ENEL Green Power

Industrial Strategy to Contrast the Decline and develop the Larderello System

Kumamoto, 20 November 2019

Davide Pallotta
Project Drilling Manager
Drilling Unit
Geo CoE & Drilling
Overview

- History of Geothermal technology
- Technologies
- EGP Geothermal fields
- What’s Next
Geothermal calendar
From origin to present

Ancient times: heat from Earth used in many parts of the world for settlings, bathing, curiosity, medicinal and cooking purposes.

1777. H.F. Hoefer discovers Boric Acid in the geothermal lagoons of Larderello (Italy)
1818. Chemin/Prat/De Larderel is born to produce boric acid from natural manifestations.
1840. First geothermal well to produce boric acid is drilled in Larderello.

1904. Prince Piero Ginori Conti lightens 5 electric bulbs using vapor. The geothermal epoch begins.
1912. First geothermal power station in Larderello (250 kW).
1928. Iceland started using geothermal heat for domestic heating.
1939. Construction of Larderello 2 (60 MW)
1958. Wairakei field in New Zealand is the second one to use geofluid for commercial purposes.
1970s. World wide grow of geothermal industry: exploration, development, installed capacity (14% per year)
1990s. Heat pumps become commonplace

2017. Production: 84.8 TWh. 14 GW installed (IEA).
Back in 1827 Francesco de Larderel boosted the industrial exploitation of the boron-bearing waters, thanks to the brilliant creation of the “Covered Lagoon”.

The lagoon allowed the utilization of the endogenous heat as heat supplier instead of the usual firewood.
Geothermal calendar

Throughout the nineteenth century the boric acid industry was thriving...

...the search for steam was even led below the ground surface by means of the first rudimentary drillings.

New plants were built; trades had been growing continuously.
In 1904, Prince Piero Ginori Conti foresaw the possibility of producing electric energy from a geothermal source. Coupling a 0.75 horsepower piston engine with a small dynamo, he succeeded in lighting five light bulbs of 5 watts each.

1913, first commercial power plant in the world (250 KWe capacity, fed by pure steam, to let boric acid be produced from natural steam; in 1916, two turboalternators of 3.5 MWe each installed at Larderello, indirect thermodynamic cycle to enable boric acid be extracted from the natural fluid produced.
In 1922 the first geothermal well was drilled in the Geysers (USA).

In 1960 the first commercial group was connected at the Geysers (USA).

In 1958, first synchronizing of Wairakei (NZ) group “A” opens the geothermal development outside Italy.

Olkaria I (Kenya) commercial in 1981.
Geothermal PP

O&M of geothermal PP: tip of the iceberg?

Only a very small part of an iceberg is visible above the water. About ninety % of it is below the surface.

It is difficult to imagine the dimensions of the underwater part from the observation of the emerged part only.
Geothermal development

O&M - GOAL

Integrated O&M management

Field management

Plant management

OPERATION
• Well monitoring
  • Prod. Inj., Obs
• Fluid separation and conduction system (wellheads, gathering)
• Period tests and measurements
• Geoscientific studies
  • Geology
  • Geochemistry
  • Geophysics
  • Hydrogeology

MAINTENANCE
• Maintenance of wells (workover)
• Repair of wells
• Surface facilities

OPERATION
• Steam system
• Water condensation
• Gas extraction
• Turbogenerator and AUX
• Electric system
• Fire safety
• Miscellaneous
• Environmental control

MAINTENANCE
• Routine
• Major
• Corrective
• Improvements
EGP geothermal value chain

Centennial experience (since 1913) in geothermal electricity generation and fluid use

- **Project Development/Finance**
  - Risk evaluation depending on country and technology
  - Transmission System Access
  - Power sales contract negotiation

- **Exploration & Drilling**
  - Best practice in drilling target identification
  - Geological Model and reservoir evaluation
  - Predictive methodology for exploration of deep geo resources

- **Plant design/construction**
  - Well proven concept design in diverse technologies: dry steam, flash and binary
  - Provide an environment of competition in equipment procurement and construction

- **Plant operation**
  - Internal safety and operation procedures systems
  - Optimized geo-resource mgmt for sustainable exploitation
  - In house maintenance and repair capability
  - Remote monitoring and control of power plants portfolio

- **R&D**
  - Low Enthalpy Innovative Geothermal Plants
  - Developing hybrid system
  - Improved efficiency and flexibility
EGP development in Geothermal business
Integrated approach

Drilling Activities
- Skills and equipment for deep deviated drilling
- High temp. logging tools
- Wells stimulation

Optimized field management
- Modeling subsurface environment
- Reinjection

Continuous improvement for excellence

O&M activities
- Plants efficiency improvement
- Fault analysis and predictive approach
- In-house maintenance
Enel Green Power
World geothermal footprint

- Stillwater (USA) 57 MW
- Cove Fort (USA) 30 MW
- Salt Wells (USA) 30 MW
- Larderello (Italy) 795 MW
- Mt. Amiata (Italy) 121 MW
- Cerro Pabellon (Chile) 40 MW
- Way Ratai (Indonesia) Planned 55 MW
ITALY
Italian geothermal footprint

- 37 generating units all equipped with AMIS\(^1\) systems
- More than 500 wells
- 570 km pipelines
- 916 MW net installed capacity
- 5.8 TWh annual production
- 87.3% average load factor
- Direct heat 310 TCal/Y
- 600 people

\(^1\) AMIS is a proprietary technology for H\(_2\)S and Hg emission abatement
Italian geothermal fields
Classification based on fluid characteristics

The different geothermal systems cultivated in Italy can be classified, according to the thermodynamic characteristics of the fluid contained in them, in dominant water and dominant steam systems. The latter can in turn be classified into three distinct clusters according to the degree of fluid overheating.

**Cluster 1 – Shallow fields**
(Larderello, Molinetto, Castelnuovo, Horst, Graben, Serrazzano, Monterotondo, Lago, Lagoni Rossi)

**Cluster 2 – Superheated steam fields**
(Gabbro, Sesta, Selva, Val di Cornia, Monteverdi, Carboli/San Martino)

**Cluster 3 – Saturated steam**
(Radicondoli deep reservoir, Travale/Montieri)

**Cluster 4 – Water dominated fields**
(Bagnore, Piancastagnaio)
# Geothermal fields classification

Thermodynamic characteristics and fluid type

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Shallow fields</td>
<td>365</td>
<td>2246</td>
<td>Depressurized system with H-superheating</td>
<td>1.6 – 7.5</td>
<td>CO2, H2S, HCl (low)</td>
</tr>
<tr>
<td>2 – Superheated steam fields</td>
<td>290</td>
<td>1687</td>
<td>L-M superheating</td>
<td>2.7 – 10.0</td>
<td>CO2, H2S, HCl (high)</td>
</tr>
<tr>
<td>3 – Satured steam fields</td>
<td>140</td>
<td>812</td>
<td>Satured fluid</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>795</strong></td>
<td><strong>4745</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – Water dominated fields</td>
<td>121</td>
<td>1012</td>
<td>-</td>
<td>7.3 – 8.0 (4.7 – 7.2)</td>
<td>CO2, H2S, Hg, Sb</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>121</strong></td>
<td><strong>1012</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The areal extension 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 area

Main characteristics

The explored area is about 250 km2, where 200 wells produce superheated steam at pressure between 2 and 17 bars and temperature ranging from 150° C to 270° C.

The non-condensible gas content ranges from 1 to 10% by weight. The installed capacity is 594.5 MWe as of December 2018, with 22 units in operation.

The deep exploration program showed the presence of permeable layers within the Metamorphic Basement, up to 3,000 – 4,000 m depth, with reservoir pressure and temperature increasing with depth up to 7 MPa and 350° C.
Travale – Radicondoli area

Main characteristics

The explored area covers approximately 50 km²; 38 wells produce superheated steam at pressure ranging from 8 to 20 bars and temperature of 190-250°C. The non-condensible gas content is in the range of 5 – 6.5% by weight. The installed capacity is 200 MWe with 8 units in operation.

40Km of pipelines in 200 branches: increasing performance with simulation
Production sustainability in Italy
Improvement to power plants efficiency

37 new units with a range capacity of 8 - 60 MW began operation in the Larderello-Travale area between 1979 - 2005

12 new units (314.5 MW) were installed and began operation between 2000 - 2005 in the Larderello-Travale/Radicondoli area

8 units, for a total of 214.5 MW, replaced old units that were in operation for many years and considered to be “obsolete”. The new units are characterized by higher efficiency and lower environmental impact.

In the period 2016 - 2018 a total of 27 geothermal wells were drilled in Italy, for a total drilled depth of 46.5 km. Fifteen are make-up wells drilled in Larderello (10) and Travale-Radicondoli (5) fields and they are relevant to the maintenance program.
Geothermal resource management

Injection strategy in a steam dominated system

It consists in the partial reintegration of the mass extracted from the geothermal system by water injection that evaporates by subtracting heat from the rocks. Characteristic parameters are evaporation efficiency and response time.

Advantages

It is a valuable tool for the heat extraction from the rocks;
It helps to reduce the natural decline of the system by reducing the “net” extracted mass from the reservoir;
It helps to reduce the chloride content and gas/steam ratio (with a considerable saving of energy necessary to power plant compressors).

Disadvantages

Possible reduction of the geothermal system temperature (favorites areas with high degree of overheating);
Possible problems of interference ("break throgh") between production and injection wells (required careful management of the injected flow rate is neede);

High permeability and low porosity zones are.
The intensive cultivation of the Valle Secolo area (Larderello) has gradually decreased the amount of fluid in the reservoir. This is evidenced by a rapid decline of reservoir pressure and consequent reduction of extracted steam flow rate.

Favorable conditions for the re-injection:

- Presence of a high-productivity areas (high permeability);
- Rapid decline of reservoir pressure and steam flow rate (lower layer of pressure: 0.5-0.8 MPa);
- Vast accumulation of thermal energy inside the reservoir rocks (high temperature: 230-250°C)
The injection strategy has increased the production of steam of approximately 150 kg/s of fluid in the Valle Secolo area, corresponding to about 60 MW.

The long injection period did not substantially modify the temperature of the fluid product.
Geothermal resource management

The reinjection is a valuable tool to extract heat from the reservoir rocks and to reduce flow rate decline due to resource cultivation.

The evaporation of the injected water produces additional steam free of dissolved gases. It allows a reduction in the gas content of total flow rate, with a considerable saving of the energy for power plant compressor.
A secondary effect of reinjection in Larderello is the NCG/steam ratio decrease together with HCl decrease.

Reinjected water is mainly steam condensate from the process itself.

Once in the reservoir it boils generating GAS FREE secondary steam ENHANCING PP performance (lower parasitic consumptions, emissions and corrosion)
Italian fields
AMIS process

AMIS
stands for «Abbattimento Mercurio e Idrogeno Solforato»
Mercury and hydrogen sulfides abatement system

It is a patented process developed by ENEL

➢ To abat Mercury emissions from the plumes
➢ Transform H2S to SO2
➢ Absorb SO2 in liquid phase (reinjected)
➢ Drives H2S dissolved in the liquid toward the gaseous phase
**Italian fields**

**AMIS process**

**Performances (abatement)**

- Hg → >90%
- H₂S → 70-80%

**Simplified schematics**
The presence of Cl⁻ in the steam in quantities from a few mg/kg to hundreds of mg/l constitutes a criticality for the management of the fluid and of the operation.

In the presence of cold points (piping, well, etc.) the steam can reach the dew point, thus condensing. Since the distribution coefficient of the Cl is in favor of the liquid, the Cl enters the formed drop making it extremely acidic (pH <3) and aggressive for the surface equipment.

The solution consists in "washing" the steam with a basic solution (NaOH) to neutralize the acid. Washing is carried out either in the well or on the surface according to the framework of the system and taking into account the superheating degree of the steam.
Corrosion effect in Larderello

Criticalities in O&M

20 cm cut

hole
Larderello field
Scaling issues

- Calcite deposition in Larderello occurs where a liquid phase enriched in Ca enters in the producing wells from shallow aquifer not isolated by casings.
- Heating and drying of these solutions in the pipes and wells brings to scale.
- Treatment is made by HCl to dissolve the scale (when possible).
- Possible effects: plugging of surface equipment, lost of production.
WHAT’S NEXT
Geothermal development

About 25 different projects for Innovation in Geothermal energy within EGP (including EU Horizon 2020 projects)

- Supercritical resources
- Drilling efficiency & new tools/materials for HT/HP enviroment
- NCGs emission reduction/water consumption reduction
- Advanced remote diagnostic and prognostic for O&M
- Alternative uses of geothermal fluids (e.g. algae production)
- Improve reservoir characterization techniques
- Scaling/corrosion
Cornia project

Description:
Cornia 2 is a revamped geothermal power plant with a biomass fired boiler. By allowing superheating of geo steam with a 5MWe increase of power output and an overall improvement of plant efficiency.

Technology: hybrid Geo-Biomass plant
Installed capacity: 5 MWe
Location: Castelnuovo Val di Cecina (Pisa)
In operation since September 2015
Geothermal development

Geothermal energy can operate in hybrid mode with other renewable energy sources (PV, CSP, Biomass and biofuels) with an overall increase in total energy conversion factor;

Cornia-2 (Italy) a hybrid GEO-Biomass PP

Stillwater (US) combines GEO-PV-CSP PP

Breakthroughs in all the technological and cross-cutting innovation themes

Reducing costs and increase performance of geothermal technologies and installations.
Geothermal development

Steam

Cooled water

Reinjection well
THANKS FOR YOUR ATTENTION
DESCRAMBLE: Drilling in dEep Super-CRitical AMBient of continental Europe

Drilling activities and lessons learnt
Timeline

28th Apr 2017
SPUD

21st Jun 2017
End of 12"1/4 drilling phase at the depth of 2470 m

30th Jun 2017
Run in hole 9"5/8 surface casing: shoes 983 m

30th Jun 2017
Run in hole 7" deep liner: shoes 2601 m and hanger 2300 m

1st Sep 2017
End of remedial job

30th Sep 2017
Preparing of sepiolitic mud and installation of MPD

23th Oct 2017
Replacement of mud with water

23th Nov 2017
End of drilling activities and execution of final log

Apr 2017
May 2017
June 2017
July 2017
August 2017
September 2017
October 2017
November 2017
Dec 2017

20th May 2017
Clogged well with inert material and start new branch at 1054 m

25th Jun 2017
Run in hole 9"5/8 liner: shoes 2468 m and hanger 993 m

24th Jul 2017
End of 8"1/2 phase at the depth of 2600 m and coring

4th Aug 2017
Stop of cement job of intermediate liner due to a fire

19th Sep 2017
Test of API 10000 BOP end start of 6" phase

22th Oct 2017
Total loss of circulation at depth of 2708 m and stuck pipe

10th Nov 2017
Clogging activity with special additive

11th Dec 2017
End of temporary closing of the well
Drilling RIG

- Massarenti 6000;
- 1700 HP Drum power;
- 350 t max hook load;
- 2 triplex pump;
- 4000 kW of GE power installed.
Work on Venelle 2 starts with clogging original branch with inert material;

Log executed during the clogging shows an absorption at 1190 m;

Top of inerts: 1135 m;

Over the inert has been executed a cement plug using cement retainer;

Cement plug is need for starting with directional drilling with 12”1/4 rock bit.
DESCRAMBLE
Start new branch

- KOP of the new branch at 1054 m;
- Direction was controlled with Mud motor and MWD (Measure while drilling);
- Target → restore verticality under well head from original inclination.
During drilling activities, well data are monitored and elaborated by a mud logging service with the following characteristic:

- Real time data recording and transmission (ROP, Pit volume, Flow in/out, weight on bit, ecc);
- First cuttings analysis;
- Gas detection in air (Explosive mixture, H2S, CO2);
- Gas analysis in mud (CO2, H2, H2S, He, Ar, O2, N2);
- Execution of daily drilling report;
- Execution of master log;
- First drilling data analysis;
The 12” 1/4 drilling phase ended at a depth of 2470 m;

A casing 9 5/8” was run in the hole and cemented in 2 stages up to the surface.

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Depth</th>
<th>Steel</th>
<th>Weight</th>
<th>Thickness</th>
<th>Drift</th>
<th>Thread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner</td>
<td>993 m - 2468 m</td>
<td>L80</td>
<td>43.5 #</td>
<td>11.05 mm</td>
<td>API</td>
<td>TSH ER</td>
</tr>
<tr>
<td>Surf csg</td>
<td>0 m - 983 m</td>
<td>L80</td>
<td>43.5 #</td>
<td>11.05 mm</td>
<td>API</td>
<td>TSH ER</td>
</tr>
</tbody>
</table>
The cooling system was installed before the cementing job of CSG 9 5/8".
DESCRAMBLE
1° Leak Off Test (Retrivable Packer at 1873 m)

After running in hole of casing column 9 5/8” (2500 m of BH), Leak Off Test has been performed.
A drilling fluid was selected water based mud with SEPIOLITE and MICRODENSE (Ilmenite) used as weighting and auto-suspending material with following challenges:

- **Maintaining of the rheological characteristics** in high temperature and pressure environment;
- **High evaporation of fluid system** that brought of continuous dilution;
- **Products degradation** for the temperature;
- **Losses in formation** minimized by utilization of property system (X-Prima system);
- **Presence of gas** ($\text{H}_2\text{S}$ and $\text{CO}_2$) that determine the use of scavenger.
Prior to set the new casing 7”, at 2585 m was set a swallable packer for open hole to perform another LOT for the bottom hole 2601 m.

LOT = 214 bar, Mud Density = 1.15 kg/l

Fracture pressure = 513 bar
DESCRAMBLE
7” Casing Sour Service

- Casing equipment had to resist to the expected high temperature and high pressure, and corrosive environment with presence of $\text{H}_2\text{S}$ and $\text{CO}_2$.
Cementing job failure

- During cementing job of intermediate liner, float valves failed (fig.1);

- This failure produce a reverse flow inside the column, and a drop in cement level into interspace between 7” and 9”5/8;

- In fig. 2 is possible to see the final situation after the transient, with the cement level balanced inside and outside the column;

- In this configuration upper part of column and hanger weren’t cemented.
In this figure is schematize the cement situation:

- From 2300 m to 1460 m: good cementing;
- From 1460 m to 1240 m: poor cementing;
- From 1240 m to 1150 m: bad cementing;
- From 1150 m to 950 m: free pipe.

This situation not guarantee mechanical and hydraulic resistance of producing casing, and so a remedial job has been needed.
Remedial job

- First part of remedial consist of cutting casing at lower part of free pipe using casing cutters (fig.1);
- The part of column cutted shall pulled out from the hole by a grapple called releasing spear (fig.2).
- First cut has been performed at 1205 m and fishing has been completed successfully.
During second cut at 1407 m, releasing spear has broken away and a stop collar is lost in hole;

After some round trip stop collar has been fished using a taper tap.
Because the second part of the column has not fished, the second part of the job consist of milling casing from 1205 m (first cut) to 1407 m (second cut)
### Final well profile

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Depth</th>
<th>Steel</th>
<th>Weight</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Liner</td>
<td>2300 m - 2601 m</td>
<td>T95</td>
<td>29 #</td>
<td>11.05 mm</td>
</tr>
<tr>
<td>Int Liner</td>
<td>1409 m - 2300 m</td>
<td>T95</td>
<td>29 #</td>
<td>11.05 mm</td>
</tr>
<tr>
<td>Suf csg</td>
<td>0 - 1407 m</td>
<td>TN125SS</td>
<td>32 #</td>
<td>11.51 mm</td>
</tr>
</tbody>
</table>
The critical aspects of the last drilling phase were constituted by high temperature above 450 °C and high pressure above 450 bar expected.
Menaged Pressure Drilling

- The most important parts of MDP system are the RCD (Rotating Circulation Device) and the automatic choke valve with Coriolis’s flow meter;
- The flow meter can detect all the minimum difference between flow in and flow out, and in case of differences the MPD’s system controls choke valves and regulates the Surface Back Pressure;
- In case of complete well shut in by the use of the BOP, the traditional Driller’s Method could be applied;
DESCRAMBLE

MPD Well Control Response Strategy

Drill Ahead

Influx detected

SBP increase automatically until flow in = flow out

Ramp down drilling pump while MPD increases SBP to compensate

Well is shut in on MPD choke

ENEL Well Control Procedure

ENEL to calculate BHP and Kill Weight Mud.
In the 6” phase, working with 3 ½ DPs, the circulation flow rate was low, causing a very high working temperature at bottom hole.

In such conditions, the risk to damage the elastomer, part of the bearings of the standard tricone bits increased significantly.

Then was used 6” full stinger rock bit;

This particular RB has allowed to obtain great performance in drilling phase, characterized by high ROP and low wear of the tool.
Stuck Pipe Problems

- At the increase of temperature, the mud rheological characteristics changed, increasing viscosity and decantation;
- Consequence of pumping problems from 2695 m;
- To resolve stuck pipe was decrease mud density and use synthetic polyelectrolyte able to remove bentonite cake (REOTAN).
At 2709 m a temporary total loss of circulation had occurred;

After this event another stuck pipe occurred and from this point the high permeability of the formation make impossible to continue drilling with mud;

To increase formation resistance a lot of squeeze with clogging materials has been performed.
➢ To continue drilling operation it has been needed to switch from mud to clean water, with the purpose to decrease hydrostatic pressure;

➢ Up to 2700 m, drilling is characterized by high ROP;

➢ Due to the impossibility to carry on the drilling of the K horizon in safe condition, it was decided to deep the well in control condition at the maximum depth possible;

➢ To carry on drilling activity was applied a new procedure and evaluated the residual risk, that was considered acceptable.
Drilling Procedures

Monitoring ROP, D-Exponent, Drilling Gas

Parameters are constant?

YES
- Formation has not changed
- We are in seismic reflector H
- Max fracture pressure lower than 300 bar

NO
- Stop Drilling
- Close the well and monitoring SIDPP and SICP
- Circulate bottom hole
Final activities

- Last part of the project has been characterized by execution of a lot of physical tests:
  - Coring from 2830 to 2839 m full recovered;
  - Coring from 2900 to 2909 m full recovered;
  - Temperature log using Kuster;
  - Temperature log using SINTEF;
  - Temperature indirect evaluation with synthetic fluid inclusions.

- The final LOT has not been executed because the 6” swellable packer after its test not guarantee the hydraulic sealing.
Temporary Mining Plugging

At the end of activities the well has been put in safe condition temporary plugging

Alternate cement plug with weight mud layer

Total Depth @ 2909 m