loops
- Heat Transfer Fluid (HTF) is demineralized water with a corrosion inhibitor added
- Solar inlet temperature – 300°F/149°C
- Solar outlet temperature - 390°F/ 199°C

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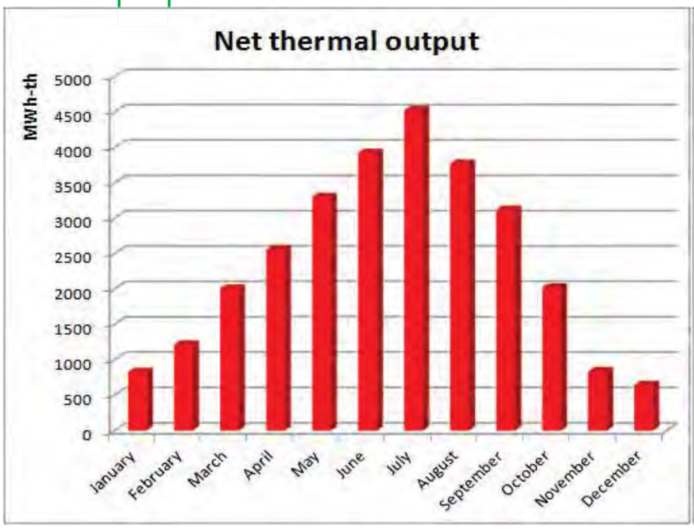
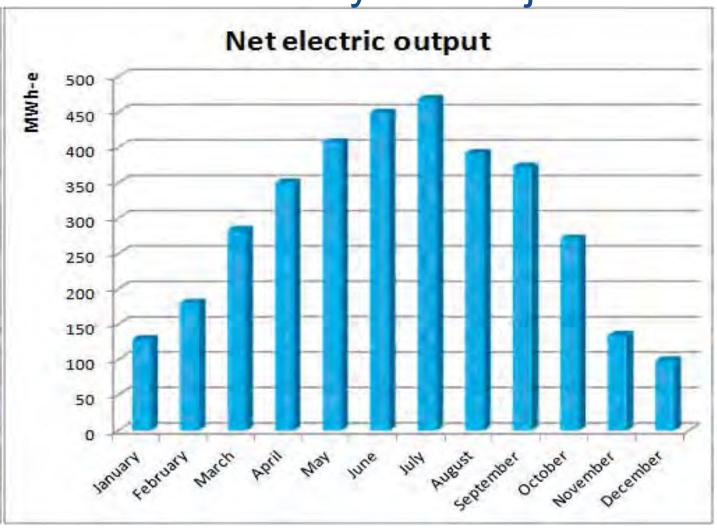
Hybrid Plants: Solar

Stillwater Solar Geothermal Hybrid Project CSP





Modeled Output of Solar Field

Annually

- Solar energy in = 56,346 MWh
- Thermal out (net) = 28,746 MWh
- Solar electric out (net) = 3,537 MWh-e

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Binary Plants

Binary Plants

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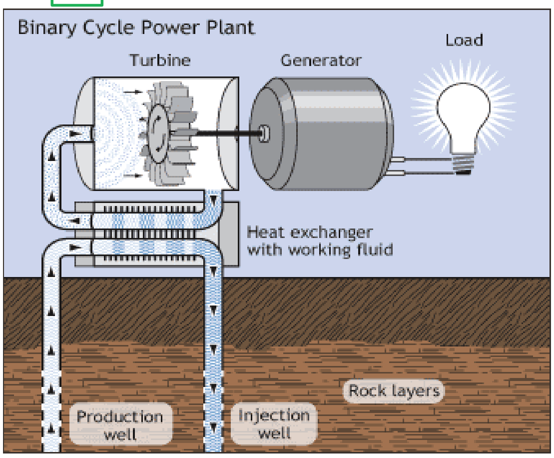
Binary Plants



- Binary Cycle can operate with fluids as low as 165°F (74°C)
- Can use dry cooling
- Recent advancements in binary cycle have opened up a lot more geothermal resource

Two Issues:

1. Actual temperature of geothermal brine frequently declines over time.
2. As ambient temperature increases, efficiency of air cooling declines – can impair plant production by 70%.

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Binary Plants

Technology Advantages
•Can exploit low temperature heat sources.
•Most equipment can be obtained from a variety of suppliers.
•Negligible emissions from NCGs
•Plant can be constructed in shops on skid mounted modules for easy shipping and field assembly
•All of the water drawn from the reservoir is return. Source generally have a higher useful life.

Technology Disadvantages
• Lower energy conversion rate than steam turbine plants.
• More process equipment thus requiring more maintenance effort and expense.
• Brines may have high concentrations of silica and/or Calcium salts which can cause troublesome scaling requiring frequent clean-ups of heat exchangers and wells.

Main Equipment Suppliers
Turbine/Expanders: Rotoflow; Elliott Turbines
Texas Turbines; Mafi-Trench
Air Products; Ormat, Turboden
Generators: GE; Alstom; Siemens, Kato

Condensers: Marley; Aerofin; BAltimore Coil

Economics
Power Plant Construction Cost:
$2,000 – $3,000 / kW

O&M Cost (direct): $15 - $20 /MWh

Typical "Binary Cycle" Geothermal Power Plant

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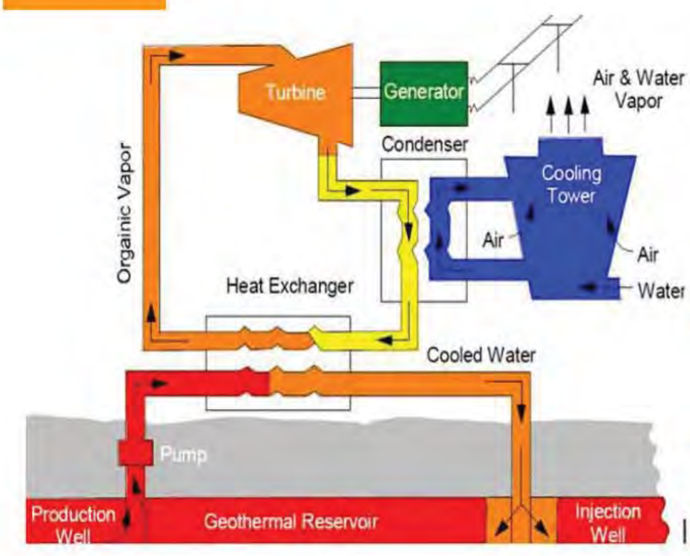
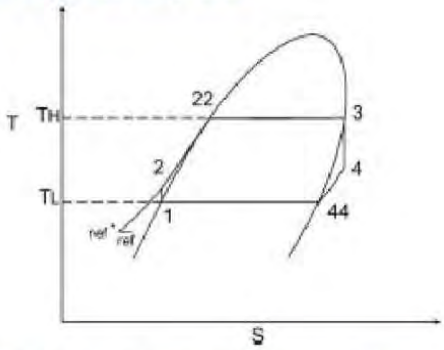
Binary Plants

Binary cycles for low enthalpy geo-resources





- For water-dominated resources with temperature lower than 180℃, the binary cycle technology is the most efficient.
- The geo-fluid energy is transferred through a heat exchanger to a secondary fluid that works in a closed ORC cycle.
- The binary power plants have the least environmental impact due to the "confinement" of the geo-fluid.

Conventional working fluid: ***-Isobutane***
-Isopentane
-Butane
-Pentane

Innovation in binary cycle technology

ORC CYCLE EFFECTIVENESS

7% ÷ 12%

ORC power production from low temperature resources has a low thermal efficiency

BYNARY PLANT CAPITAL COST

1200 ÷1600 €/KW (1 ÷ 5 MWe unit)

2300 €/kW (400 ÷ 500 kWe unit)

Low efficiency requires increased power plant equipment size that can become cost prohibitive

STATE OF THE ART

INNOVATION MAINSTAYS

ENHANCED PERFORMANCES & OPERATIONAL FLEXIBILITY

- To upgrade geothermal resources exploitation (electric generation more profitable)
- To better match the intrinsic characteristics of geothermal reservoirs
- To avoid performance decline due to the natural resources depletion and temperature drop

The objective of a multi-year collaboration between ENEL, the MIT, the Politecnico di Milano and TURBODEN is to evaluate power conversion options for geothermal applications and to propose designs for an innovative, cost-effective binary power plant for geothermal applications.

The design is intended to be sufficiently flexible and robust to utilize low-to-moderate temperature resources ranging in temperature from 130 to 160°C, or higher, while maintaining close to its optimum thermodynamic performance.

Enel Development of Binary Cycle Technology

Geothermal Electricity Plant: Innovative Design

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Binary Plants

The project aims to develop innovative electric generation systems to upgrade the exploitation low enthalpy geothermal resources.

ENHANCED PERFORMANCES

- to upgrade geothermal resources exploitation thus making the electric generation more profitable

GREATER FLEXIBILITY

- to better match the intrinsic characteristics of geothermal reservoirs
- to avoid performance decline because of the natural resources depletion and temperature drop

INNOVATION

Optimization of low enthalpy geothermal resources exploitation

Geothermal Electricity Plant: Innovative Design

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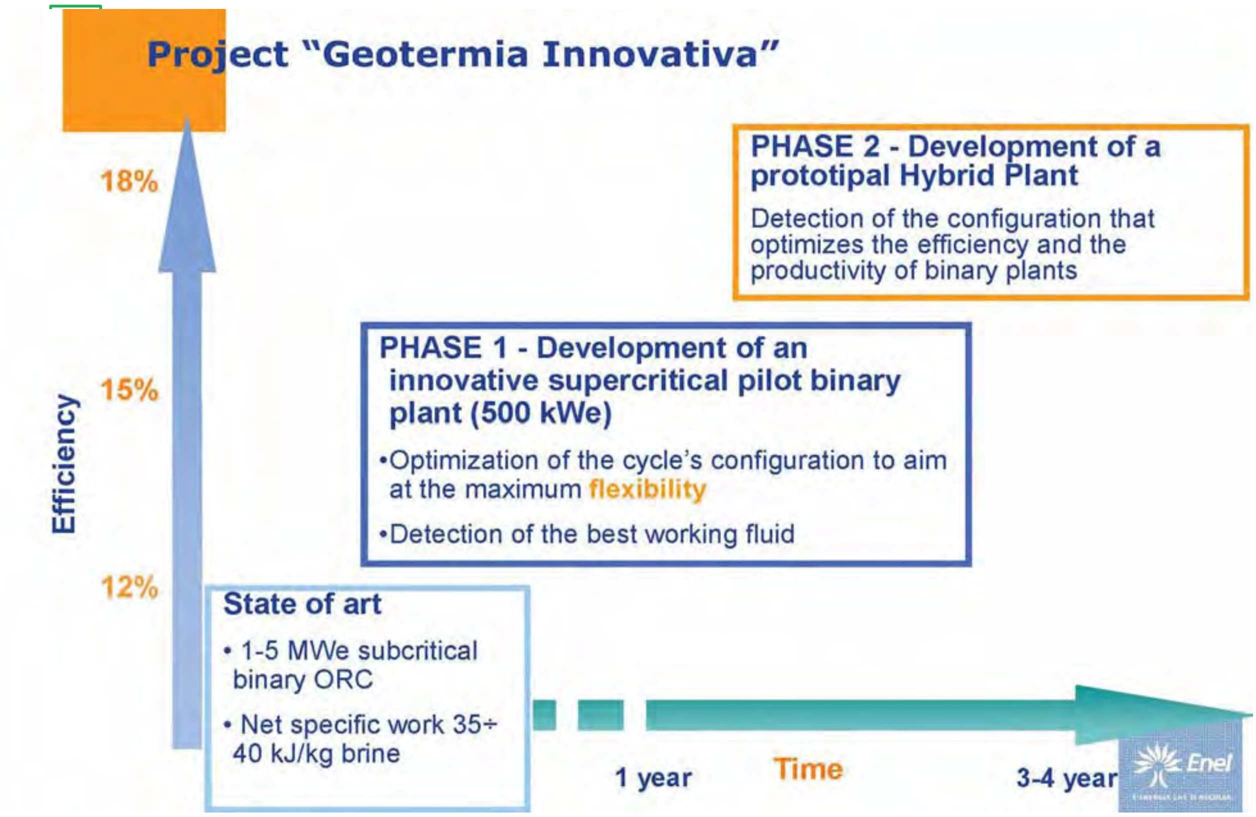
Binary Plants



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Binary Plants

- To develop an advanced, supercritical, ORC technology in order to improve ENEL's geothermal production from low enthalpy geothermal resources worldwide (with a specific focus to USA).
  - Net specific work > 44 kJ/kg brine (~ +30% compared to actual technology).
  - High operation flexibility (capability to work with high performances in a wide range of brine temperatures).
  - Reduced investment cost.
- To demonstrate an advanced ORC at the pilot scale (500kWe).
  - Cycle thermodynamic performance.
  - Operating flexibility.
  - Component design and scale-up criteria (with a particular focus on turbo - expander).
  - Component reliability during long term operation (some thousands hours).
- To evaluate the feasibility to increase the productivity of ENEL's ORC geothermal plants in the USA by means of integration with solar energy.

EGP Innovation

Binary Plants

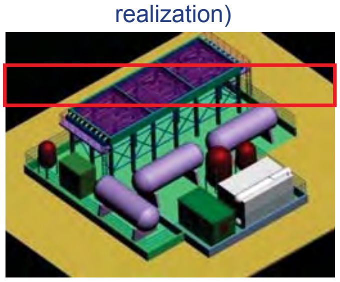
CONVENTIONAL BINARY CYCLE POWER PLANT → ***INNOVATIVE BINARY CYCLE POWER PLANT***

Suitable working fluid screening → Working fluid selection

Suitable operative cycle screening → operative cycle selection

Operative cycle optimization (thermodynamic simulations)

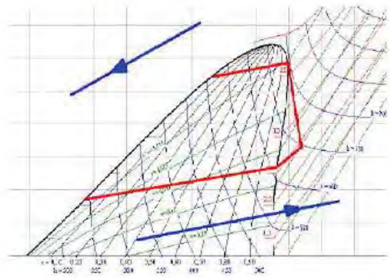
Testing theoretical data (prototypal sized pilot innovative binary plant realization)



Geothermal Electricity Plant: Innovative Design

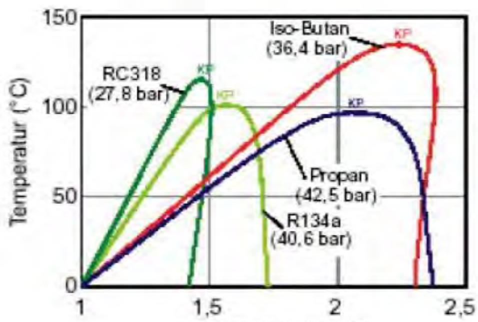
Cycle optimization and working fluid selection

- **Cycle modelling**
  - Sub-critical cycles (saturated, superheated)
  - Super-critical cycles



- **Working fluid screening criteria**
  - **6** Hydrocarbons tested
  - **4** Refrigerants tested

- Low boiling point and high vapor pressure fluids related to operating T and P
- Heavy fluid, characterized by small enthalpy drop; hence, the turbo-machinery stress is reduced



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Binary Plants

Calculation Hypotheses

Constraints of the model and cycle optimization criteria

OPTIMIZATION VARIABLES

- Working fluid mass flow rate
- Working fluid turbine inlet pressure
- Working fluid condensing pressure

PERFORMANCE INDICATORS

- **Utilization efficiency** → $\eta_u = \frac{W_{net}}{E_{in}}$
- Thermal efficiency → $\eta_{th} = \frac{W_{net}}{Q_{in}}$

MAIN INPUT DATA

Brine inlet temperature: 100°C ÷ 200°C
Brine reinjection temperature: ≥70°C
Cooling water: NOT AVAILABLE
Geothermal fluid mass flow: 100 kg/s
Dead-state temperature (Air ambient temperature): 20°C
Turbine isentropic efficiency:
 85% for fully-vapor expansions
 <85% when liquid is present (calculated from the Baumann equation)
Turbine exit vapor quality: 90%
Pump efficiency: 80%

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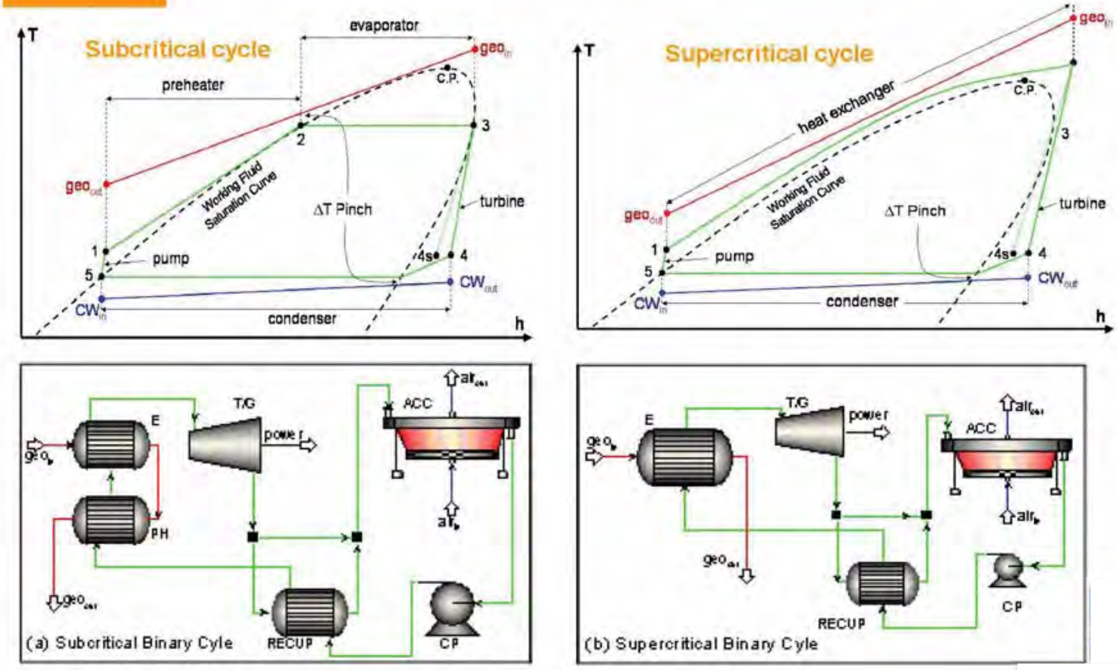
Binary Plants
Subcritical vs. Supercritical Cycles



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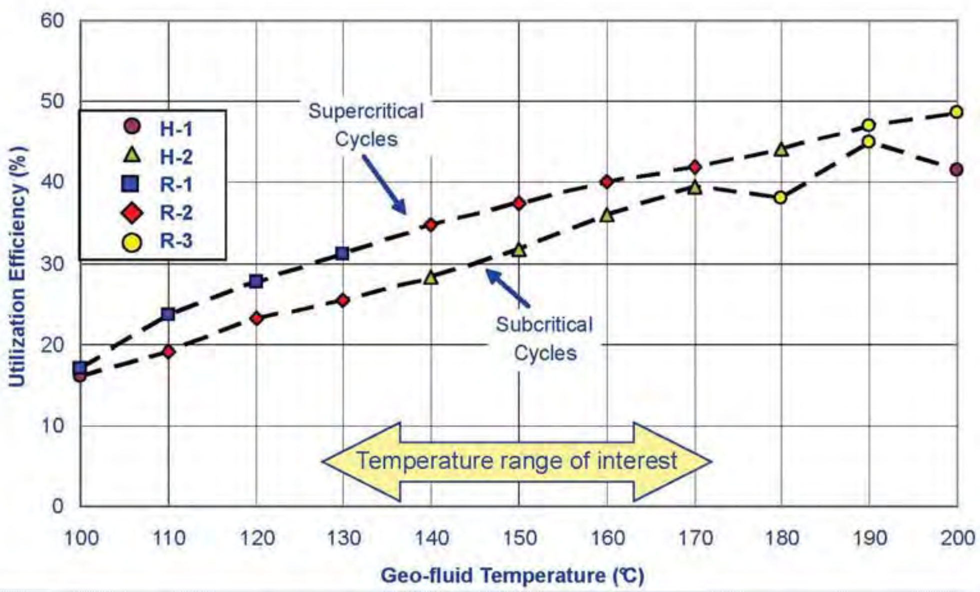

Supercritical cycles provide higher utilization efficiency for the whole geo-fluid temperature range, resulting in 23% max. increase in net power.

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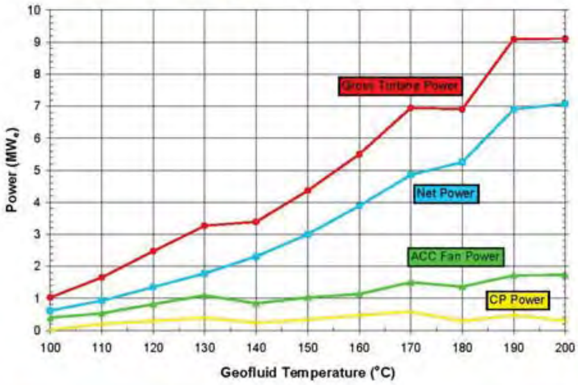
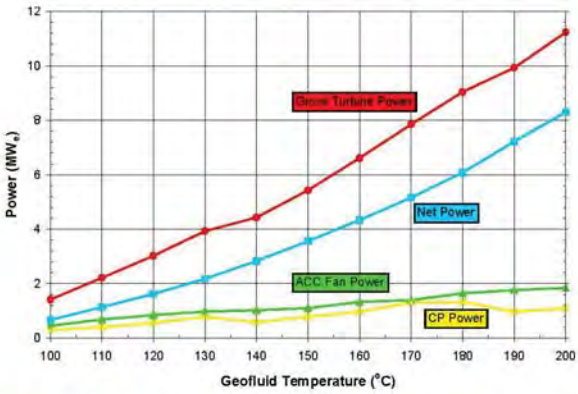
Binary Plants

Subcritical cycle



Power, MW	H-1 @ 100°C	H-2 @ 150°C	H-1 @ 200°C
Gross	1.03	4.37	9.12
Parasitic losses	40%	31%	22%
Net	0.62	3.00	7.07

Supercritical cycle



Power, MW	R-1 @ 100°C	R-2 @ 150°C	R-3 @ 200°C
Gross	1.41	5.43	11.23
Parasitic losses	53%	34%	26%
Net	0.66	3.56	8.30

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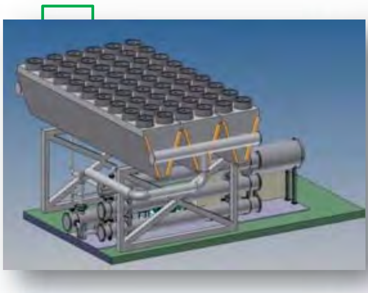

Plant type: geothermal prototype with supercritical cycle

Customer: Enel Green Power

Location: Livorno, Italy

Heat source: hot water at 150°C nominal

Cooling device: ‘dry & spray’ condenser

Total electric power: 500 kW_{el}

Working fluid: refrigerant (non flammable)

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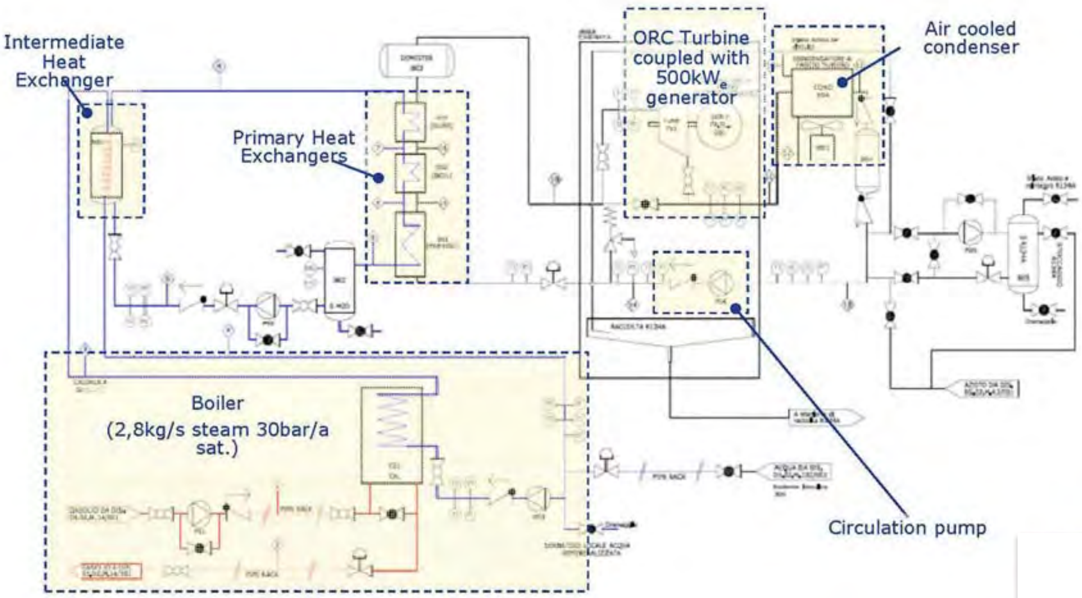
Binary Plants



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Binary Plants

Advanced 500 KW_e ORC pilot plant

Auxiliary boiler already available 5,6 MW (8,5 t/h, 250℃)

200 m² foundation platform for pilot plant installation

EGP Innovation
Binary Plants

- COD 20-3-2012
- Calibration and initial performance tests
- August: final set up with improvement in heat exchangers
- Long run test
- Performance tuning with manufacturer
- Preliminary results are promising

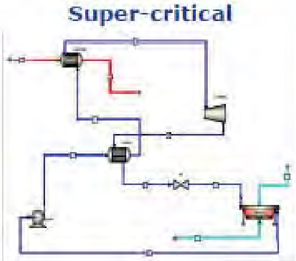
Geothermal Electricity Plant: Innovative Design

Experimental campaign – ORC power plant prototype realization

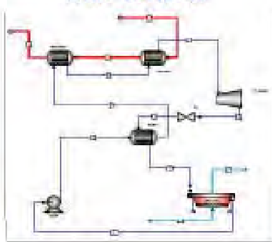
EGP Innovation
Binary Plants

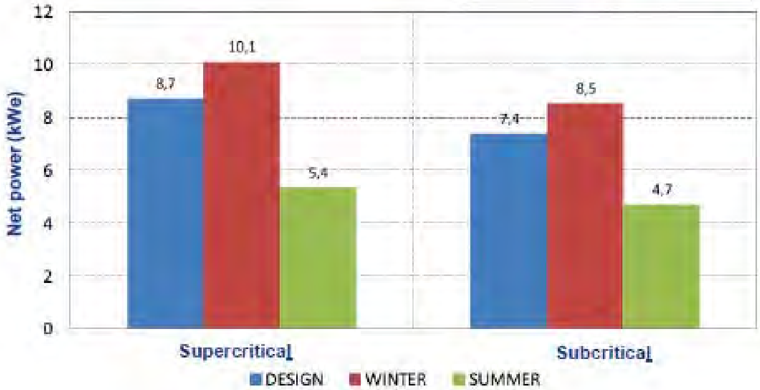
INPUT DATA
- Brine inlet temperature: 152°C
- Brine mass flow: 190 kg/s
- Design net power: 10 MWe
- Design ambient temperature: 10.7 °C
- Summer ambient temperature: 31.1 °C
- Winter ambient temperature: -1.1 °C

Super-critical



Sub-critical





Annual net energy production estimation ~ 15-20% higher for supercritical ORC with respect to subcritical

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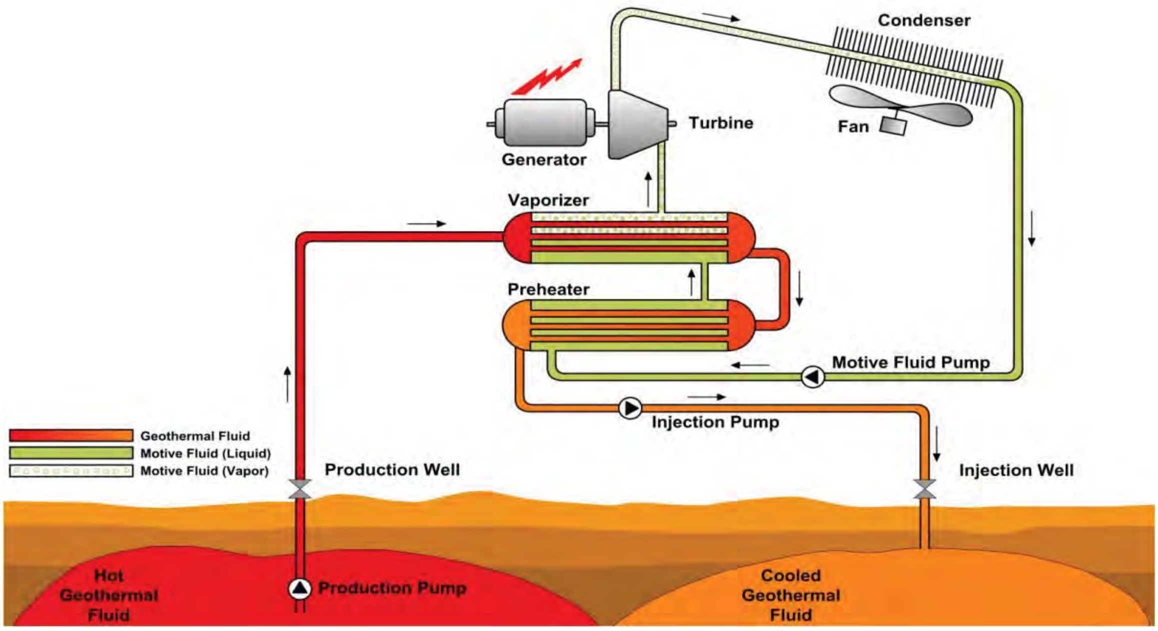
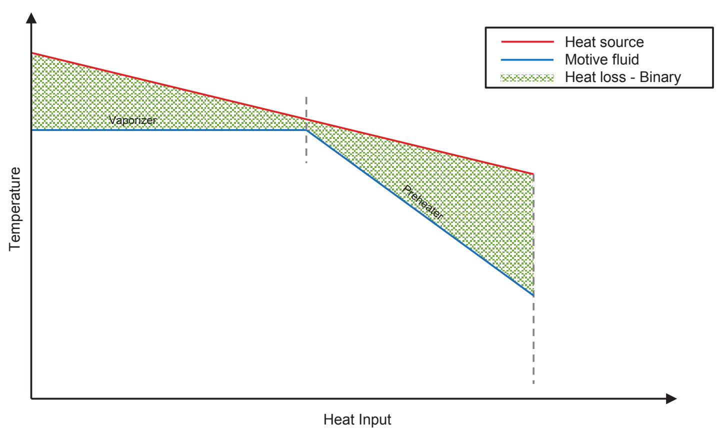
Binary Plants



New Project: Cove Fort, Utah

EGP Innovation
Binary Plants



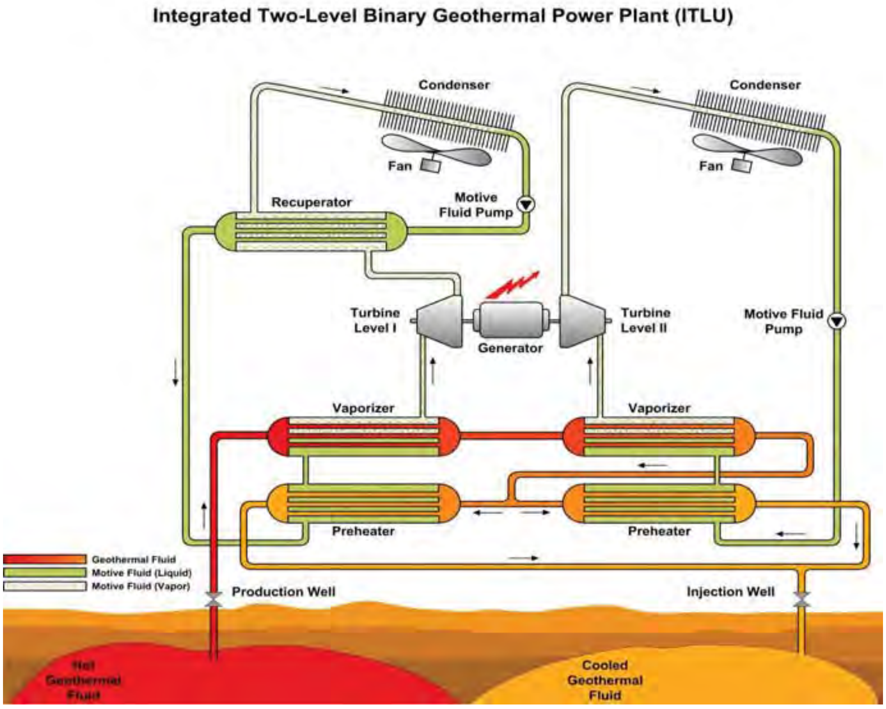
Power production potential with simple binary unit: 23±1 MW

New Project: Cove Fort, Utah

EGP Innovation

Binary Plants

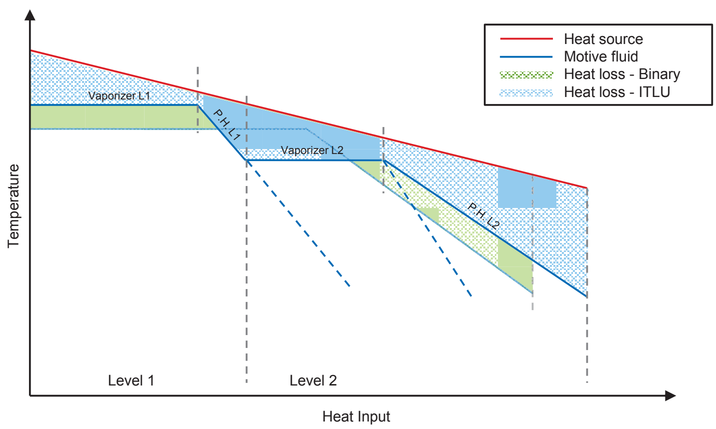
Two Level Binary Cycle Geothermal



New Project: Cove Fort, Utah

EGP Innovation

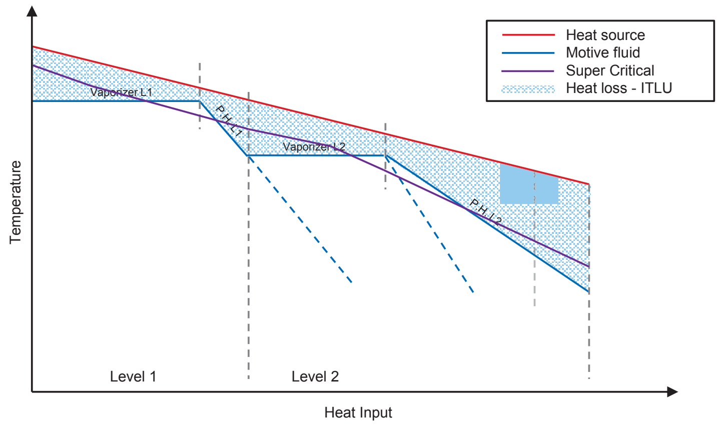
Binary Plants



Power production potential with simple binary unit:
23±1 MW

Power production with ITLU:
26.4 MW
≈ **15% Improvement** over simple binary unit !

EGP Innovation
Binary Plants



* Although gross power is higher than ITLU, **NET** power is ~ 4% lower due to high feed pump loads!

Power production potential with simple binary unit: 23±1 MW

Power production with ITLU: 26.4 MW
≈ **15% Improvement** over simple binary unit !

Power production with Super Critical unit: 28.3* MW

New Project: Cove Fort, Utah

EGP Innovation
Binary Plants

New Project: Cove Fort, Utah

EGP Innovation

Binary Plants

New Project: Cove Fort, Utah

EGP Innovation

Binary Plants

New Project: Cove Fort, Utah

EGP Innovation
Binary Plants

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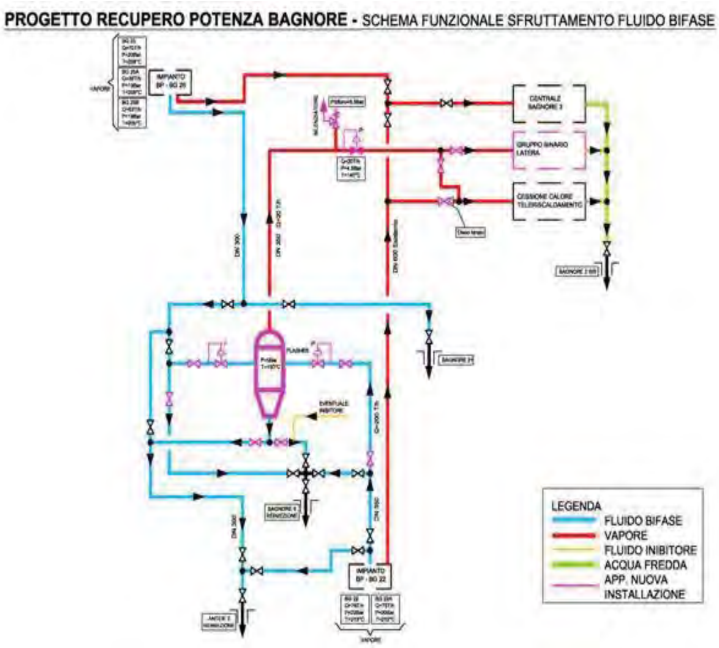
EGP Innovation
Binary Plants

- Water dominated high temperature geothermal reservoir >300°C
- At 20 bar well head separation unitsM hot water reinjection of about 250 t/h;
- Silica presence: not possible to allow excessive water cooling;
- SOLUTION: a second flash at 5 bar, producing 20- 30 t/h of steam at 5 bar and 160°C



New Project: Mount. Amiata, Italy

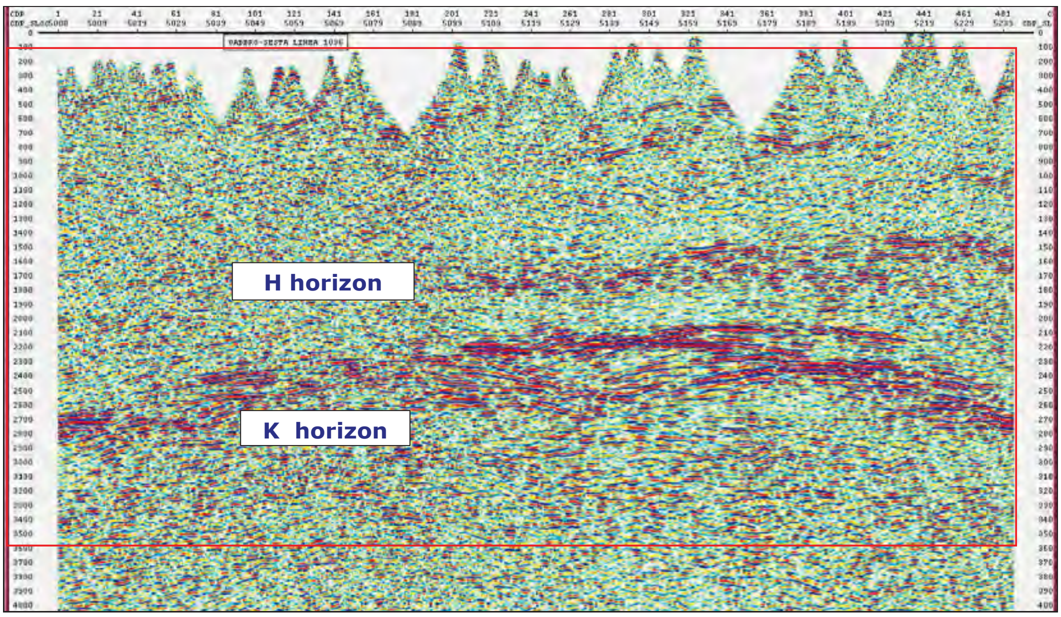
EGP Innovation
Binary Plants

Heat Ex

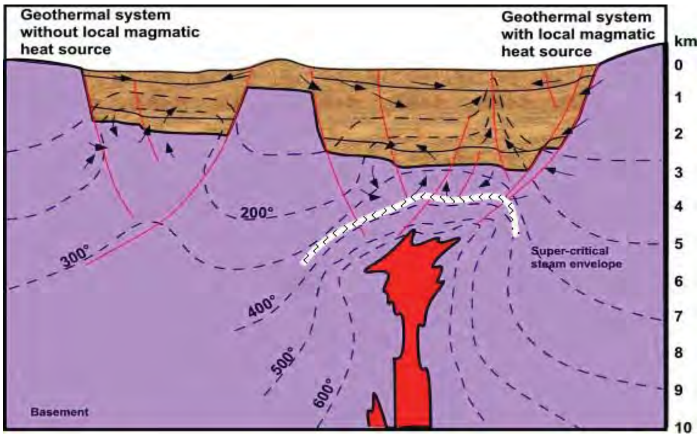
ine

EGP Innovation
Supercritical fluids

Supercritical fluids



EGP Innovation
Supercritical fluids



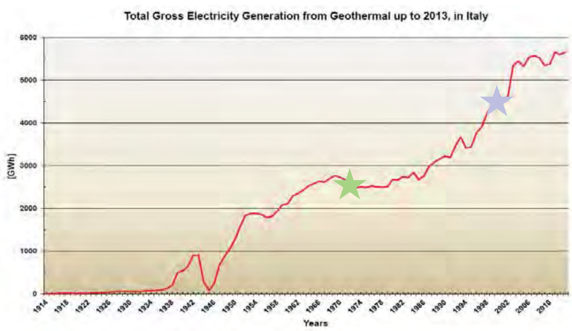
High heat flow conditions ➡ rift zones, subduction zones and mantle plumes.

Thick blankets of thermally insulating sediment covering a basement rock that has a relatively normal heat flow ➡ lower grade

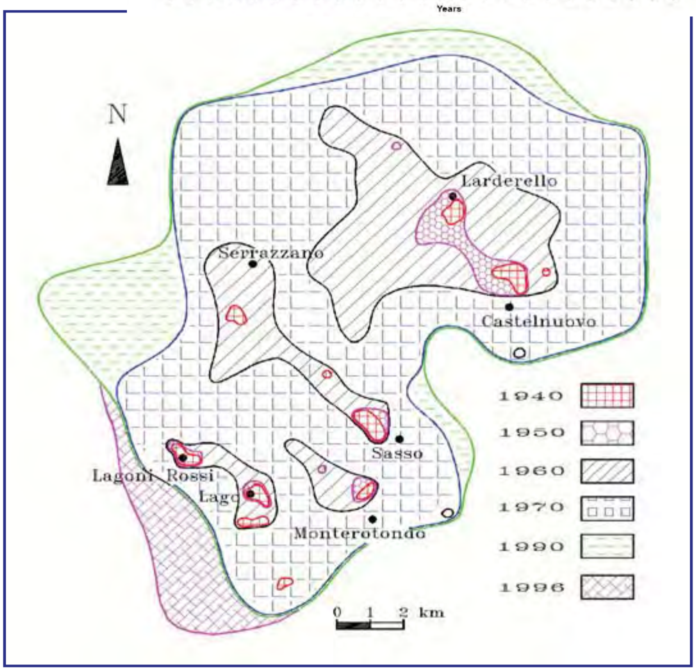
Other sources of thermal anomaly:

- Large granitic rocks rich in radioisotopes
- Very rapid uplift of meteoric water heated by normal gradient

EGP Innovation
Supercritical fluids

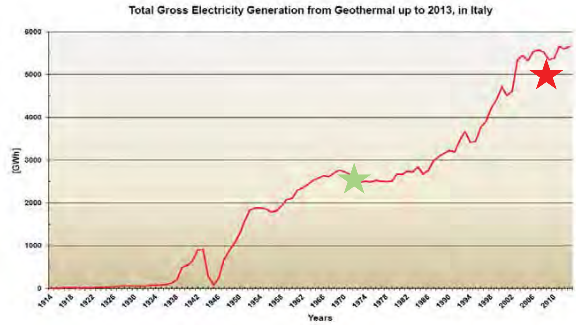


<u>The areal extension</u> of the Larderello exploited area increased till the '70, when the external boundaries of the system have been reached. No new development was done in the last 30 years for extending the surface of the field.

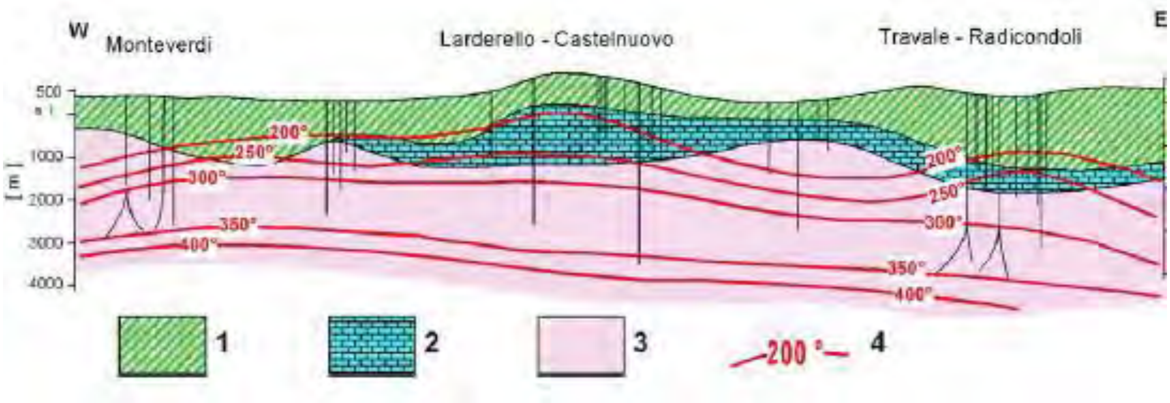


Larderello
A success history

Supercritical fluids

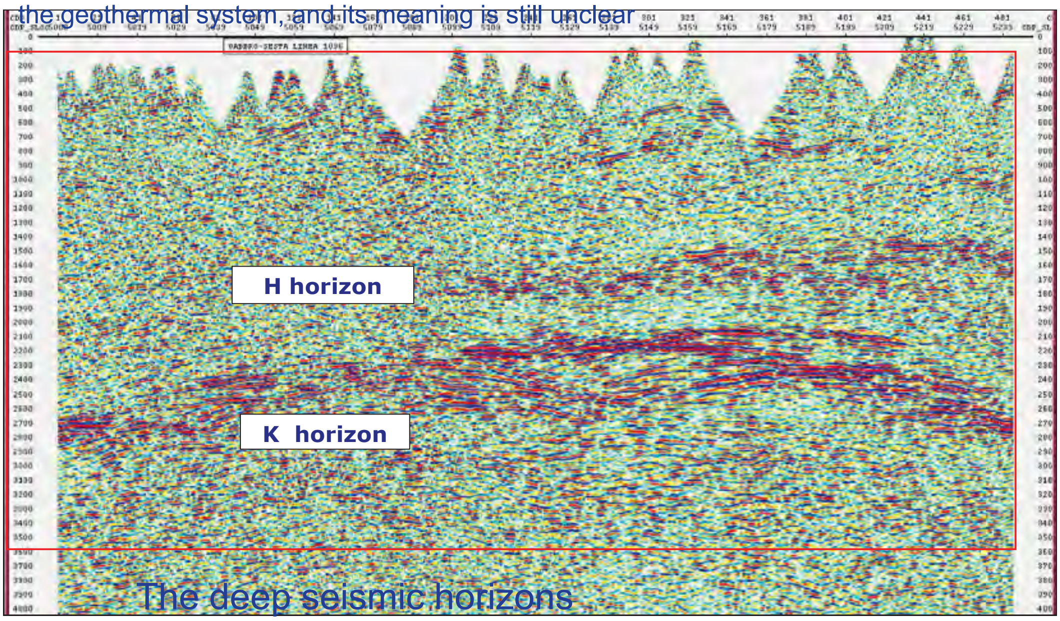


<u>The deep exploration</u> the Larderello system started after the '70, after the exploitation (which still is on going!) of the shallow reservoir [2], drilling into the metamorphic basement down to 4-5 km depth [3]. Today the production is stabilized from the combined effect of reinjection and deep wells. No new increasing ramp is expected.



Supercritical fluids

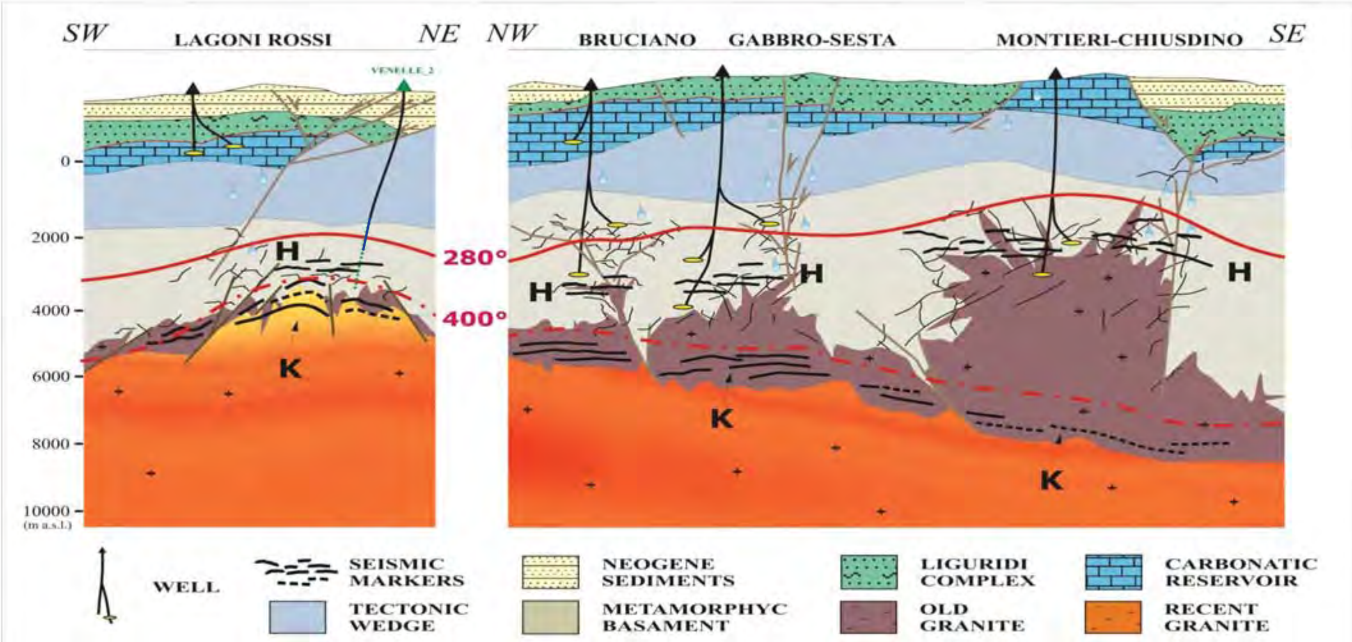
1) **<u>H Horizon</u>**: it is relatively shallow (2500-3500m), non-continuous, and it represent a target for deep wells in the metamorphic basement, with a significative permeability, even if not-homogeneous
2) **<u>K Horizon:</u>** it is deeper (3000-10000m), almost continuous, present in all the area of the geothermal system, and its meaning is still unclear



The deep seismic horizons

EGP Innovation

Supercritical fluids



Drilling into the K horizon

will open the possibilities of exploiting the deep supercritical fluid that can be hosted in the young granites, with a new development phase for the Larderello field.

EGP Innovation

Supercritical fluids

Deepening Venelle 2 Project

THE PROJECT

Our proposal is aimed to the exploration of the K horizon, in order to investigate the presence of supercritical fluids and their characterization, physical and chemical. The project will be realized through the deepening of an existing dry well Venelle 2 in Larderello, which has been halted quite near to such a target.

The thermodynamical conditions could be very challenging and rich of perspectives:

- **Temperature > 450°C**
- **Pressure >250 bar**
- **Supercritical fluids**
- **Chemical components**

EXPECTED OUTCOMES

- **Well with high specific productivity = up to 30 MW per single well**
- **Closed loop production**
- **Reassessment of the reserves in our leases**
- **Possibility of high value chemical component extractions**
- **Technological and scientific challenge-fruitful international cooperation**

Deepening Venelle 2 Project

WHY NOW?

Supercritical fluids utilization
is important for a new growing phase
of the geothermal development in Italy,
using the important source of funds from UE
(Horizon 2020)
and the opportunity of an
international cooperation.

Supercritical fluids have been investigated
by Japan and Iceland,
with controversial results.

There is a strong international interest
in such a research frontier.

Worldwide a few attempts at drilling in very high temperature/pressure conditions:

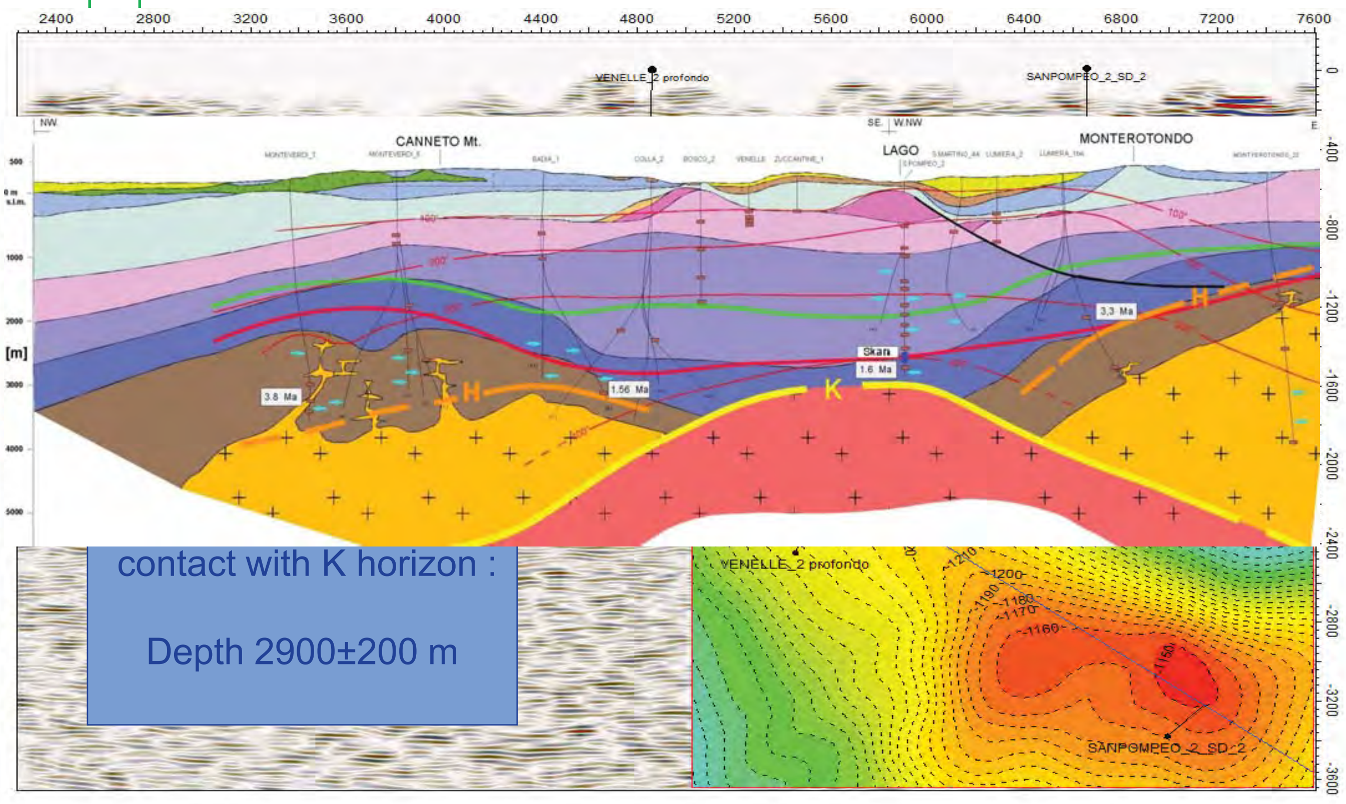
•**San Pompeo 2** well in **Italy**: drilled by EGP in **1979**, with the target of a deep fractured layer inside the metamorphic basement in Larderello. At about a 3 km depth it produced a very different fluid from earlier experiences in the exploited hydrothermal reservoir. Its pressure was above 24 MPa (five times higher than the standard) and the extrapolated temperature exceeded 400°C. The well was closed after a hydrogen gas explosion, which severely damaged the drilling string. Sampling of the deep fluids highlighted the important presence of gases, and a strongly corrosive environment.

•Deep Seated Geothermal Resources Survey well in **Japan**: drilled in **1994-1995** by NEDO to investigate the characteristics of the deep-seated part of the **Kakkonda** geothermal field, one of the largest liquid dominated geothermal systems in Japan. When a depth of 3.7 km was reached, the operation stopped for safety concerns, principally due to a H_2S discharge and difficulty in controlling the drilling. The inferred temperature was above 500°C.

•IDDP-1 well in **Iceland**: in **2009** the drilling of the first IDDP well, designed to reach a 4.5 km depth, was attempted at **Krafla**. The drilling terminated abruptly at only a 2.1 km depth when the drill bit hit 900 °C hot rhyolitic magma. The IDDP consortium decided to complete the well as a subcritical well designed to produce from the contact zone of the intrusion, which in its first few months to operations has proved to be highly productive. A new well is planned.

EGP Innovation
Supercritical fluids

Deepening Venelle 2 Project



contact with K horizon :

Depth 2900±200 m

EGP Innovation
Supercritical fluids

Deepening Venelle 2 Project

- **Demonstrate the feasibility of safely drilling a deep super-critical geothermal well**, by identifying technical problems created by super-critical conditions, solving these problems by developing improved drilling procedures, equipment and well design, and extending the Venelle 2 well into a very high temperature formation.

- **Reduce the technical and financial risks of drilling and exploiting deep geothermal wells** by improving knowledge of the physical and chemical conditions in deep geothermal formations. Characterisation of the physical and chemical properties of deep crustal fluids and rocks will be performed. In addition to standard logging during drilling, a novel measurement tool will be developed and used to measure pressure and temperature in super-critical conditions. The knowledge gained will be disseminated in industry related channels.

- **Reduce pre-drill uncertainty in the exploration of deep geothermal wells** by applying the latest seismic processing, imaging and interpretation technology for exploring the super-critical reservoir prior to drilling. The seismic methods will be evaluated and calibrated based on results obtained during drilling.

- **Investigate the potential of improving the competitiveness of geothermal power**, the possibility of exploiting chemicals from deep crustal conditions will be also addressed during the project.

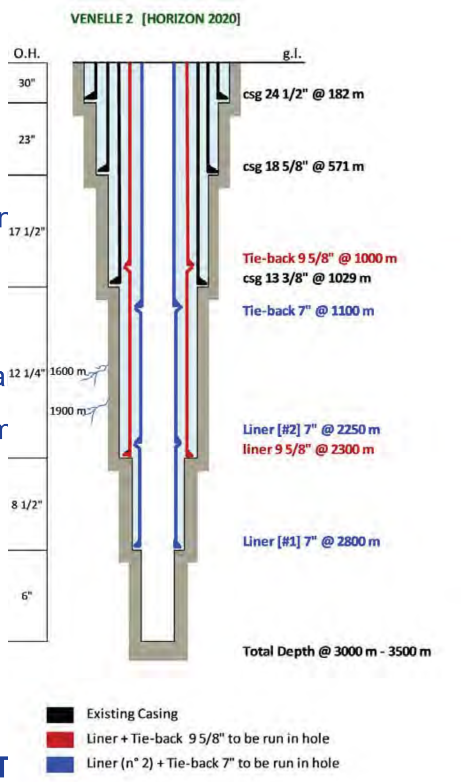
EGP Innovation
Supercritical fluids

Deepening Venelle 2 Project

- New drilling technologies for high temperature ar
- New materials and procedures
-
- tory a
- al com
- ns
-
- Liquid and gas phase samplings
- Measurements during drilling
- Production test

•Probability of success : about 25%

• Total cost for the research phase: 13 M€



FIRST EXPERIMENT IN THE WORLD FOR T

IN A GEOTHEMAL ENVIRONMENT

EGP Innovation
Supercritical fluids

Deepening Venelle 2 Project: DESCRAMBLE

The "Drilling in dEep, Super-CRitical AMBient of continentaL Europe" (DESCRAMBLE) project proposes to drill in continental-crust, super-critical geothermal conditions, and to test and demonstrate novel drilling techniques to control gas emissions, the aggressive environment and the high temperature/pressure expected from the deep fluids, and to improve knowledge of deep chemical-physical conditions for predicting and controlling critical drilling conditions. An existing well in Larderello (Tuscany, Italy), Venelle 2, will be drilled from its present depth of 2.2 km down to 3-3.5 km.

DESCRAMBLE's Vision is to contribute to reaching the EU strategic energy and climate targets for 2020 and 2050 by fostering increased growth in the geothermal electricity market, through increased awareness of the potential of geothermal electricity production and the demonstration of the feasibility of extracting electricity from super-critical deep geothermal reservoirs.

EGP Innovation

Supercritical fluids

Deepening Venelle 2 Project: DESCRAMBLE

Enel Green Power Project Leader

Consortium members from three countries:

- CNR/IGG (**Italy):** geochemical and numerical modelling;
- Aachen, Kiel and Freiberg Universities (**Germany**): petrological analysis, geophysical acquisition and elaboration, numerical modeling, well log analysis and interpretation;
- SINTEF (**Norway),** an important oil/gas research company, with experience also in drilling, instrumentation and ICT, for high pressure and temperature measuring tool and drill control techniques in severe conditions.

EGP Innovation

Supercritical fluids

Deepening Venelle 2 Project: DESCRAMBLE

Section 1: Drilling in super-critical conditions.

- •Definition of the drilling program: deepening the Venelle 2 well.
- •Selection/development of appropriate equipment and material to withstand the harsh downhole conditions.
- •Definition/development of drilling procedures.
- •Develop procedures for well monitoring and control in order to secure the safety of the well in terms of health and the environment.

Deepening Venelle 2 Project: DESCRAMBLE

Section 2: Geo-scientific activities to increase knowledge of super-critical wells.

- Geophysical survey and reinterpretation of all data for a better identification of the drilling target, with a new seismic data acquisition campaign, a VSP and the accompanying deployment of seismographs in a 10-20 km area around the drill site, sounding the underground for a comprehensive and areal seismic characterization of the target horizon.

- Definition of procedures for supercritical fluid handling and sampling; planning production test.

Deepening Venelle 2 Project: DESCRAMBLE

Section 2: Geo-scientific activities to increase knowledge of super-critical wells.

- Geophysical logs during drilling, to obtain a full dataset of valuable information.

- Measurement of physical and chemical data from rock cores, cuttings and sampled fluids.

- Characterization of the downhole environment: a logging tool will be realized to measure wellbore temperatures up to 450°C and pressures up to 50 MPa, for a minimum of 8 hours logging.

Future Perspectives
Supercritical fluids exploitation

If the experin … nd design of a pilot plant
could be plar … eothermal research in
Larderello, w … elle 2 one at an
acceptable d … e will allow a substantial
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A 30 MW ge … sociated reinjection one,
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only due to … of a further 10% cost
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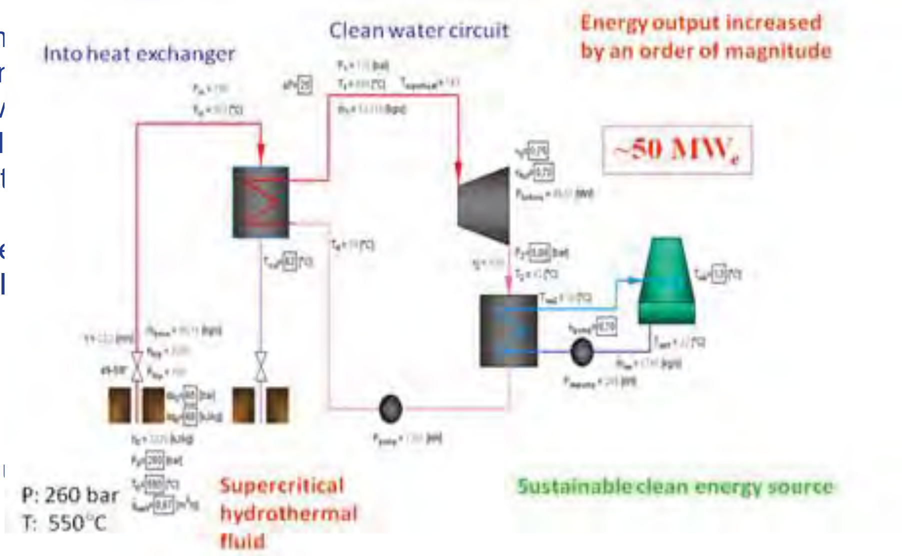


The success of the research will open great perspectives both in term of increasing the installed capacity, and in term of cost reduction for the new projects.

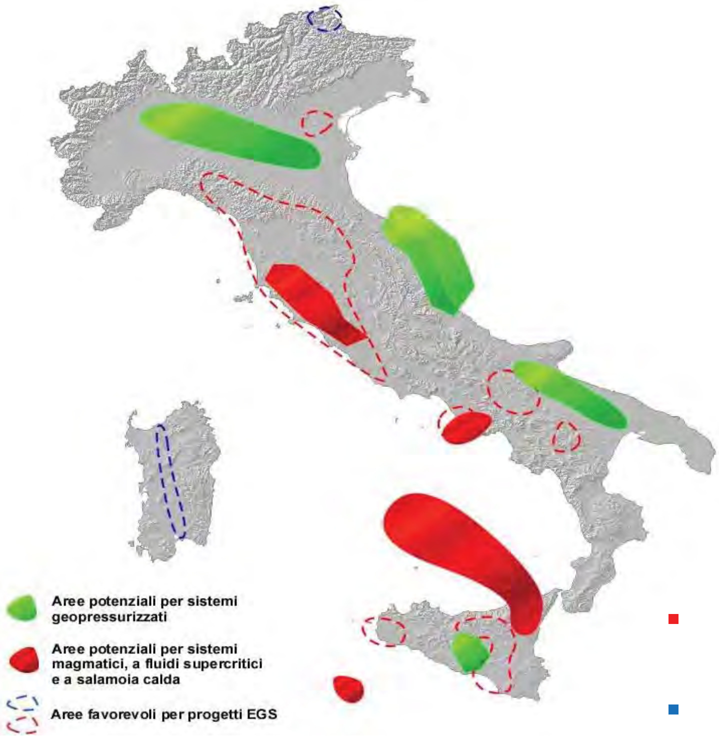
EGP Innovation
Supercritical fluids

Deep Resources:

Unconventional Geothermal Systems

(Working Group, Unione Geotermica Italiana, 2010)

EGP Innovation
Unconventional

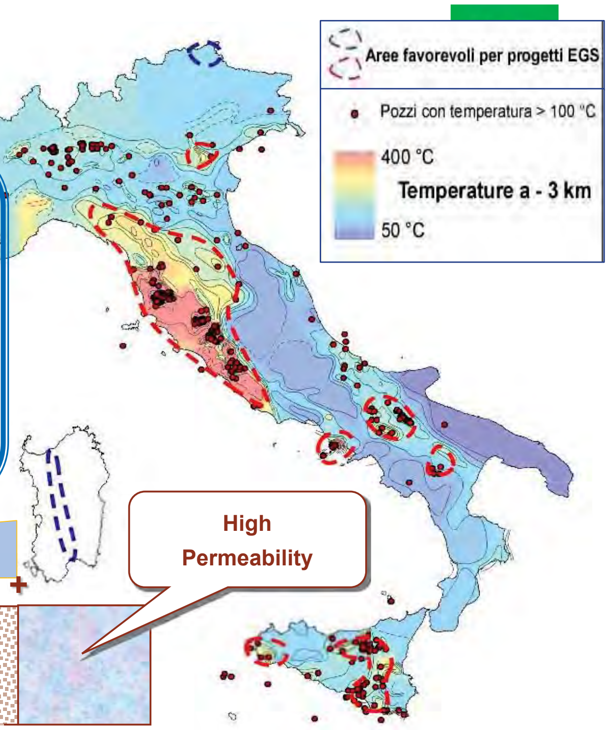


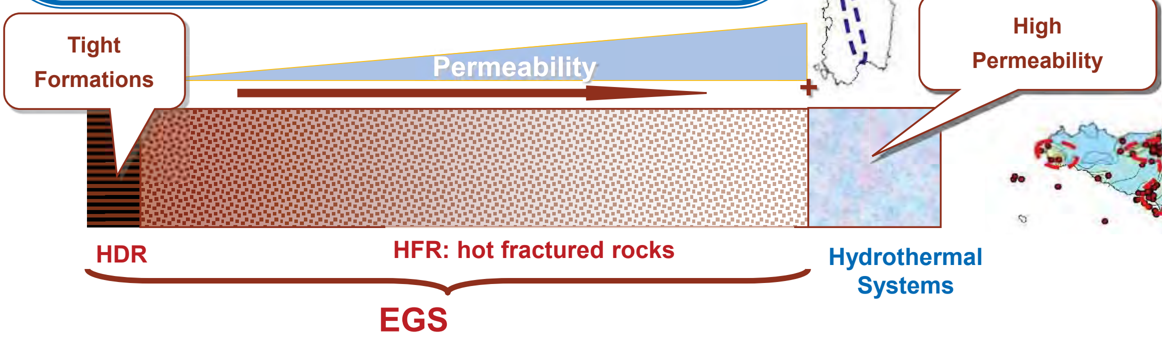
- *Hot Dry Rocks - Enhanced Geothermal Systems (high temperature and low-to-very low permeability)*
- *Pressurized systems in clastic complexes*
- *Hot brines, Mainly in volcanic systems. High temperature fluids at very high salinity (>> 10 g/l).*
- *Supercritical fluids, high temperature and depth in supercritical conditions*
- *Magma systems, heat capture in active volcanic areas*

Unconventional Geothermal Systems (UGS), can exist in Italy at depths 2 – 5 km

EGP Innovation
Unconventional

Any system where reservoir stimulation techniques such as “hydro-fracking” and chemical stimulation are used to enhance permeability, and hence increase circulating flow rates and energy production rates





EGP Innovation

Unconventional

DEEP EXPLORATION METHODS

Geology, geophisics,s geochiemistruy, reservoir models

PERMEBILITY - MINING RISK

DEEP DRILLING

- High pressure and temperature
- Aggressive fluids
- Adequate materials: sensor, casing, mud, additives, cement
- Operative technology: well control and cementing

PRODUCTION

- Not conventional fluids (aggressive, flash and scaling)
- Surface plants: special materials, valve, fittings, pipes, thermal insulation
- High temperature and high pressure

EFFICIENCY OF HEAT PRODUCTION AND POWER GENERATION

- Steam group, binary groups
- Heat pipe (?), rock / well fluid heat exchange

SUSTAINABILITY

- Reinjection
- Induced sismicity
- dissolved gas management

EGP Innovation

Cascade Utilizations

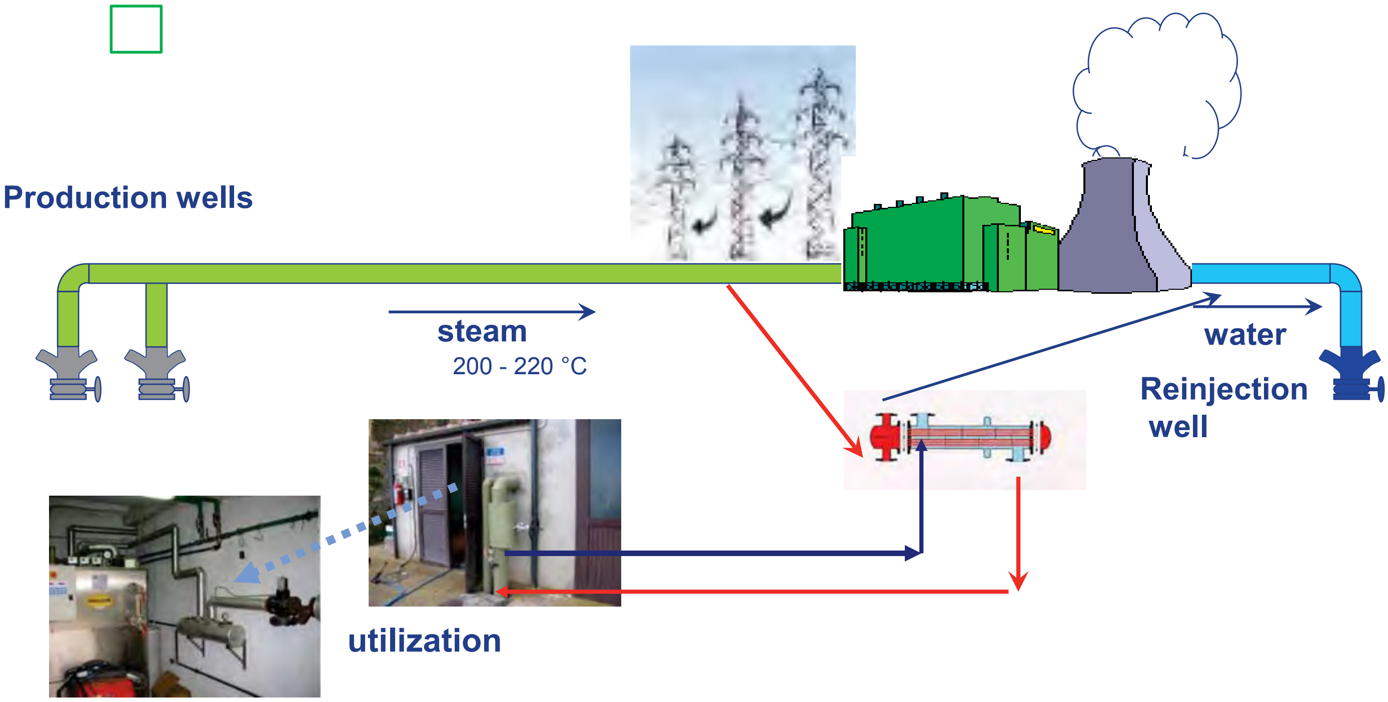
Cascade Plant

Thermal Energy for heating:

- houses
- greenhouses

Process heating:

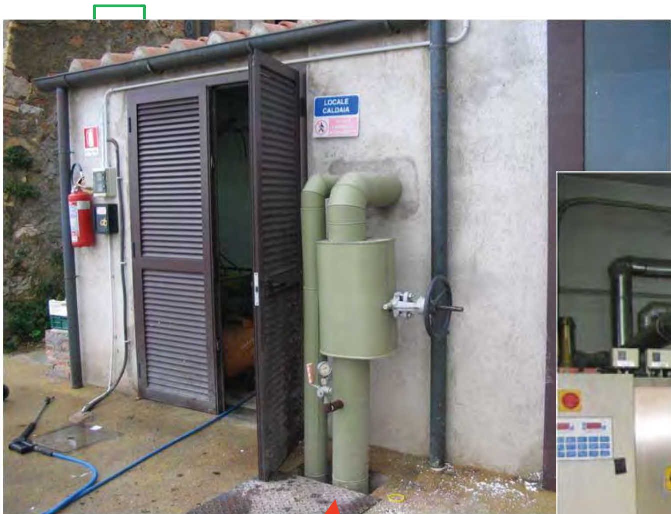
- cheese factory
- salami
- aquaculture
- beer production



EGP Innovation
Cascade Utilizations

Main heater on secundary steam for Cheese factory

EGP Innovation
Cascade Utilizations



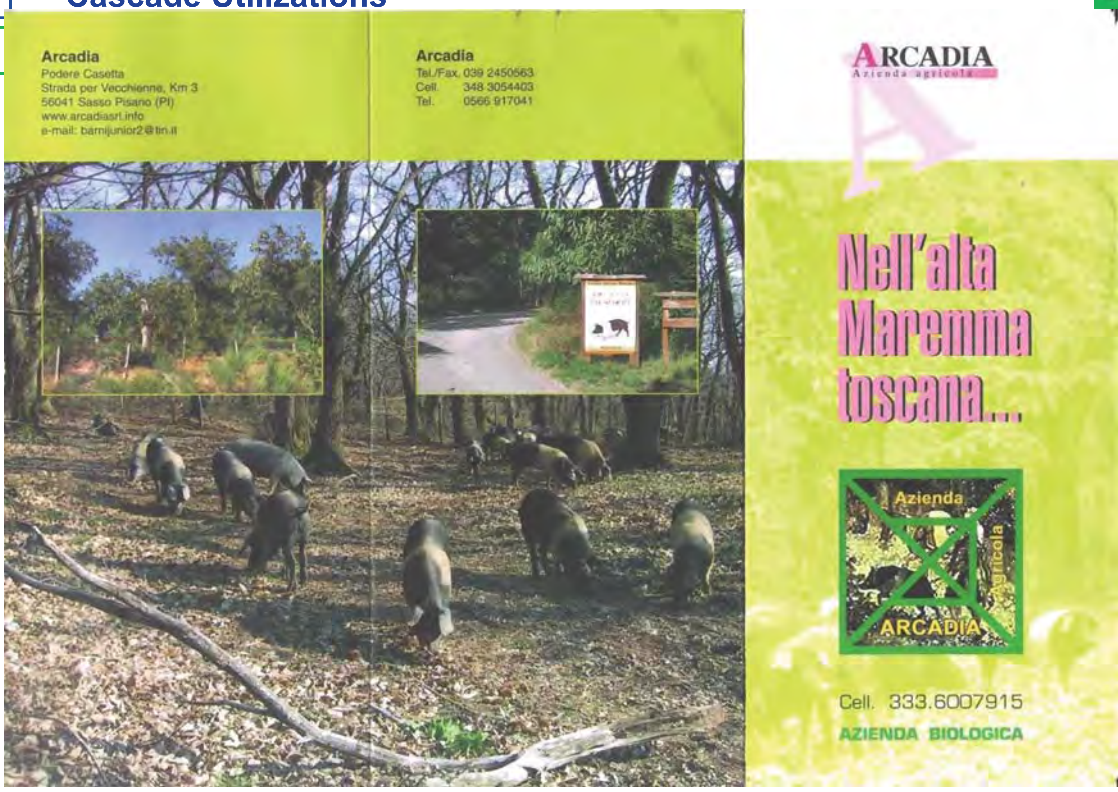
Secundary steam inlet

Pressure regulation

EGP Innovation
Cascade Utilizations

Salami factory

EGP Innovation
Cascade Utilizations



EGP Innovation
Cascade Utilizations

Aquaculture

EGP Innovation
Cascade Utilizations

Green houses Heater

EGP Innovation

Cascade Utilizations

Enel Green Power

Greenhouses of Radicondoli

EGP Innovation

Cascade Utilizations

Enel Green Power

Greenhouses of Radicondoli

EGP Innovation
Cascade Utilizations

Greenhouses of Radicondoli

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Cascade Utilizations

Greenhouses of Castelnuovo

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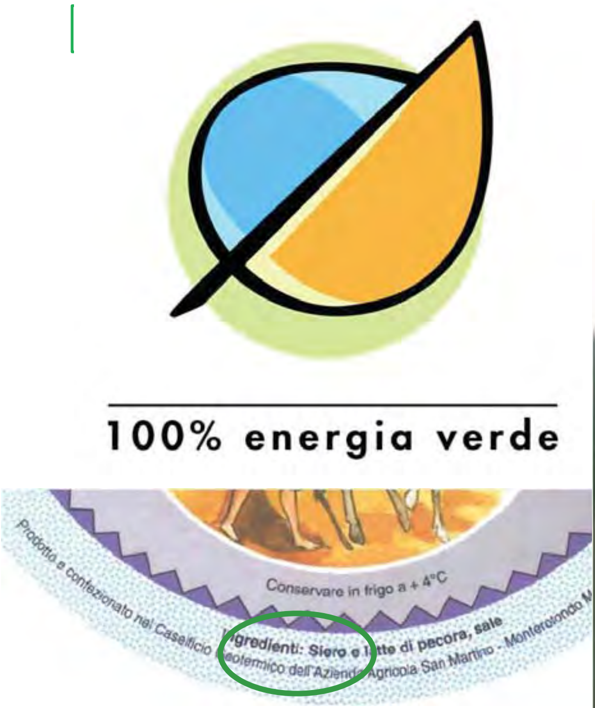
Cascade Utilizations



Green Certificate of Origin: Branding

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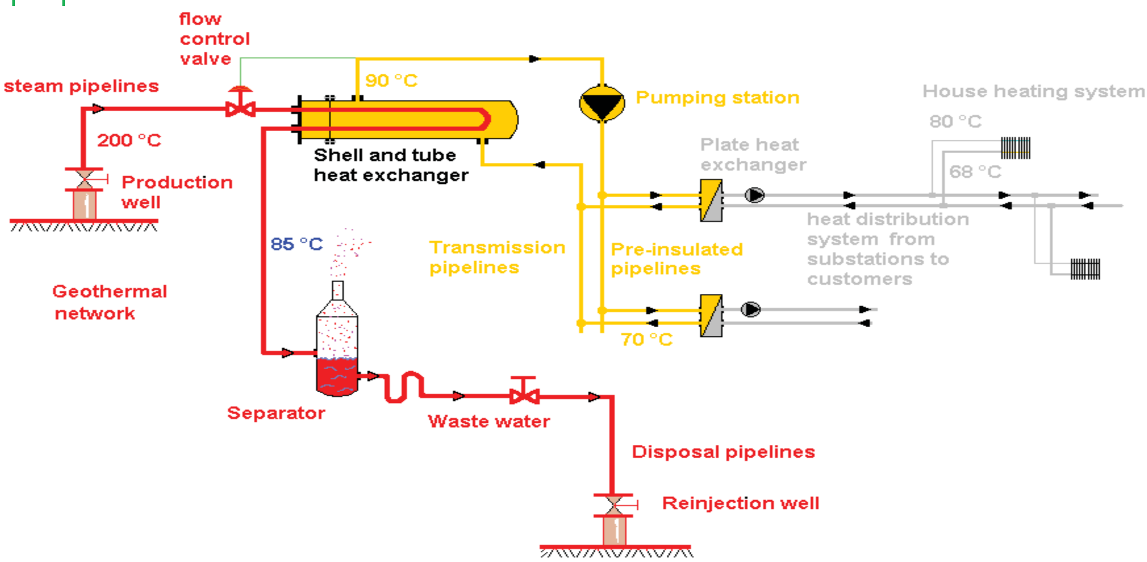

District Heating Scheme

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Cascade Utilizations

Forniture Calore nome	inizio fornitura data	Potenza nominale Gcal/h	tipo di fluido	energia fornita Gcal	energia fornita ktep	quantità di fluido kt	CO_2 evitata t	uso
COMUNE CASTELNUOVO V.C. (capolugo)	01/03/1986	6,24	vap. id.	19.087	1,909	38,17	5.917	Teleriscaldamento
COMUNE CASTELNUOVO V.C. (Montecastelli)	in prova	2,50	vap. id/n.id					Teleriscaldamento
ISOLVER	01/10/1987	0,15	vap. id.	150	0,015	0,30	47	Usi industriali
COMUNE POMARANCE (Ina casa)	01/11/1988	0,62	vap. id.	1.070	0,107	2,14	332	Teleriscaldamento
COSVIG ACQUACOLTURA	17/06/1993	0,64	vap. n. id.	1.368	0,137	2,74	424	Agro Alimentare
SOCIETA' CHIMICA LARDERELLO	01/08/1994	8,50	vap. id.	13.135	1,314	26,27	4.072	Usi industriali
UTENZA PRIVATA	15/10/1994	0,01	vap. id.	12	0,001	0,02	4	Teleriscaldamento
COMUNE POMARANCE (Montecerboli)	01/12/1995	3,00	vap. id.	5.669	0,567	11,34	1.757	Teleriscaldamento
UTENZA PRIVATA	20/03/1998	0,02	vap. id.	40	0,004	0,08	12	Teleriscaldamento
UTENZA PRIVATA	15/02/1999	0,01	vap. id.	20	0,002	0,04	6	Teleriscaldamento
COMUNE POMARANCE (San Dalmazio)	01/12/1999	0,60	vap. n. id.	977	0,098	1,95	303	Teleriscaldamento
LA BORACIFERA S.r.l.	01/09/2001	5,30	vap. id/n.id	3.539	0,354	7,08	1.097	Serricoltura
UTENZA PRIVATA	12/11/2001	0,03	vap. id.	29	0,003	0,06	9	Teleriscaldamento
COMUNE POMARANCE (Capoluogo)	01/01/2003	10,00	vap. id.	15.030	1,503	30,06	4.659	Teleriscaldamento
UTENZA PRIVATA	01/10/2005	0,06	vap. id.	53	0,005	0,11	16	Teleriscaldamento
UTENZA PRIVATA	01/01/2006	0,02	vap. id.	33	0,003	0,07	10	Teleriscaldamento
UTENZA PRIVATA	15/10/2008	0,06	vap. id.	96	0,010	0,19	30	Teleriscaldamento
UTENZA PRIVATA	01/10/2008	0,03	vap. id.	26	0,003	0,05	8	Teleriscaldamento
UTENZA PRIVATA	01/10/2008	0,05	vap. id.	80	0,008	0,16	25	Teleriscaldamento
UTENZA PRIVATA	01/07/2008	0,03	vap. id.	51	0,005	0,10	16	Teleriscaldamento
SEI - TR villaggi aziendali		2,84	vap. id/n.id	4.203	0,420	8,41	1.303	Teleriscaldamento
Totale Age		**40,701**		**64.670**	**6,467**	**129,34**	**20.048**	

Some of the Heat utilizations in Larderello

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Cascade Utilizations

Forniture Calore nome	inizio fornitura data	Potenza nominale Gcal/h	tipo di fluido	energia fornita Gcal	energia fornita ktep	quantità di fluido kt	CO_2 evitata t	uso
UTENZA PRIVATA	15/10/1993	0,01	vap. id.	24	0,002	0,05	7	Teleriscaldamento
COMUNE MONTEROTONDO M.mo	14/10/1994	2,00	vap. id.	9.472	0,947	18,94	2.936	Teleriscaldamento
COMUNE POMARANCE (Lustignano)	07/03/1996	0,60	vap. n. id.	885	0,088	1,77	274	Teleriscaldamento
COMUNE POMARANCE (Serrazzano)	25/03/1996	1,70	vap. id.	2.811	0,281	5,62	871	Teleriscaldamento
COMUNE CASTELNUOVO V.C. (Sasso Pisano)	25/10/1996	2,00	vap. id/n.id	4.377	0,438	8,75	1.357	Teleriscaldamento
LA BORACIFERA S.r.l.	01/09/2001	5,30	vap. id/n.id	5.385	0,539	10,77	1.670	Serricoltura
UTENZA PRIVATA	01/03/2004	0,04	vap. n. id.	401	0,040	0,80	124	Teleriscaldamento
ARCADIA S.r.l.	01/05/2005	0,01	vap. n. id.	10	0,001	0,02	3	Agro Alimentare
SOLEMME S.p.a.	01/06/2005	2,00	vap. id.	-	-	-	-	Teleriscaldamento
UTENZA PRIVATA	01/01/2006	0,04	vap. id.	33	0,003	0,07	10	Teleriscaldamento
UTENZA PRIVATA	01/01/2006	0,03	vap. id.	25	0,003	0,05	8	Teleriscaldamento
UTENZA PRIVATA	29/05/2006	0,02	vap. id.	24	0,002	0,05	7	Teleriscaldamento
Az. Agr. LA GUARDIANA	15/10/2006	1,50	vap. id.	1.489	0,149	2,98	462	Serricoltura
Az. Agr. S. Martino	15/10/2006	0,40	vap. id.	356	0,036	0,71	110	Serricoltura
UTENZA PRIVATA	21/02/2007	0,02	vap. id.	15	0,002	0,03	5	Teleriscaldamento
UTENZA PRIVATA	21/02/2007	0,02	vap. id.	18	0,002	0,04	6	Teleriscaldamento
UTENZA PRIVATA	15/01/2007	0,02	vap. id.	71	0,007	0,14	22	Teleriscaldamento
UTENZA PRIVATA	01/12/2008	0,40	vap. id.	356	0,036	0,71	110	Agro Alimentare
UTENZA PRIVATA	01/01/2006	0,20	vap. id.	51	0,005	0,10	16	Teleriscaldamento
UTENZA PRIVATA	02/01/2009	0,73	vap. id.	121	0,012	0,24	38	Teleriscaldamento
Società Agricola La Guardiana S.r.l.	01/03/2009	3,30	vap. id.	513	0,051	1,03	159	Serricoltura
SEI - TR villaggi aziendali			vap. id/n.id	1.556	0,156	3,11	482	Teleriscaldamento
TOTALE AGE		**20,342**		**27.992**	**2,799**	**55,98**	**8.678**	

Some of the Heat utilizations in Lago

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Cascade Utilizations

Forniture Calore | inizio | Potenza | tipo di fluido | energia fornita | quantità di | CO_2 | uso

Forniture Calore	PROVINCIA	uso	utenze servite n°	utenze servite m^3	Consumo Gcal/anno	Consumo Mwh/anno	risparmio annuo TEP	risparmio annuo CH_4 [m^3]	CO_2 evitata t
COMUNE MONTIERI	GR	TR	300	90.000	5.940	6.907	594	792.000	1.841
COMUNE RADICONDOLI	SI	TR	800	240.000	15.840	18.419	1.584	2.112.000	4.910
COMUNE CHIUSDINO	SI	TR	500	150.000	9.900	11.512	990	1.320.000	3.069
COMUNE MONTEVERDI	PI	TR	800	240.000	15.840	18.419	1.584	2.112.000	4.910
MONTECASTELLI CASTELNUOVO	PI	TR	300	90.000	5.940	6.907	594	792.000	1.841
Totale Estensione			**2.400**	**720.000**	**47.520**	**55.256**	**4.752**	**6.336.000**	**14.731**

Some of the Heat utilizations under construction

ご清聴ありがとうございました。