BHGE: Innovative technology solutions across the Geothermal Fullstream

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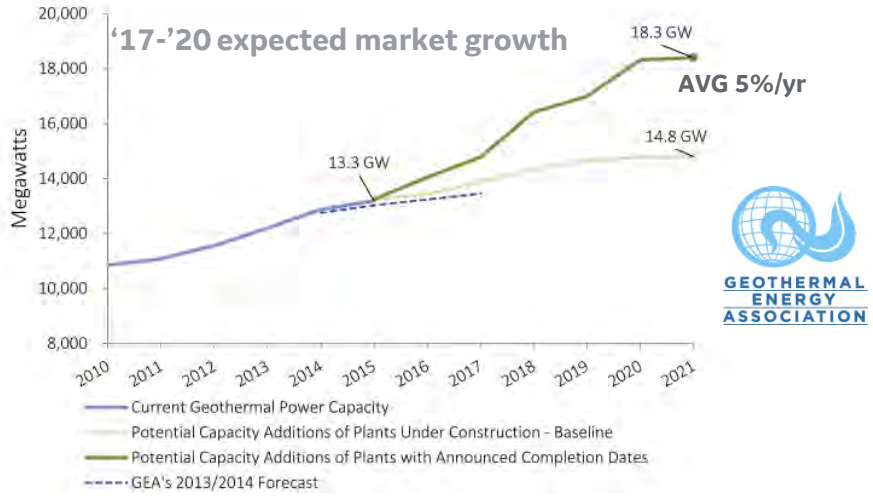
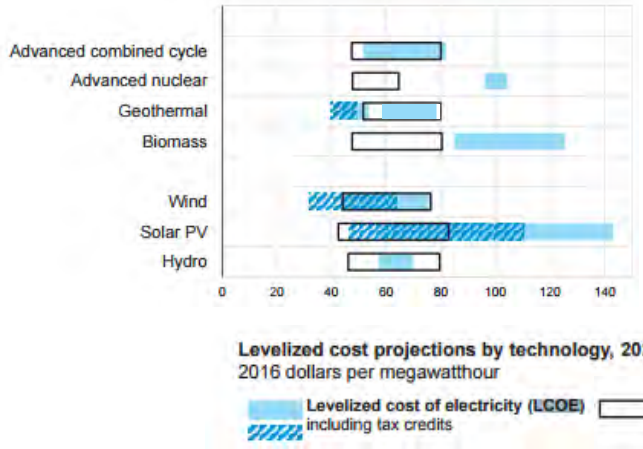
The Geothermal market

GROWING



GEOTHERMAL ENERGY ASSOCIATION

COMPETITIVE among RES



LCOE dependent on Region … 50-72$/MWh

Modulable Baseload

Power island CAPEX … 1.5-2M$/MW

eia U.S. Energy Information Administration

EVOLVING

Easy resources (high enthalpy fluids, shallow wells) **already exploited**

Technology challenge to install new capacity (low/medium enthalpies, deep and directional wells)

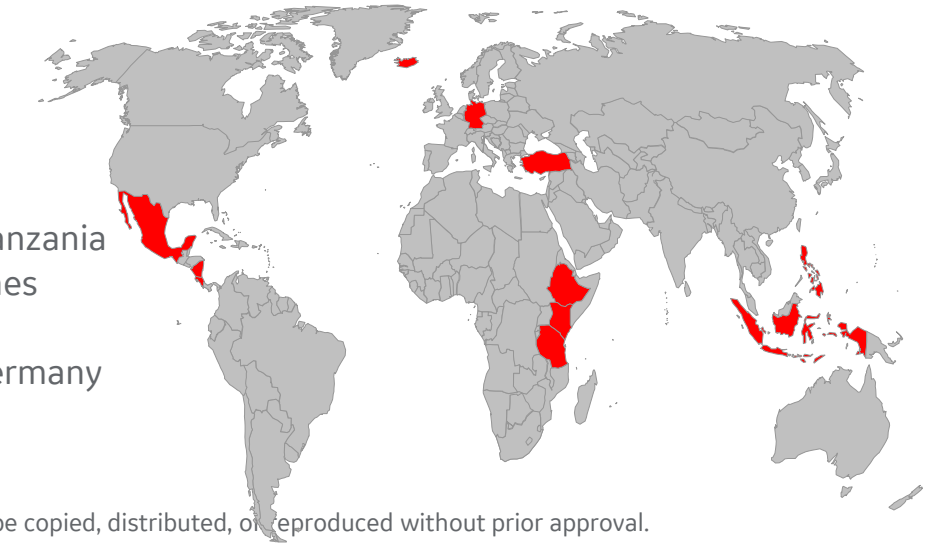
Shift from ST to Binary (Since 2012 78% of new installed capacity are Binary cycles)

EGEC GEOTHERMAL

Four HOT world areas

Top areas:

- Kenya / Ethiopia / Tanzania
- Indonesia / Philippines
- Costa Rica / Mexico
- Iceland / Turkey / Germany



Technology Solutions across the Fullstream

Key Technology and Services from the underground system to the power production

Well

- **Submersible Pumps**
- Well Head Equipment
- Logging Technology

Power Island

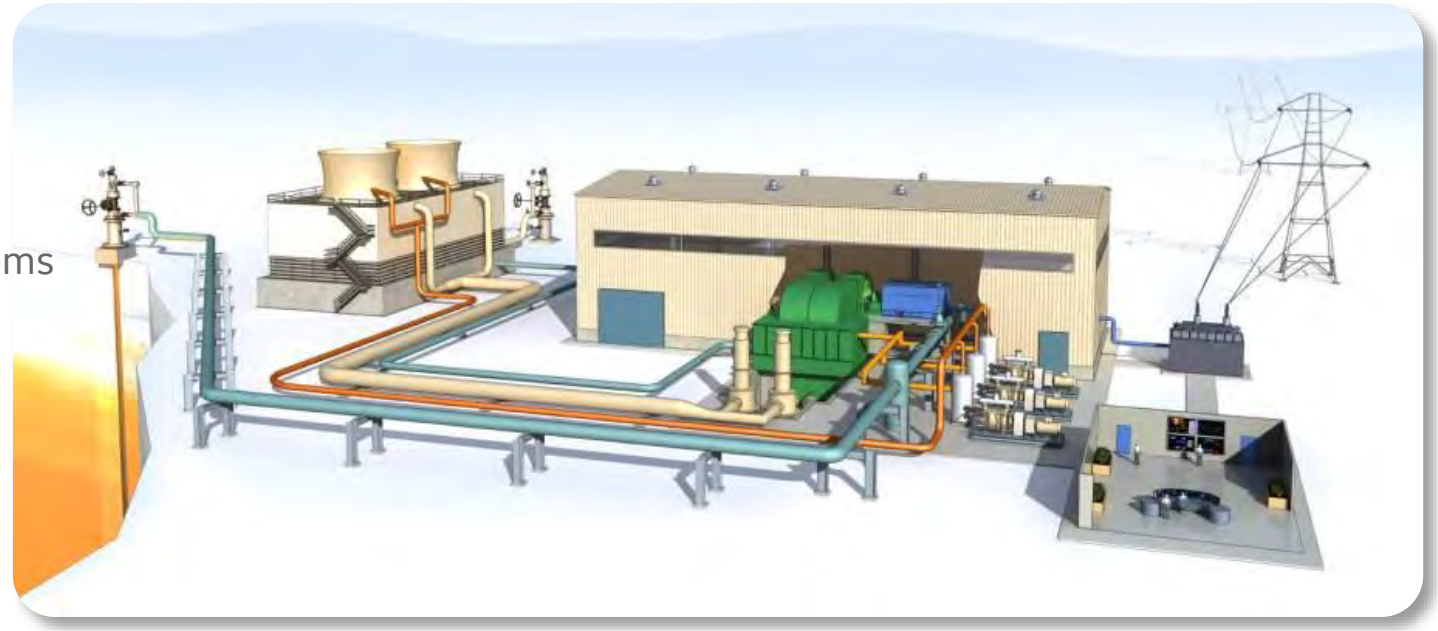
- **Steam Turbine** & Generators
- ORC systems & **Expanders**
- Condensate & Re-injection Pumps
- Air Cooled Condensers
- Remote M&D

Power Delivery

- Primary Equipment
- Power Sensing & Quality
- Protection & Control
- Automation
- Remote M&D

Drilling

- **Drill-bits**
- Drilling & Evaluation systems
- **Cementing services**
- Completion systems
- Fishing services
- Chemical services

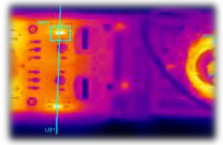


Underground systems- Drilling and evaluation

Cementing
eXtreme set (312 Cº)

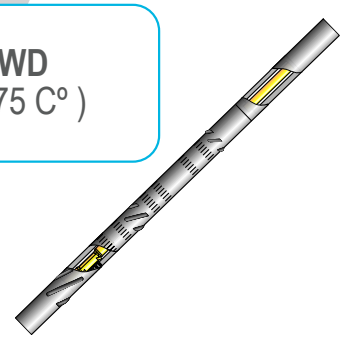
Fluids
PYRO-DRILL™ drilling fluids (340 Cº)

Coring
HT™ core barrels and disposable steel inner barrels (>163 Cº)

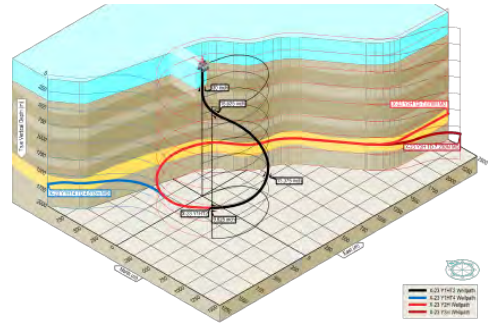


Wireline
NAUTILUS ULTRA™
XMAC F1 (232 Cº)

MWD/LWD
(150 C - 175 Cº)



Automated drilling systems
Auto-Trak™ X-treme
(175 Cº)



Motors
X-treme, Performance
(to 160- 200 Cº)

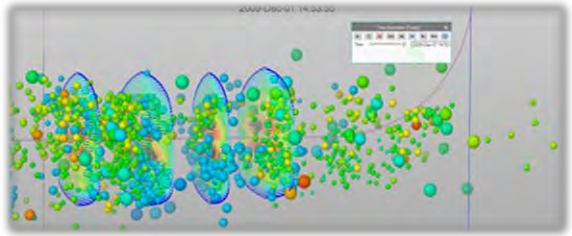
Drill Bits
Quantec™ Force PDC
Kymera™ Hybrid
Vanguard™ bits (>288º C)

Underground systems- Completion and production

Completion systems

Wellbore intervention

Hydraulic fracturing/ stimulation
Planning, monitoring, evaluating

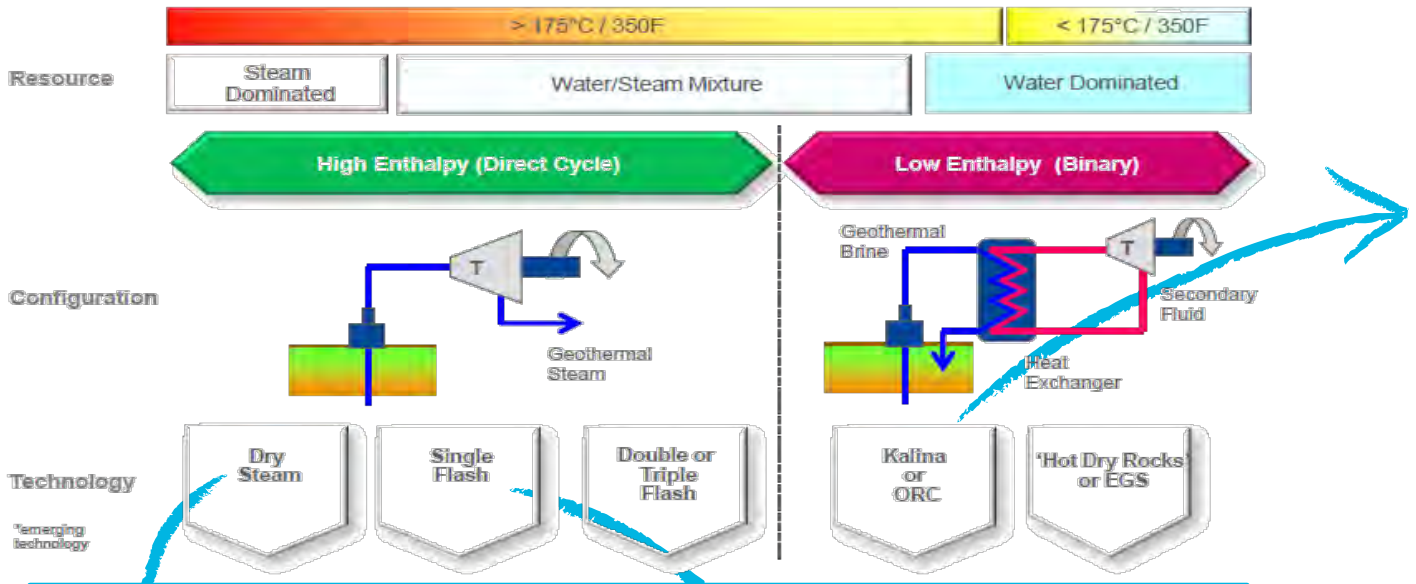


Specialty Chemical
Flow assurance control
Scale Control, O2 scavenger, corrosion inhibitors, biocide

Completion

ESP
CENetic Geothermal Pump (200 C°)

Topside Solutions



Thermodynamic cycle adaptation depending on resources conditions

Direct dry Steam power plants

- Use in conjunction with high enthalpy vapour-dominated resources
- Reach the highest efficiency among all geothermal power plants
- Simple to operate
- Require relatively low capital costs

Single and dual flash power plants

- The most common type of geothermal power plants
- Use liquid-dominated hydrothermal resources with medium to high enthalpy

Binary cycle power plants / Organic Rankine Cycle:

- Operate at lower water temperatures of about 75-175 °C
- Use the heat from the hot water to boil a working fluid (an organic compound with a low boiling point)

Topside Solutions - Steam Turbines

Power outputs from 5-50 MW

Characteristics

- **Efficient**: high performance steam path thanks to Inconel & Titanium materials
- **Simple**: compact concept, integral bearing pedestrial, electric actuators for trip and control valves
- **Scalable**: multiple size (Back-pressure and condensing types)
- **Tailored**: modular single, double flow, fully packaged at shop for short installation
- **Cost effective**: low maintenance thanks to anti-corrosion features and advanced moisture removal system

References

Year	ST Model	Plant Location
1998	GST	MEXICO
2000	SGC4-23	ITALY
2000	SGC4-23	ITALY
2000	SGC4-26	ITALY
2000	SGC4-23	ITALY
2000	SGC4-23	ITALY
2001	SGC4-26	ITALY
2001	GST	INDONESIA
2003	GST62	MEXICO
2003	GST62	MEXICO
2003	GST62	MEXICO
2003	GST62	MEXICO
2003	SGC4-26	ITALY
2004	SGDFC4-22	EL SALVADOR
2009	GST62	MEXICO
2009	GST62	MEXICO
2013	GST62	MEXICO
2015	GST55	INDONESIA
2016	SGNC1-6	USA

Berlin, El Salvador - Hybrid Flash/ORC Power Plant

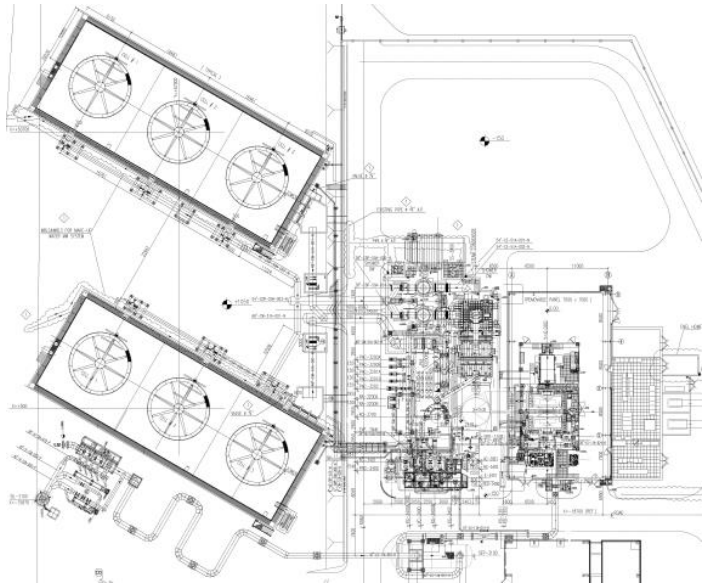
Berlin Plant

Geothermal Station

Total installed Power: **~58 MW**

Steam Turbine SGDFC4-22 rated **~45 MW**

ORC rated **~13 MW**



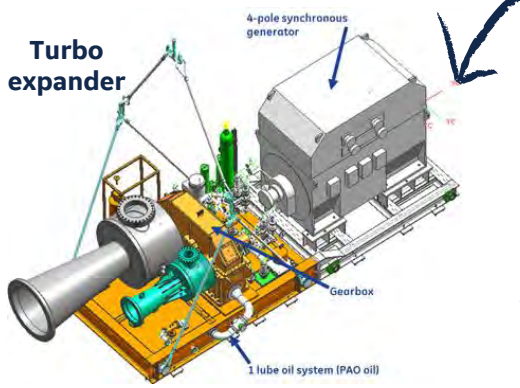
SGDFC4-22 (steam turbine)

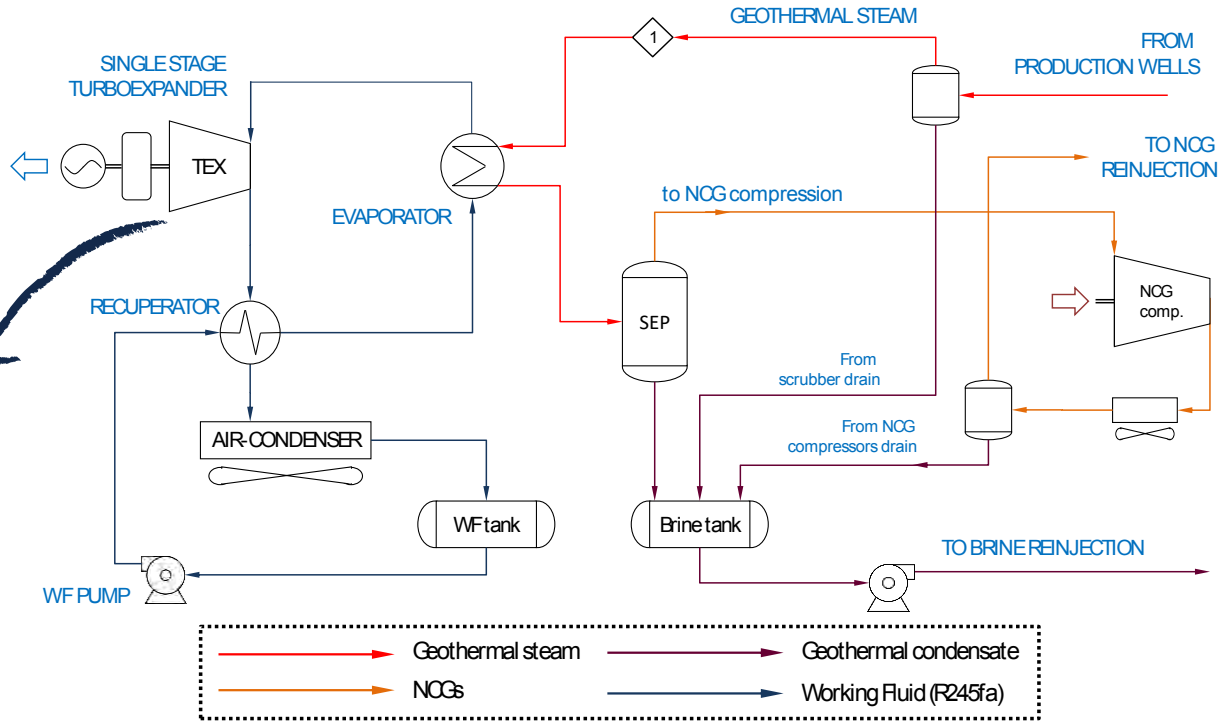
- Power 45 MW
- Rot. Speed 3600 rpm
- Inlet pressure 6-10 bar
- 22 inches LPB
- Radial double exhaust

ORC

- Power 13 MW
- Rot. Speed 6500 rpm

Topside Solutions - Organic Rankine Cycle





Plant data	
Working Fluid	R245fa
WF mass flow	- kg/s
TEX T inlet	- °C
Geofluid Delta T	180°C – 89 °C
ACC	seven bays, with VFD
Evaporator	off-line cleaning

Design case Power	kW
Expected gross power	6525
ORC pump consumption	570
NCG compressor consumption	325
Air cooled condenser fan consumption	375
Auxiliary systems	60
Net expected power	5147

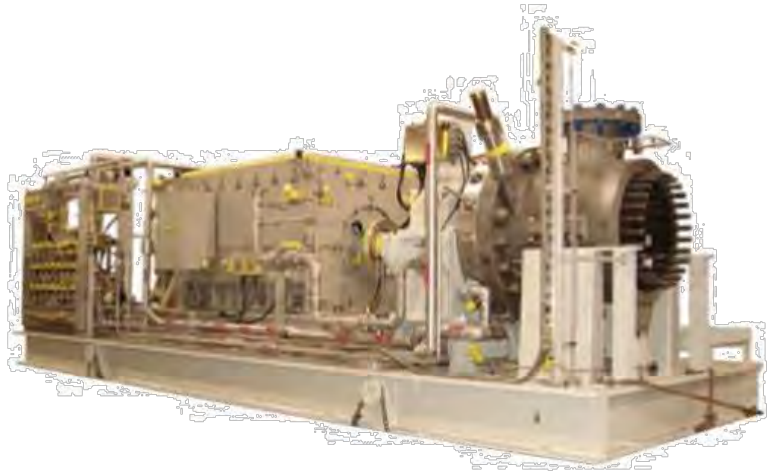
Topside Solutions - ORC / Turboexpanders

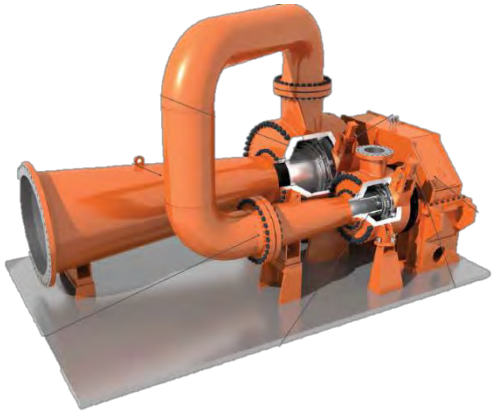
Turboexpanders and **generators** are the **core** of an ORC geothermal project

- GE has an extensive experience protected by more than 120 patents
- Any possible services, including generator drive applications, compressor drive applications and dynos.
- Direct drive or external gearboxes with a common oil supply system

TEX References

Year	Plant Location	Plant type
1984	USA	ORC
1987	USA	ORC
1990	USA	DIRECT STEAM
1990	USA	ORC
1992	USA	BYNARY – ORC
2000	USA	DIRECT STEAM
2000	USA	BYNARY – ORC
2004	ICELAND	KALINA
2006	EL SALVADOR	ORC

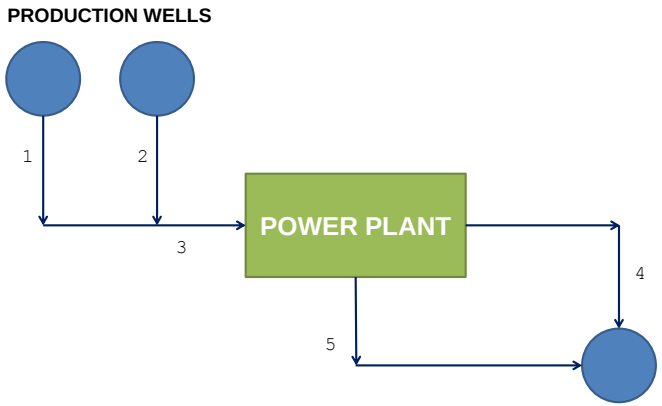




Castelnuovo, Italy

SUCCESS STORY

- **Total reinjection** of fluids and non-condensable gases
- Use of **medium-high enthalpy** geothermal steam
- Condensation in the main HX in presence of Non-Condensable Gases (NCG)
- ORC working fluid is **cooled by air** with no water consumption
- Reinjection well on the same drilling pad, **minimizing pipelines**
- **Landscape integration** of the ORC plant



Gathering system main layout

Main layout of the plant and drilling area

5 MW of electric net power target

Zero emissions

Resource and Environmental sustainability