GE OIL&GAS
PRODUCTS AND SERVICES FOR GEOTHERMAL POWER GENERATION

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ABSTRACT

Geothermal resources are evenly distributed around the world. Depending on the temperature of the fluid, they can be exploited for power generation using different technologies. Low temperature resources in particular are expected to be developed in future representing a relevant market segment. African and Asian countries show the highest potential to sustain this future growth. GE continues to invest in the development of innovative technologies for this sector of the power generation industry. This paper provides geothermal players with an overview of the main equipment and technologies GE can offer to maximize profitability and sustainability of their operations.

1. GEOTHERMAL POWER AN OVERVIEW

1.1 Rationale for geothermal energy

There is a pressing need to accelerate the development of advanced energy technologies in order to mitigate climate change through the generation of sustainable development. At the 2015 United Nations Climate Change Conference, COP 21, member countries have recently restate the objective to reduce their carbon output.

Geothermal technologies represent a credible answer to these needs using renewable energy resources to generate electricity while producing very low levels of emissions.

According to (Geothermal Energy Association, 2015) the global geothermal industry is expected to reach between 27 GW by 2020 and 30 GW by the early 2030s.

Thermal energy generated from the Earth, can offer enormous potential and benefits over conventional sources:

- **No fuel required**
  It is therefore immune to fuel cost fluctuations in a period of significant price volatility.

- **Low environmental impact**
  It has potentially zero emissions using closed ORC power cycles with minimal global warming potential.

- **Low investment cost**
  Geothermal plants show lower CAPEX when comparing with others renewable energy plants. Capital cost for low depth conventional resources can be as low as 1 million USD per MWe against the 16 million per MWe of a high cost tidal project.

- **Base load capability**
Geothermal power output can typically provide base-load generation, since it is immune from weather effects or seasonal variations.

- **High reliability**
  It can be run at constant rate for long periods of time with a capacity factors up to 95% for new geothermal power plants.

- **Low LCOE**
  Levelized cost of electricity represents the per-kWh cost of building and operating a generating plant over an assumed financial life and duty cycle. In literature, geothermal energy shows the lowest LCOE value of 48 $/MWh to be compared with 142 $/MWh of a conventional combustion turbine (Administration, U.S. Energy Information, 2015).

1.2 **Market potential**

The geothermal market is expected to continue its growth in the next future at a rate equal or higher than the current 5% reaching 17.6 GW by 2020 (Geothermal Energy Association, 2015). Moreover exploitation of geothermal energy has been so far concentrated in areas of naturally occurring water or steam sources. However, the vast majority of geothermal energy is located in relatively dry and low-permeability rock.

Engineered Geothermal Systems (EGS) is expected to boost geothermal energy production and to cost effectively produce large amounts of electricity almost anywhere in the world by tapping into the earth’s deep geothermal resources that are otherwise not exploitable due to lack of water and fractures.

Currently flash and dry steam technologies continue to be the more prevalent. Flash technologies, including double and triple flash, make up a little less than two thirds of the global market (58%), while dry steam is about a quarter (26%) and binary is the remaining (15%) (European Commission Joint Research Centre, 2015).

The portion of ORC technology with respect to the global geothermal market is expected to significantly increase in future as binary cycles are able to use low to medium-temperature resources, which are the most prevalent ones.

2. **GE GEOTHERMAL SOLUTIONS**

GE can provide solution to exploit the entire range of geothermal resources ranging from low temperature resources below 100 °C, to medium and high-enthalpy resources with temperature between 100-180 °C and above 180 °C, respectively. Depending on the resource characteristics, GE can provide equipment’s and engineering capability for all the possible geothermal power plants configurations:
• **Direct dry steam**
  They are used in conjunction with high enthalpy vapour-dominated resources. Dry steam power plants have the highest efficiency among all geothermal power plants, reaching values of 50-70%. They are commercially proven, simple to operate and require relatively low capital costs (DiPippo, 2012).

• **Single and dual flash cycles**
  Flash steam power plants are the most common type of geothermal power plants, making up about two thirds of geothermal installed capacity. The flash steam technology makes use of liquid-dominated hydrothermal resources with medium to high enthalpy. The single-flash and dual-flash power plants reach efficiencies between 35–45% (DiPippo, 2012).

• **Binary cycles**
  Binary cycle power plants, employing organic Rankine cycle (ORC) operate at lower water temperatures of about 75-180 °C using the heat from the hot water to boil a working fluid, usually an organic compound with a low boiling point. The ORC can reach efficiencies around 25% (DiPippo, 2012).

Current GE product portfolio and technological capability can support engineering, commissioning and operating of these power plants providing the following services and equipments:

• Steam Turbines
• Turboexpanders
• Pumps, Compressors
• Air Cooled Condensers
• Balance of Plant and full EPC Services
• Electric generators
• Trainings & Maintenance Services
• Diagnostics & Operation support
• Financing Solutions

### 2.1 Steam Turbines

GE offers a complete range of Industrial Steam Turbines to meet the most challenging requirements of the Oil & Gas and Power Generation Industries.

The GE Steam Turbine product line includes both impulse and reaction technology. Every steam path is optimized for the specific thermal cycle requirements to provide high efficiency over the entire operating range.
GE geothermal steam Turbines have a unique design to withstand direct geothermal steam conditions (saturated or slightly superheated steam, presence of corrosive contaminants, low pressure). The special inlet section has a large volumetric flow capability. Partial arc of admission control permits maintenance of full turbine capacity with time varying well production.

Butterfly type valves, generally installed on admission piping, provide normal control. The shaft material is a high alloy steel, selected to limit corrosion. Low pressure stages have a special stellite coating to limit erosion by water droplets. The unshrouded configuration of these stages avoids erosion of shrouds and permits water film slippage along stators.

For particularly aggressive steam compositions, special materials are available for the blades located within the dew point region. Special features are also employed to avoid the formation of deposits inside the sealing labyrinths.

GE currently has in its portfolio 2 families of geothermal steam turbines the SG and GST series:

The **SG/SDFG Series** is API 612 compliant and can be used in a variety of industrial applications thanks to its flexibility. It is characterized by scalability and is available in different sizes and can be tailored to the customer needs can be configured in single or double flow configuration in the same shell for condensing or back pressure applications.

<table>
<thead>
<tr>
<th>Specification</th>
<th>SG/SDFG Series</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated power output:</strong></td>
<td>5-50 MW, 50/60 HZ</td>
</tr>
<tr>
<td><strong>Inlet pressure:</strong></td>
<td>up to 30 bar</td>
</tr>
<tr>
<td><strong>Inlet temperature:</strong></td>
<td>up to 300°C</td>
</tr>
<tr>
<td><strong>Speed:</strong></td>
<td>3,000 / 3,600 rpm</td>
</tr>
<tr>
<td><strong>Blading type:</strong></td>
<td>Reaction w/ optional impulse control stage</td>
</tr>
<tr>
<td><strong>Inlet configuration:</strong></td>
<td>Twin scroll with partial admission valves</td>
</tr>
<tr>
<td><strong>Rotor:</strong></td>
<td>One piece forging</td>
</tr>
</tbody>
</table>

![Figure 2 SG Series steam turbine](image1)

The **GST Series** is characterized by simple and compact design together with good efficiency tanks to a high performance steam path design. An advanced moisture removal system allows long maintenance intervals.

<table>
<thead>
<tr>
<th>Specification</th>
<th>GST Series</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated power output:</strong></td>
<td>20-30 MW 60HZ</td>
</tr>
<tr>
<td></td>
<td>40-55 MW 50 HZ</td>
</tr>
<tr>
<td><strong>Inlet pressure:</strong></td>
<td>Up to 10 bar</td>
</tr>
<tr>
<td><strong>Inlet temperature:</strong></td>
<td>Up to 300°C</td>
</tr>
<tr>
<td><strong>Speed:</strong></td>
<td>3,000 / 3,600 rpm</td>
</tr>
<tr>
<td><strong>Blading type:</strong></td>
<td>High performance full 3D pre-twisted impulse blading with integral shrouds</td>
</tr>
<tr>
<td><strong>Inlet configuration:</strong></td>
<td>Twin scroll with 100% admission</td>
</tr>
<tr>
<td><strong>Rotor:</strong></td>
<td>One piece forging</td>
</tr>
</tbody>
</table>

![Figure 3 GTS Series steam turbine](image2)

GE Oil&Gas has more than 700 steam turbines references in mechanical drives and 250 in power generations. A summary of the main geothermal ones is available in the following table:
Table 4 GE Geothermal steam turbines references

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Plant Location</th>
<th>Plant Type</th>
<th>Speed RPM</th>
<th>Power MW</th>
<th>Inlet Press. Bar-a</th>
<th>Inlet Temp. °C</th>
<th>Exhaust Press. Bar-a</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>SGD4-23</td>
<td>ITALY</td>
<td>Dry Steam</td>
<td>3000</td>
<td>2</td>
<td>120</td>
<td>0.061</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>SGD4-23</td>
<td>ITALY</td>
<td>Dry Steam</td>
<td>3000</td>
<td>20</td>
<td>2</td>
<td>159</td>
<td>0.075</td>
</tr>
<tr>
<td>2000</td>
<td>SGD4-26</td>
<td>ITALY</td>
<td>Single Flash</td>
<td>3000</td>
<td>40</td>
<td>8</td>
<td>200</td>
<td>0.085</td>
</tr>
<tr>
<td>2000</td>
<td>SGD4-23</td>
<td>ITALY</td>
<td>Dry Steam</td>
<td>3000</td>
<td>20</td>
<td>6</td>
<td>190</td>
<td>0.065</td>
</tr>
<tr>
<td>2000</td>
<td>SGD4-23</td>
<td>ITALY</td>
<td>Dry Steam</td>
<td>3000</td>
<td>10</td>
<td>2</td>
<td>120</td>
<td>0.065</td>
</tr>
<tr>
<td>2001</td>
<td>SGD4-26</td>
<td>ITALY</td>
<td>Single Flash</td>
<td>3000</td>
<td>40</td>
<td>8</td>
<td>200</td>
<td>0.085</td>
</tr>
<tr>
<td>2003</td>
<td>SGD4-26</td>
<td>ITALY</td>
<td>Dry Steam</td>
<td>3000</td>
<td>40</td>
<td>8</td>
<td>170</td>
<td>0.064</td>
</tr>
<tr>
<td>2004</td>
<td>SGD4-22</td>
<td>EL SALVADOR</td>
<td>Single Flash</td>
<td>3000</td>
<td>5</td>
<td>9.5</td>
<td>177</td>
<td>0.065</td>
</tr>
<tr>
<td>2009</td>
<td>GST</td>
<td>MEXICO</td>
<td>Dry Steam</td>
<td>3000</td>
<td>25</td>
<td>8</td>
<td>170</td>
<td>0.08</td>
</tr>
<tr>
<td>2009</td>
<td>GST</td>
<td>MEXICO</td>
<td>Dry Steam</td>
<td>3000</td>
<td>25</td>
<td>8</td>
<td>170</td>
<td>0.08</td>
</tr>
<tr>
<td>2013</td>
<td>GST</td>
<td>MEXICO</td>
<td>Dry Steam</td>
<td>3000</td>
<td>27</td>
<td>8</td>
<td>170</td>
<td>0.08</td>
</tr>
<tr>
<td>2015</td>
<td>GST</td>
<td>INDONESIA</td>
<td>Single Flash</td>
<td>3000</td>
<td>33</td>
<td>6.5</td>
<td>162</td>
<td>0.1</td>
</tr>
</tbody>
</table>

2.2 Turboexpanders

Turboexpanders and generators can represent up to the 37% of CAPEX for an ORC geothermal project.

GE has an extensive experience protected by more than 120 patents into designing and producing turboexpanders for any possible services, including generator drive applications, compressor drive applications and dynos.

Radial expanders offer a series of advantages in power generation up to 15 MW over the axial turbines:

- High enthalpy drop per stage (one stage radial equivalent to 2-3 axial stages)
- Higher resistance to liquid and hard particle erosion
- Robustness to thermal transients
- Higher efficiency on application characterized by lower specific speed
- Machinery simplicity
- Effectiveness of sealing system
- Forged casing obtaining more robustness and higher flanges loads
- Hirth impeller connection, max reliability and mini material stress

Moreover GE turboexpanders are resistant to aggressive environments including hydrocarbons mixtures, refrigerants, Air, N2, H2, NH3, H2O steam, Organic fluid, sour/acid gas and other industrial gases.

The turboexpanders product line is standardized and casing, bearing housing, bearings are usually pre-designed in terms of frames and ratings. The ratings are function of the material selected for the component, operating temperature and pressure.
More in details, the GE expanders are currently able to withstand a maximum temperature of 315 °C in fixed IGV configuration, pressures up to 200 bars and a maximum content of liquid of 35% in weight. The speed range varies for different applications from 3000 to 120000 RPM with pressure ratios up to 14.

During the last decade, extensive improvement programs have been carried out on expanders, enabling GE to guarantee 4-5 years of uninterrupted run time decreasing the overall plant maintenance costs.

Moreover, a patented, Inlet Guide Vane (IGV) controls the turboexpander gas flow in order to maintain high efficiency over a wide range of process conditions. Key benefits of the IGV control assembly are the elimination of blow-by, which reduces efficiency.

In addition, GE turboexpanders dynamically balanced center section can be easily replaced or disassembled for inspection by operating personnel. This allows our customers to purchase a spare mechanical centre section instead of an entire spare machine.

Global Service support for these machines is available 24 hours a day, every day of the year, from local facilities with experienced service personnel supported by Remote Monitoring and Diagnostics. Contractual Service Agreements allow the customer to ensure future performance at a fixed cost.

GE has several references, having installed more than 200 external gear turboexpander-generators up to 50 MW for hydrocarbon processing and refrigeration applications worldwide. GE has also installed more than 100 turboexpanders with integral gear and generators up to 7.5 MW eliminating the requirement for high-speed coupling. A summary of the GE geothermal turboexpanders references is available in the table below:

<table>
<thead>
<tr>
<th>Frame</th>
<th>Shaft power (kW)</th>
<th>Expander outlet flow (m³/h)</th>
<th>Available casing ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1,600</td>
<td>4,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>25</td>
<td>2,000</td>
<td>5,500</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>30</td>
<td>4,800</td>
<td>9,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>40</td>
<td>6,500</td>
<td>16,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>50</td>
<td>10,000</td>
<td>25,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>60</td>
<td>15,000</td>
<td>36,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>80</td>
<td>20,000</td>
<td>45,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>100</td>
<td>25,000</td>
<td>70,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>130</td>
<td>30,000</td>
<td>100,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>160</td>
<td>40,000</td>
<td>150,000</td>
<td>150 300 600 900 1500</td>
</tr>
<tr>
<td>180</td>
<td>45,000</td>
<td>200,000</td>
<td>150 300 600 900 1500</td>
</tr>
</tbody>
</table>

Table 6 GE Turboexpanders available frames

Table 7 GE Geothermal turboexpanders references
2.3 Organic Rankine Cycle power systems

In ORC plants, geothermal fluid is usually pumped from production well to a heat exchanger train before it is pumped back into injection wells. In the evaporator a preheated working fluid coming from a pre-heater is evaporated prior to entering a turboexpander unit. The working fluid is condensed in a condenser and pumped back to the heat exchanger train in a closed loop. Cooling water is pumped from a cooling tower towards the condenser and make-up water is pumped into the cooling tower to compensate for losses by evaporation. As an alternative, an air cooled condenser can be used.

An ORC plant offers several advantages over conventional steam cycles:

- Easy operability also in remote controlled and unmanned plants.
- Closed loop with zero emissions in the atmosphere.
- No need to superheat the vapour before the turbine inlet as consequence of the favourable saturated vapour curve.
- Due to the low boiling point of the working fluid, heat can be recovered at much lower temperature than using steam.
- ORC cycles have higher process fluid density and therefore lower volume flow when compared to steam allowing for more compact plant machineries.
- ORC cycles enable the use of once-through boilers, which avoids steam drums and recirculation.
- Low temperature organic have condensing pressure higher than atmosphere avoid air infiltration in the cycle.
- ORC cycles have lower enthalpy drop then steam, and single or two-stage turbines are usually employed.

In summary, the ORC cycle is more interesting in the low to medium power range (typically less than a few MWe). For high power ranges, the steam cycle is generally preferred, except for low temperature heat sources.

**ORegen™** is the GE Organic Rankine Cycle solution currently available for power range between 5 and 17 MW designed to recover waste heat from gas turbines or similar sources (geothermal). It uses regeneration between expander exit flow and heat recovery unit inlet in order to increase thermal efficiency. It is currently available for power generation or mechanical drive applications using subcritical Cyclopentane as working fluid and with air condensing capability. A diathermic oil loop is used to transfer heat from the waste heat recovery unit to the power generation loop in order to maximize fire safety and increase the flexibility in the plant arrangement.

**MINI ORC** is the solution complementary to OREGEN for 2 MW size range. It is based on the same cycle architecture and it has been optimized for low grade heat sources. The technology is delivered in a modular approach with all items mounted on skids with a total footprint area of 15m x 15m.
GE can adapt its ORC power systems to the specific needs of the customer in terms of produced power ambient conditions and temperature of the geothermal resource.

2.4 Centrifugal pumps

GE has a 50-year history in manufacturing a wide range of centrifugal pumps for hydrocarbon processing, refineries, water injection and pipeline services with over 18,000 pumps installed.

Pumps can represent a significant portion of a geothermal plant in particular in case of EGS where high pressure pumping systems are required to stimulate the reservoir in addition to normal water reinjection. Multi stage axially split and multi stage radially in the GE portfolio are particularly suitable for this kind of service.

In particular, DDHF BB5 pumps are designed for the most demanding onshore and offshore water and C02 injection applications processing 800 m\(^3\)/h up to a pressure of 255 bar with a total power of 6.3 MW.

Another pump model successfully employed for water injection services is the MSN BB3. This pump can process 320m3/h of water with high H2S content up to 350 bar with a power of 2.2 MW.

These machines are produced with impeller diameters between 250 and 385 mm and five standard frames of: 4x11, 6x11, 6x12, 8x15 and 10x16.

In addition, C02 pumps technology currently under development within GE might be of interest for applications in combined carbon sequestration and energy production geothermal plant. C02 pumps for injection in reservoir with pressure up to 550 bar with a flow of 1500 m3/h at 430 °C in liquid and supercritical phases are currently under development within GE based on the BB5 type multistage barrel pump.
GE also owns a Pumps Centre of Excellence in Bari, Italy, including comprehensive testing facilities, with a model test laboratory to accurately characterize new hydraulics. Expert in-field maintenance and repair services can use advanced remote monitoring capabilities to improve operating efficiency and avoid unplanned downtime.

2.5 Electric submersible pumps

GE can also provide electrical submersible pumps (ESP) for geothermal applications to produce fluid in both low-and high-volume. They consist of rotating impellers and stationary diffusers that can be assembled in either floater or compression configurations to meet the most demanding performance requirements.

These ESPs are also equipped with wide vane openings to improve performance in viscous fluids and can use Tungsten Carbide Bearings to reduce the effects of sand and abrasive wear. They can produce anywhere from 150-50,000 barrels of fluid a day (BPD) operating in high-temperature environments (up to 230°C bottom hole) including Geothermal.

Available in radial-flow and mixed-flow designs, these pumps provide some of the highest efficiency and head-per-stage ratings in their pump class range.

<table>
<thead>
<tr>
<th>Series</th>
<th>338 Series</th>
<th>400 Series</th>
<th>500 Series</th>
<th>675 Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA 400</td>
<td>TD 150 to TD 6000</td>
<td>TE 1500 to TE 11000</td>
<td>TJ 7000 to TJ 20000</td>
<td></td>
</tr>
<tr>
<td>4.50 inches</td>
<td>5.00 inches</td>
<td>7.00 inches</td>
<td>8.00 inches</td>
<td></td>
</tr>
<tr>
<td>3.50 inches</td>
<td>6.00 inches</td>
<td>9.00 inches</td>
<td>12.00 inches</td>
<td></td>
</tr>
</tbody>
</table>

Table 14 GE Electric Submersible Pumps

2.6 Reciprocating compressors

For EGS operation where very high injection pressures are required GE can provide also reciprocating compressors with flexible modular designs for long-term reliability and minimized costs.

GE’s API618 compressors are renowned for low pulsation and vibrations that translates directly to exceptional efficiency, smooth operation, low maintenance and low power consumption. GE proven modular design allows for 1 to 10 cylinders on a single frame, with a cylinder size of up to 1,250 mm. Machines range from 100 kW to 41 MW, with pressure capabilities up to 800 bar and designs optimized for each application.
At the same time the full line of API 11P high-speed reciprocating compressors, ranging from 45 kW to 6,714 kW, provide economic, flexible and modular solutions. These machines are designed to be directly connected to reciprocating natural gas engines and electric motors.

Over 15,000 GE compressors can be found around the globe, working in gas lift, gas boost, reinjection and vapor recovery applications.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Of Throws</td>
<td>1-2</td>
<td>1-2-4</td>
<td>2-4</td>
<td>1-2-4</td>
<td>2-4</td>
<td>2-4</td>
<td>2-4</td>
<td>2-4</td>
<td>2-4-6</td>
<td>2-4-6</td>
<td>2-4-6</td>
</tr>
<tr>
<td>Stroke (Inches)</td>
<td>3</td>
<td>3</td>
<td>3.5</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Max. Speed (RPM)</td>
<td>1800</td>
<td>1800</td>
<td>1800</td>
<td>1800</td>
<td>1500</td>
<td>1500</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>Power/Throw (HP/Throw)</td>
<td>60</td>
<td>100</td>
<td>145</td>
<td>200</td>
<td>600</td>
<td>594</td>
<td>850</td>
<td>680</td>
<td>900</td>
<td>900</td>
<td>1500</td>
</tr>
<tr>
<td>Rod Load (lbf)</td>
<td>6000</td>
<td>10000</td>
<td>11000</td>
<td>12500</td>
<td>42000</td>
<td>35000</td>
<td>48000</td>
<td>52000</td>
<td>52000</td>
<td>55000</td>
<td>70000</td>
</tr>
</tbody>
</table>

Table 16 GE High speed reciprocating compressors

2.7 Plant design and EPC services

Starting from the earliest stage of a project, GE supports its Costumer from the engineering feasibility study and permitting release, tailoring technical studies for emissions and noise that matches country specifications and costumizing solutions for modular power generation sets with guarantees over the time. Layout and performances are optimized accordignly to the Costumers needs offering a solution that represents the best trade off between CAPEX and output requirements.

Furthermore, GE uses to partner with EPC companies to provide turnkey services for complete plants from feasibility to operations, including financial services and contracts of maintainance.

2.8 Maintenance and services

GE has a long lasting experience on maintenance and services on its equipment. Pursuing efficient operations on its equipment and plants GE protects lifecycle performance providing spare parts and extending parts life with first-in-class repair technologies.

With qualified and experienced field service engineers GE ensures that the right expertise is on site, garanteeing as higher as possible availability and reliability values of plant and equipment. Additionally, GE optimizes expenditures through long-term maintenance simulations.

GE global services organization supplies conversions, modifications and uprates (CM&Us), contractual service agreements (CSA), high technology overhauls, repairs, and uprated parts.

2.9 Diagnostics and operation support

Always innovating its technologies, GE works to provide costumers digital solutions that optimize Operation Services. Managing issues before they becomes problems and partnering with costumers on the journey to zero unplanned downtime are GE’s goal.

With a Global iCenter network with 24/7 coverage that leverages over 11 milions hours of machine data, GE provides predictive warnings wich enable optimized outage planning.

2.10 Finance advisory services

GE supports its Costumer by providing if needed financial advisory services. GE can raise capital on behalf of the customer from multiple sources and perform detailed analysis to assess project feasibility and bankability. GE Finance staff understands Customer finance requirements and provides them the best solutions to optimize the project economic results.

Furthermore GE structure underwrite investments in customer projects and provide restructuring expertise for specific industries while analysing key competitors financing activity and structuring intelligence on third party transactions.
3. AN INNOVATIVE ORC GEOTHERMAL PLANT SUPPORTED BY GE TECHNOLOGY

GE is currently supporting Graziella Green Power in the development of a geothermal ORC power plant, in Castelnuovo Val di Cecina (Italy). The power plant will install a single stage turboexpander manufactured by GE Oil&Gas.

This geothermal ORC is designed for 5 MW net power production and it has been studied to create an innovative “closed loop” power plant, respecting the principle of a safe, clean and environmentally integrated system.

The main characteristics of the plant are:

- Closed loop with total reinjection of fluids. Non-condensable gases are collected and pressurized by a GE reciprocating compressor in order to be also re-injected.
- ORC working fluid is cooled by air cooled condenser with no water consumption.
- Reinjection well on the same drilling pad, minimizing the length of required pipelines.
- Use of medium-high enthalpy geothermal steam (the majority of the geothermal ORC plants use liquid resources).
- Condensation in the main heat exchanger in presence of Non-Condensable Gases (NCG).
- Geothermal condensate water also available for direct use 90 °C.
- Landscape and environmental integration with the surroundings.

The environmental impact of the plant is further reduced by placing a curved green roof, covered by vegetation above the air coolers area. The result is a closed structure, allowing both a mitigation of the plant impact and the containment of the noise emissions.

![Figure 17 Castelnuovo Graziella plant layout](image)

![Figure 18 Castelnuovo Graziella plant rendering](image)
One of the innovative aspects of the Castelnuovo plant is to operate an ORC fed with high enthalpy steam in presence of phase change at the ORC evaporator. This also requires to remove NCG from the condensing surfaces and to compress it for reinjection.

The brine and the NCGs will be released inside the reinjection well by means of concentric pipes, allowing separate, parallel streams down to the “mixing point”, which will be located at few hundred meters in depth. At the mixing point a mixture is formed which goes down along the casing dragging and partially dissolving the gas in the liquid streamflow (Vaccaro, Batini, Stolzuoli, Bianchi, & Pizzoli, 2016).

4. CONCLUSIONS

GE is highly committed to invest in technology aimed to reduce the environmental impact of power generation including but not limited to geothermal.

The advanced technological position, financial solidity and field experience makes GE one of the most suitable partners for private stakeholders and governmental institutions operating in the geothermal market.

REFERENCES


