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.

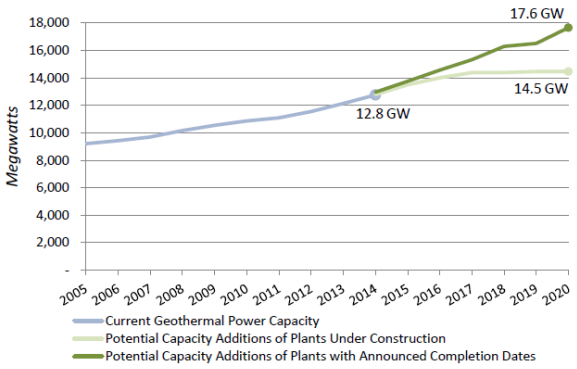

Figure 1 Global geothermal market capacity trend

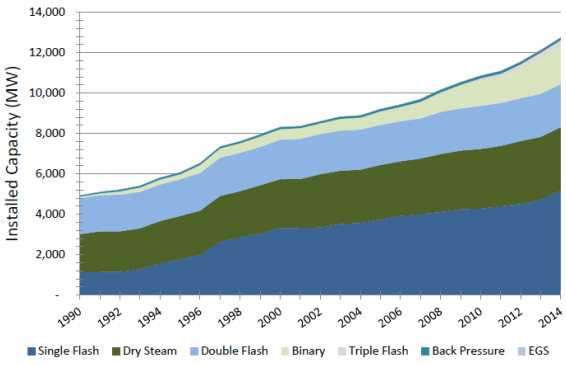

Figure 2 Global geothermal market technology trend

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).

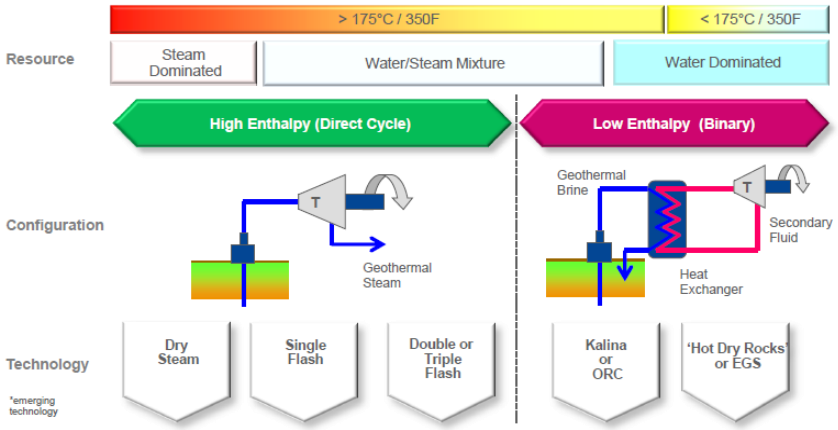

Figure 1 Thermodynamic cycle adaption depending on resources conditions

Current GE product portfolio and technological capability can support enginerring, commisioning 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 currenlty has in its porfolio 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 aplications thanks to its flexibility. It is characherized by scalabilty and is avaibale 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.

Rated power output:	5-50 MW, 50/60 HZ
Inlet pressure:	up to 30 bar
Inlet temperature:	up to 300°C
Speed:	3,000 / 3,600 rpm
Blading type:	Reaction w/ optional impulse control stage
Inlet configuration:	Twin scroll with partial admission valves
Rotor:	One piece forging

Figure 2 SG Series steam turbine

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.

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

Figure 3 GTS Series steam turbine

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

Year	Model	Plant Location	Plant Type	Speed RPM	Power MW	Inlet Press. Bar-a	Inlet Temp. °C	Exhaust Press. Bar-a
2000	SGC4-23	ITALY	Dry Steam	3000	10	2	120	0.061
2000	SGC4-23	ITALY	Dry Steam	3000	20	6	159	0.075
2000	SGC4-26	ITALY	Single Flash	3000	40	8	200	0,065
2000	SGC4-23	ITALY	Dry Steam	3000	20	6	190	0.065
2000	SGC4-23	ITALY	Dry Steam	3000	10	2	120	0.065
2001	SGC4-26	ITALY	Single Flash	3000	40	8	200	0.065
2003	SGC4-26	ITALY	Dry Steam	3000	40	8	170	0.064
2004	SGDFC4-22	EL SALVADOR	Single Flash	3600	45	9.5	177	0.065
2009	GST	MEXICO	Dry Steam	3000	25	8	170	0.08
2009	GST	MEXICO	Dry Steam	3000	25	8	170	0.08
2013	GST	MEXICO	Dry Steam	3000	27	8	170	0.08
2015	GST	INDONESIA	Single Flash	3000	33	6.5	162	0.1

Table 4 GE Geothermal steam turbines references

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 turbo expanders for any possible services, including generator drive applications, compressor drive applications and dynos.

Figure 5 GE Turboexpander generator skid

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.

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

Table 6 GE Turboexpanders available frames

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:

N° UNIT	Plant Location	Geothermal System	Frame	Power (HP)	Speed RPM	Inlet Press. Bar-a	Inlet Temp. °C	Exhaust Press.. Bar-a	Ship Date
2	CALIFORNIA, USA	BYNARY – ORC (IC4)	60	7169	11000	34.5	138	3.7	1984
1	CALIFORNIA, USA	BYNARY – ORC (IC4)	60	7169	11000	34.5	138	3.7	1987
1	CALIFORNIA, USA	DIRECT STEAM	60	4846	15000	18.3	208	9.3	1990
6	CALIFORNIA, USA	BYNARY – ORC (IC4)	60	7169	11000	34.5	138	3.7	1990
4	NEVADA, USA	BYNARY – ORC	60	13728	9000	35.5	146	4.6	1992
1	CALIFORNIA, USA	DIRECT STEAM	60	15687	12500	21.1	216	8.5	2000
1	NEVADA, USA	BYNARY – ORC (IC5)	50	1744	13000	9.2	112	1.2	2000
1	HUSAVIK, ICELAND	BYNARY – (KALINA)	40	3376	25000	30.8	119	6.5	2004
1	BERLIN, EL SALVADOR	BYNARY – ORC (IC5)	60S	12950	6500	21.2	159	1.9	2006

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.

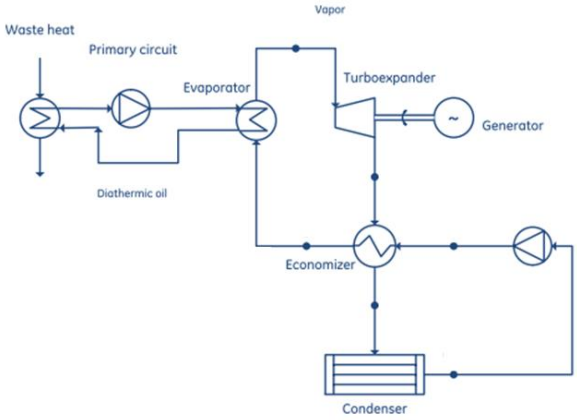

Figure 8 ***ORegen™*** *plant layout*

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.

*Figure 10 **ORegen™** turboexpander skid*

GT Model	GT Power (KW)	Exhaust Flow (Kg/sec)	Exhaust Temp (°C)	GT Efficiency (%)	ORC Output (MWe)	System Efficiency (%)
PGT25 (*)	23 261	68.9	525	37.7%	6.9	48.9%
PGT25+ (*)	31 364	84.3	500	41.1%	7.9	51.5%
PGT25+ G4 (*)	33 973	89.0	510	41.1%	8.6	51.5%
MS5001 (*)	26 830	125.2	483	28.4%	11.3	40.4%
MS5002B (*)	26 100	121.6	491	28.8%	10.8	40.7%
MS5002C (*)	28 340	124.3	517	28.8%	12.4	41.4%
MS5002D (*)	32 580	141.4	509	29.4%	13.8	41.9%
MS5002E (*)	32 000	101.0	510	36.2%	9.8	47.2%
MS6001B (*)	43 530	145.0	544	33.3%	15.6	45.2%
MS7001E (*)	87 300	302.0	535	33.1%	31.1	44.9%
LM6000 (**)	43 397	125.6	454	41.7%	9.7	51.1%
LMS100 (**)	100 700	216.8	423	43.8%	15.7	50.8%

*Table 9 **ORegen™** recovered power in GT WHRU applications*

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.

API Family	GE Oil&Gas Model	Head	Capacity	Max Operating Temperature
OH2	TC	Up to 320 m	Up to 2300 m³/h	450 °C
BB2 – single stage	DVSHF	Up to 275 m	Up to 1800 m³/h	400 °C
BB2 – two stages	THF/ DSTHF	Up to 600 m	Up to 1500 m³/h	450 °C
BB1 – single stage	DVE/ DVS	Up to 350 m	Up to 20000 m³/h	200 °C
BB5	DDHF	Up to 4000 m	Up to 1200 m³/h	450 °C
BB3	MSN/ MSND	Up to 2500 m	Up to 3000 m³/h	200 °C
BB1 – two stages	BF	Up to 1000 m	Up to 8000 m³/h	200 °C
VS6	VCD/ VDA	Up to 50 m/st	Up to 5000 m³/h	155 °C
VS7	VCMS	Up to 55 m/st	Up to 110 m³/h	155 °C

Table 11 GE centrifugal pumps

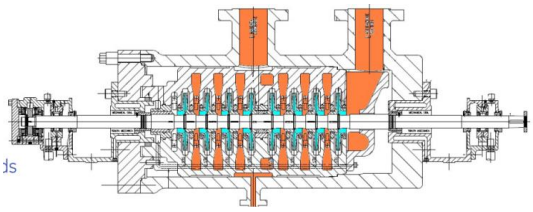

Figure 13 GE radially split centrifugal pump

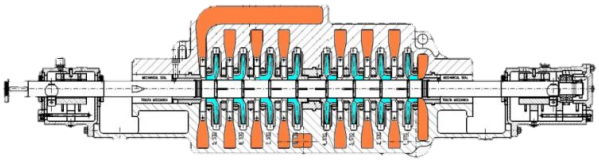

Figure 12 GE axially split centrifugal pump

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.

	338 Series TA 400 to TA 2700	400 Series TD 150 to TD 6000	500 Series TE 1500 to TE 11000	675 Series TJ 7000 to TJ 20000
Housing Outer Diameter	3.38 inches	4.0 inches	5.38 inches	6.75 inches
Minimum Casing Size	4.50 inches	5.50 inches	7.0 inches	8.83 Inches
Operating Range	150 – 3,400 BPD @ 60Hz	80 – 7,500 BPD @ 60Hz	400 - 14,000 BPD @ 60Hz	4,200 –26,000 BPD @ 60Hz
Housing Pressure	6,000 PSI	6,000 PSI	6,000 PSI	3,000 PSI
Shaft HP Limit	255 HP	435 HP	1019 HP	1300 HP

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.

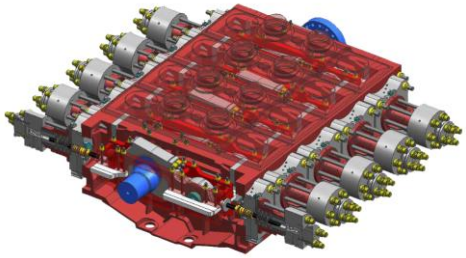

Figure 15 GE Hyper compressor

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.

Product Name	Frame: M	Frame: H	Frame: CFA	Frame: A	Frame: GH	Frame: RAM	Frame: CFR	Frame: CFH	Frame: MH	Frame: WH	Frame: WG
No. Of Throws	1-2	1-2-4	2-4	1-2-4	2-4	2-4	2-4	2-4	2-4-6	2-4-6	2-4-6
Stroke (Inches)	3	3	3	3.5	5	5	5	6	6	7	7
Max. Speed (RPM)	1800	1800	1800	1800	1500	1500	1500	1200	1200	1200	1200
Power/Throw (HP/Throw)	60	100	145	200	600	594	850	680	900	900	1500
Rod Load (lbf)	6000	10000	11000	12500	42000	35000	48000	52000	52000	55000	70000

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 matchs country specifications and costumizing solutions for modular power generation sets with garantees over the time. Layout and performances are optimized accordignly to the Costumers needs offering a solution that reppresents 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 maintanance.

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.

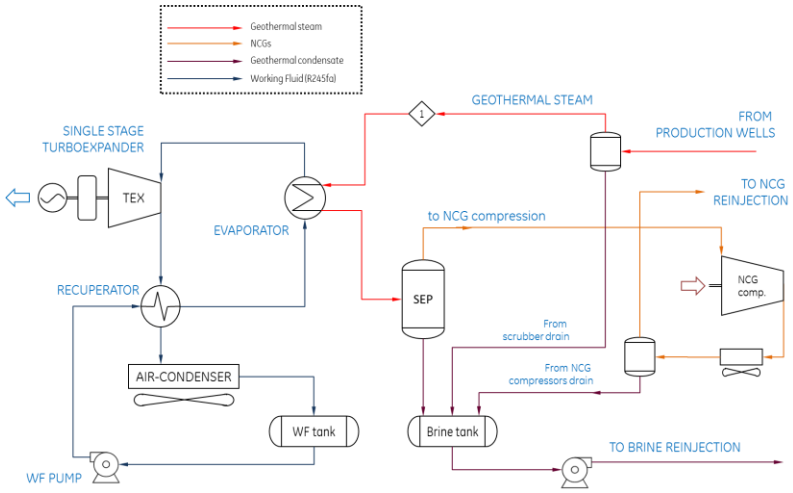

Figure 17 Castelnuovo Graziella plant layout

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 18 Castelnuovo Graziella plant rendering

Mass flow rate (steam)	kg/s	18
Geofluid inlet (vapor)		
Temperature	°C	180
Pressure	bar	10
Geofluid outlet (liquid)		
Temperature	°C	89
Pressure	bar	11.7
Geofluid outlet (NCG)		
Temperature	°C	50
Pressure	bar	60
Environment condition		
Temperature	°C	20
Relative humidity	%	60

Table 19 Castelnuovo Graziella plant design data

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.

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