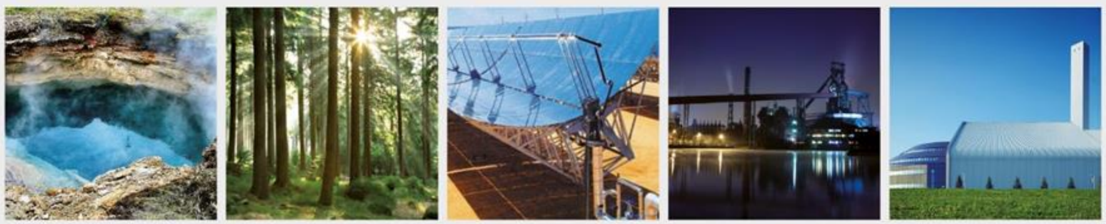

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The Company and the Geothermal Applications

ISO 9001

Doc.: 11-COM.P-5-rev.54

Update: 06/04/2016

About Us

Turboden is a leading European company in development and production of ORC (Organic Rankine Cycle) turbogenerators. This state-of-the-art equipment generates heat and power from renewable sources and heat recovery in industrial processes.

The company was founded in 1980 in Milan by Mario Gaia, Associate Professor at *Politecnico di Milano*, teaching Thermodynamics, Renewable Energy and specifically studying ORC systems. At present Prof. Gaia is Honorary Chairman. A number of his former students are key persons in the Company and the whole Company is permeated by innovative and research oriented spirit.

Turboden has always had a single mission: to design ORC turbogenerators for the production of heat and electrical power from renewable sources, while constantly striving to implement ORC technical solutions.

In 2009, Turboden became part of UTC Corp., a worldwide leader in development, production and service for aero engines, aerospace drive systems and power generation gas turbines, to develop ORC solutions from renewable sources and waste heat worldwide.

In 2013 UTC exits the power market forming strategic alliance with Mitsubishi Heavy Industries.

In 2013 Mitsubishi Heavy Industries acquires from UTC Pratt & Whitney Power Systems (now PW Power Systems, Inc.) and the affiliate **Turboden.**
Today Turboden S.r.l. and PW Power Systems, Inc. are MHI group companies to provide a wider range of products and services for thermal power generation systems.

In 2013 Turboden's Quality Management System gets certified to ISO 9001:2008.

35 Years of Experience

- Prof. Mario Gaia makes experience in the field of ORC within his research group at *Politecnico di Milano*
- 1976 – First prototype of a solar thermodynamic ORC

'60-'70

1980-1999

- 1980 – Prof. Mario Gaia founds Turboden to design and manufacture ORC turbogenerators
- Turboden develops research projects in solar, geothermal and heat recovery applications
- 1998 – First ORC biomass plant in Switzerland (300 kW)

2000-2009

- Turboden installs ORC biomass plants, especially in Austria, Germany and Italy
- Turboden plans to enter new markets, with focus on North America
- First heat recovery applications

2009-2013

- **2009 – Turboden achieves 100 plants sold**
- United Technologies Corp. (UTC) acquires the majority of Turboden's quota. PW Power Systems supports Turboden in new markets beyond Europe
- UTC exits the power market forming strategic alliance with **Mitsubishi Heavy Industries**
- PW Power Systems becomes an MHI group company

2016…

- **2013 - MHI acquires the majority of Turboden. Italian quotaholders stay in charge of management**
- **Today - Over 320 ORC plants in the world, over 260 in operation**

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35 Years of Experience

1984 – 40 kW_{el} ORC turbo-generator for a solar plant in Australia

1987 – 3 kW_{el} ORC turbo-generator for a biomass plant in Italy

1988 – 200 kW_{el} ORC geothermal plant in Zambia

2008 – 3 MW_{el} ORC turbo-generator for heat recovery on a waste incinerator in Belgium

2009 – First 100 plants and first installed 100 MW_{el}

2010 – First plant overseas

2016 – Over 320 ORC plants in the world

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Turboden – a Group Company of MHI

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Energy & Environment

the largest segment of MHI

over $13 billion (in fiscal 2014)

Mitsubishi Heavy Industries is one of the world's leading heavy machinery manufacturers, with consolidated sales of over $33 billion (in fiscal 2014).

Foundation July 7, 1884

MITSUBISHI HEAVY INDUSTRIES, LTD.

Energy & Environment

Providing optimal solutions in the energy-related fields of thermal power, nuclear energy and renewable energy in different environmental areas and for Chemical plants & other industrial infrastructures elements.

Machinery, Equipment & Infrastructure

Providing a wide range of products that form the foundation of industrial development, such as machine tools, material handling, construction machinery, air-conditioning and refrigeration systems.

Commercial Aviation & Transport Systems

Delivering advanced land, sea and air transportation systems, including civilian aircraft, commercial ships and transit networks.

Integrated Defense & Space Systems

Providing advanced land, sea and air defense systems, including naval ships, defense aircraft, launch vehicles and special vehicles, as well as space-related services.

What We Do

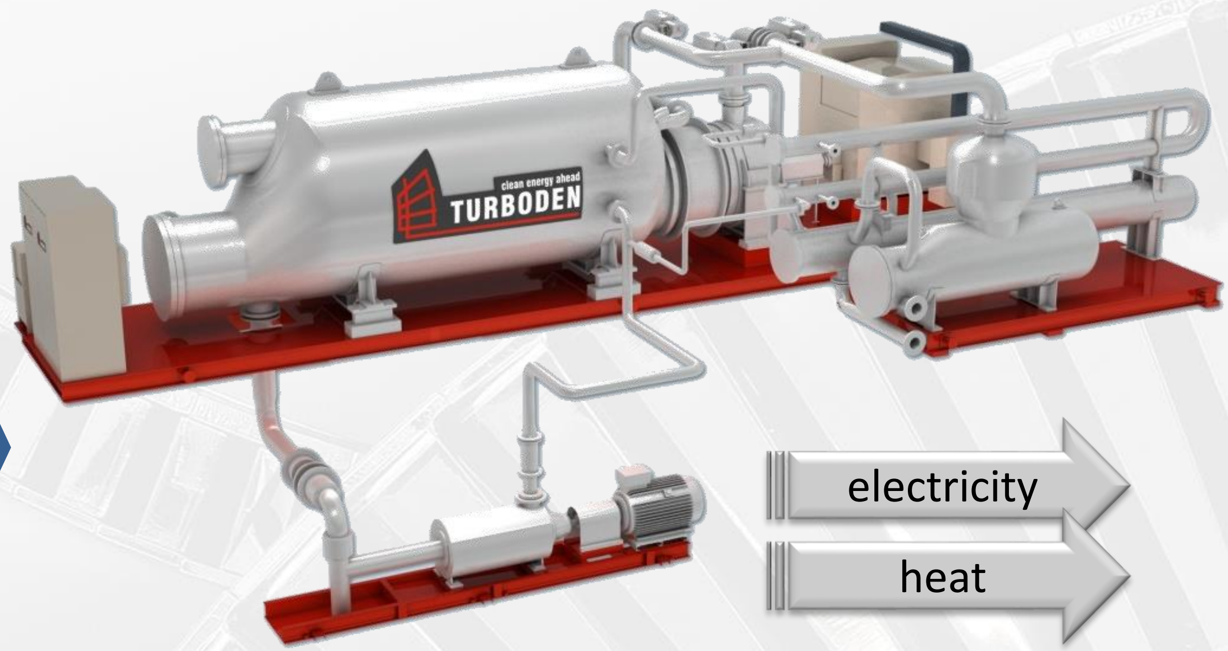

Biomass

Heat recovery

Waste to energy

Geothermal

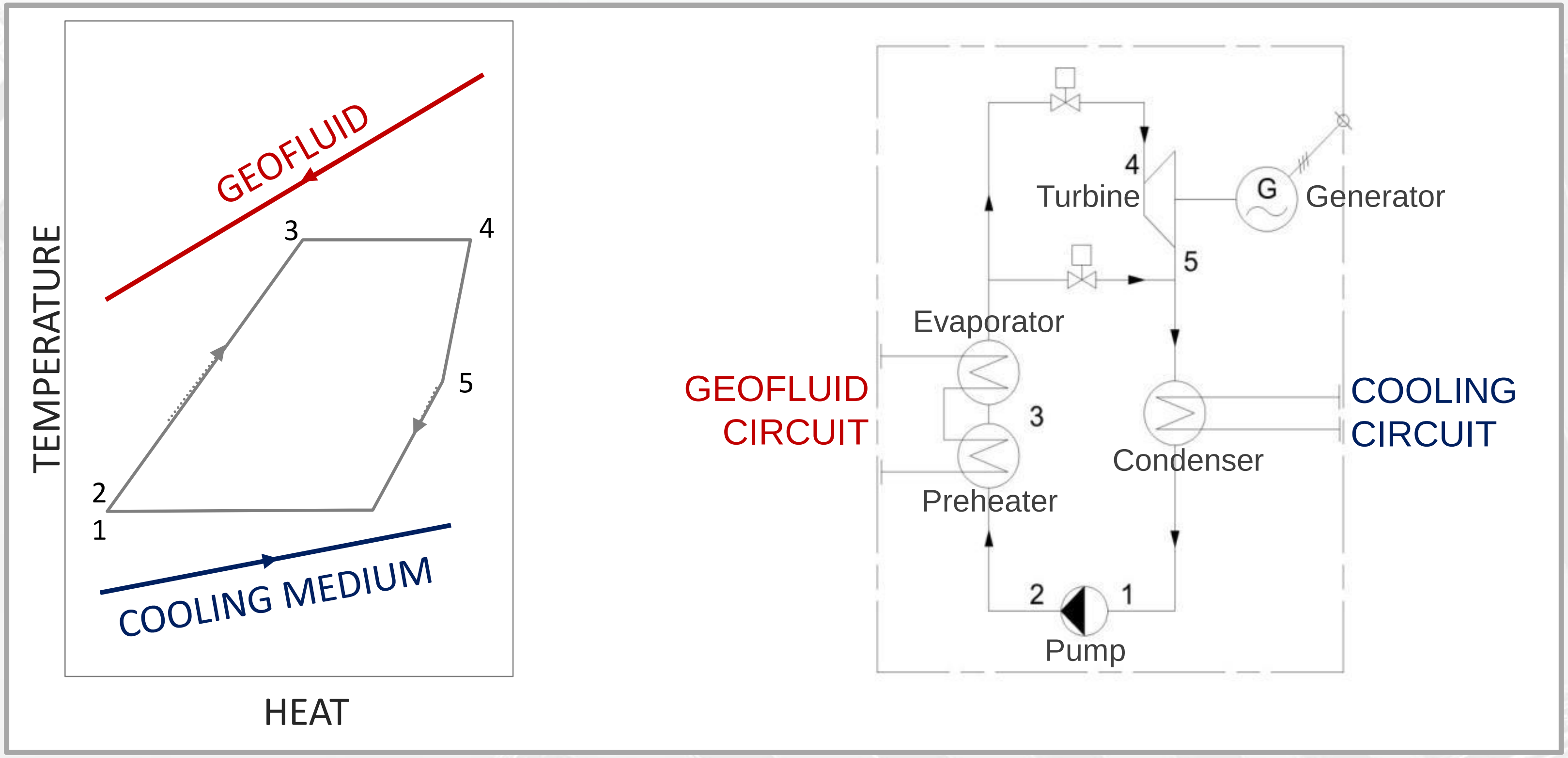
Solar



Turboden designs, develops and maintains turbogenerators based on the Organic Rankine Cycle (ORC), a technology for the combined generation of electric power and heat from various renewable sources, particularly suitable for distributed generation.

- **standard units** from 200 kW to 20 MW electric per single shaft

The Thermodynamic Principle: the ORC Cycle



The turbogenerator uses the geothermal water to pre-heat and vaporize a suitable organic working fluid in the evaporator (2→3→4). The organic fluid vapor powers the turbine (4→5), which is directly coupled to the electric generator through an elastic coupling. The vapor is then condensed in the condenser, cooled by water or air (5→1). The organic fluid liquid is finally pumped (1→2) to pre-heater and evaporator, thus completing the sequence of operations in the closed-loop circuit.

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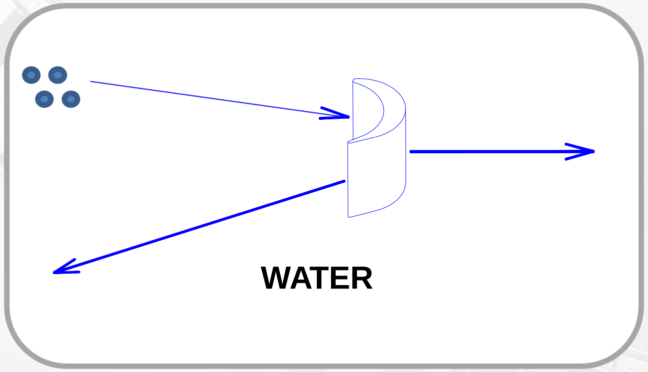
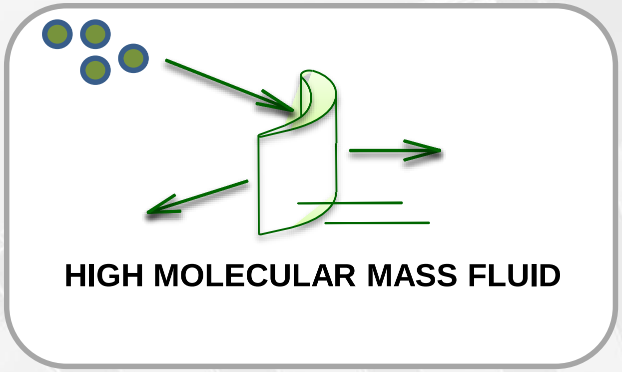
Why High Molecular Mass Working Fluid Instead of Water?





Water

- Small, fast moving molecules
- Metal parts and blade erosion
- Multistage turbine and high mechanical stress

Organic Fluid

- Very large flow rate
- Larger diameter turbine
- No wear of blades and metal parts

Advantages of Turboden ORC Turbogenerators

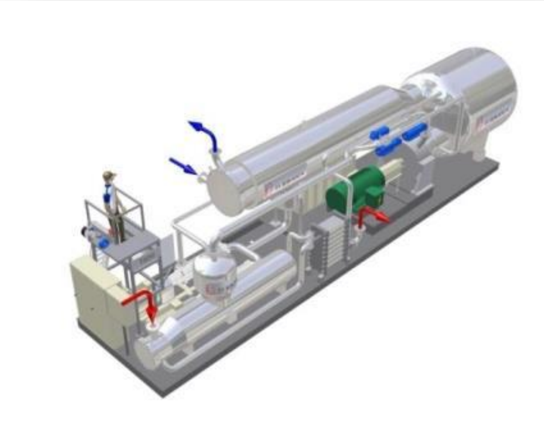
Technical advantages

- ❑ High cycle efficiency
- ❑ Very high turbine efficiency (up to 90%)
- ❑ Low mechanical stress of the turbine due to the low peripheral speed
- ❑ Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear
- ❑ No erosion of blades, thanks to the absence of moisture in the vapor nozzles

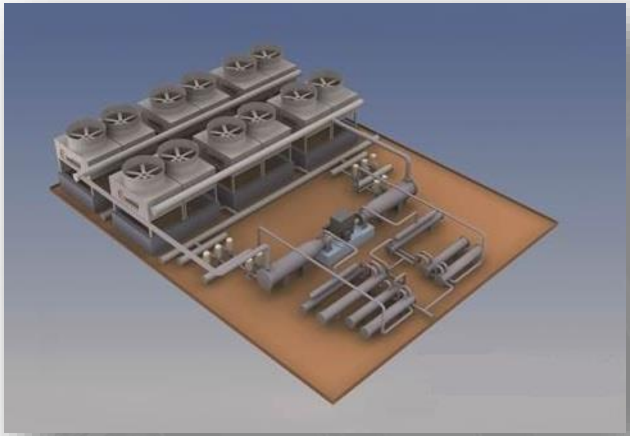
Operational advantages / results

- ❑ Simple start-stop procedures
- ❑ Automatic and continuous operation
- ❑ No operator attendance needed
- ❑ Quiet operation
- ❑ High Availability
- ❑ Partial load operation down to 10% of nominal power
- ❑ High efficiency even at partial load
- ❑ Low O&M requirements: about 3-5 hours / week
- ❑ Long life

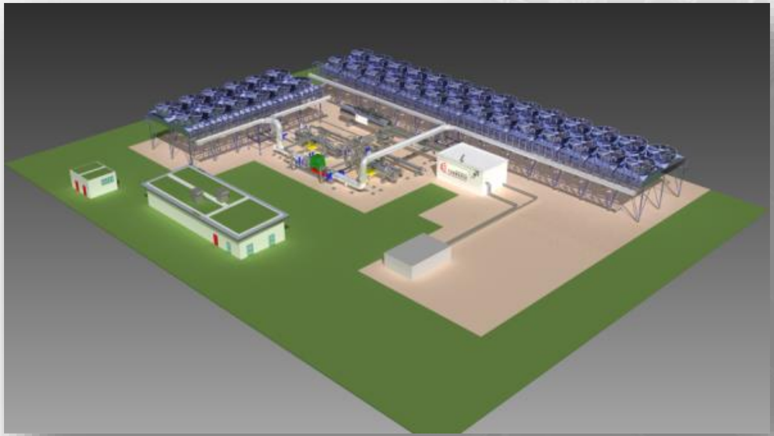
Layout – Some Examples



TURBODEN 7 layout



Geothermal 5 MW water-cooled



Geothermal 5 MW Air-cooled

TURBODEN 10 layout

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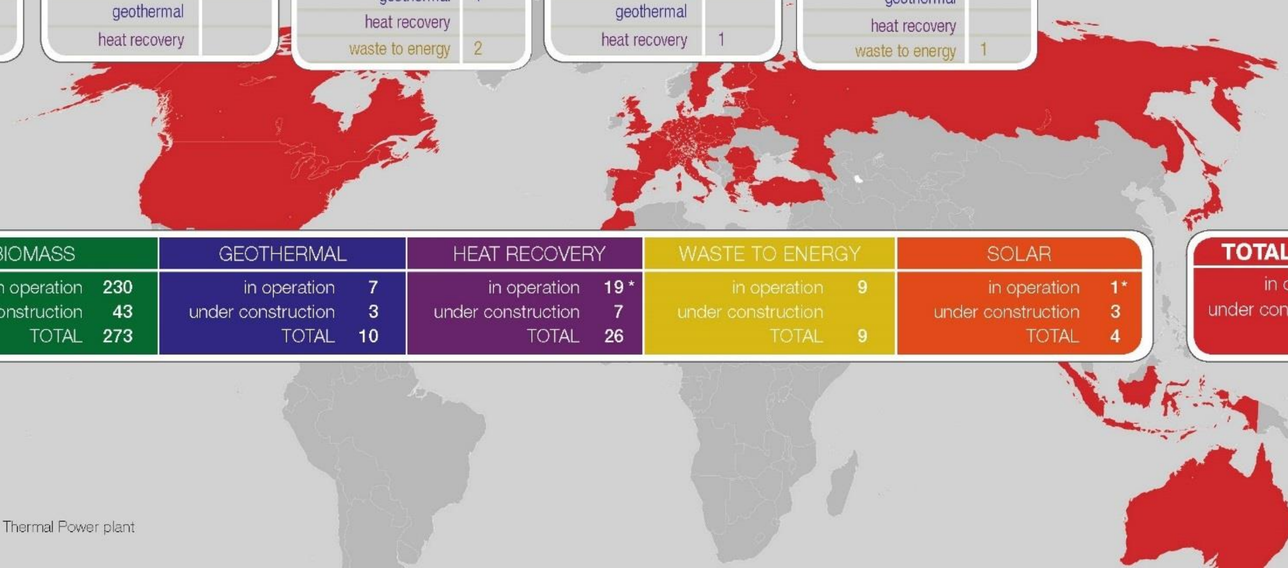
Turboden ORC Plants in the World

Country	Total	biomass	geothermal	heat recovery	waste to energy	solar thermal power
AUSTRALIA	1	1				
AUSTRIA	31	29	1	1		
BELARUS	4	4				
BELGIUM	2	1			1	
BULGARIA	1	1				
CANADA	6	5		1		
CROATIA	8	7	1			
CZECH REP	3	3				
DENMARK	2	2				
ESTONIA	2	2				
FINLAND	3	2			1	
FRANCE	4	1	1		2	
GERMANY	82	74	4	4		
GREECE	2	2				
INDONESIA	1	1				
ITALY	92	76	1	10	2	3
JAPAN	2		1	1		
LATVIA	15	15				
MOROCCO	1			1*		1*
NETHERLANDS	1	1				
POLAND	11	11				
ROMANIA	4	2		2		
RUSSIA	6	4		2		
SINGAPORE	1			1		
SLOVAKIA	2	1		1		
SLOVENIA	1	1				
SPAIN	7	7				
SWEDEN	1	1				
SWITZERLAND	9	8		1		
THE PHILIPPINES	1	1				
TURKEY	6	3	1		2	
UNITED KINGDOM	8	7		1		
U.S. AMERICA	2	1			1	



	BIOMASS	GEOTHERMAL	HEAT RECOVERY	WASTE TO ENERGY	SOLAR	TOTAL PLANTS
in operation	230	7	19 *	9	1*	265
under construction	43	3	7		3	56
TOTAL	273	10	26	9	4	321

Update February 2016

*Hybrid Heat Recovery and Solar Thermal Power plant

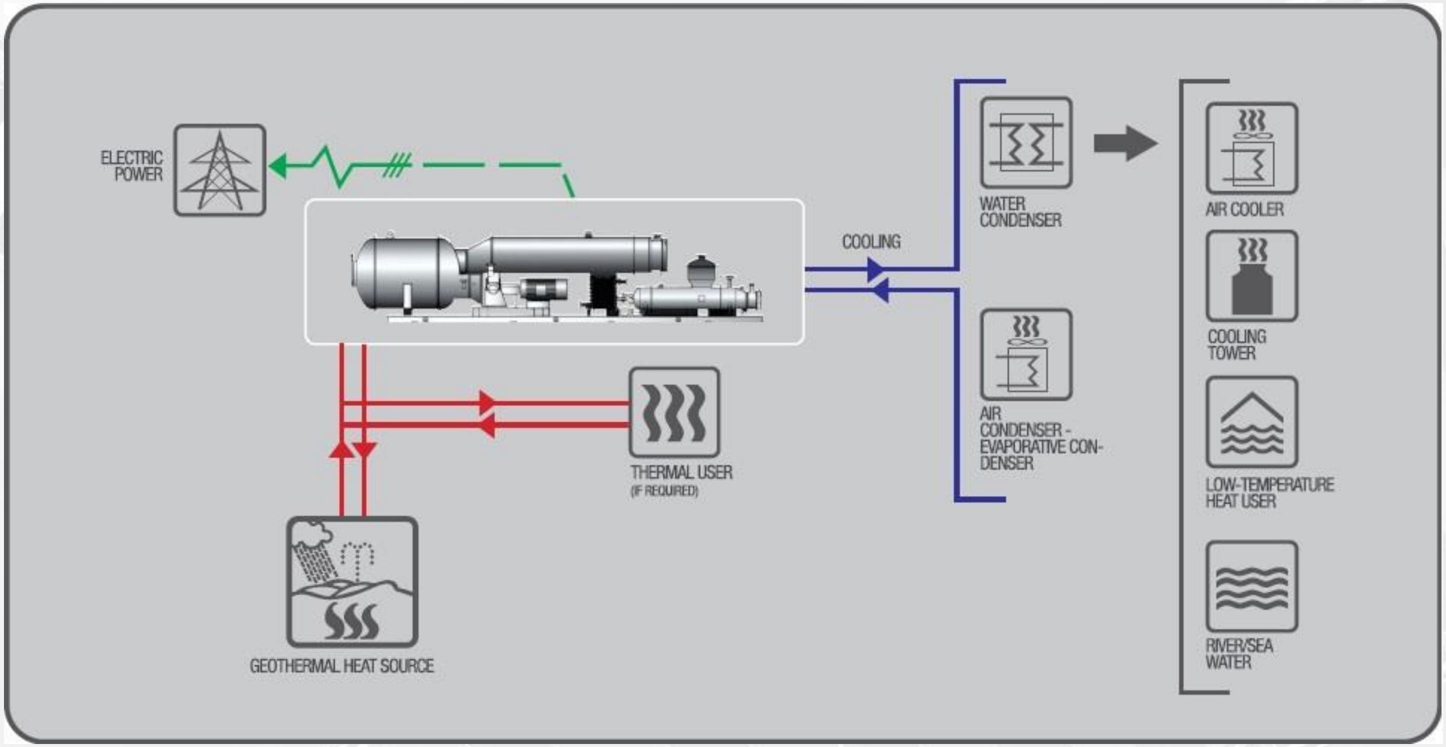
ORC Applications - Geothermal

Biomass | **Heat Recovery** | **Waste to energy** | **Geothermal** | **Solar Thermal Power**

Geothermal
ORC technology is particularly suitable for the exploitation of medium to low enthalpy sources.
Cost-effective solution with power output up to 40 MWe per single generator and water temperature above 100°C*.

* 212 °F

Binary Plant Schematic



No standard heat/cooling sources → highly customized solutions

Geothermal ORC Design

Main issues to consider

• Corrosion → special and costly materials for the heat exchangers

great influence on the cost of the unit

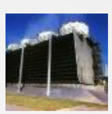
longer delivery period

• Scaling → limits in cooling the geothermal brine

• Fouling → removable covers and straight cleanable tubes

• Working fluid flammability: critical in urban areas & for insurance cost

• Cascade use / cogeneration: schemes, feasibility



• Vapor plume and need for makeup water in case of evaporative devices

• Larger footprint and noise emissions from the fans in case of air cooling

Geothermal ORC Design

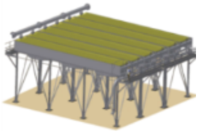
Evaluation of the proper Cooling System: wet Vs dry

WATER CONDENSERS

EVAPORATIVE TOWERS

EVAPORATIVE CONDENSERS

AIRCOOLERS



AIR CONDENSERS

AVAILABLE

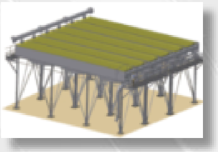
MAKE UP WATER

NOT AVAILABLE

Evaporative towers

- Smaller footprint
- Efficient in hot dry climate
- Higher own-consumption
- Fresh water consumption
- Chemical water treatment → operation cost, environment

Air condensers

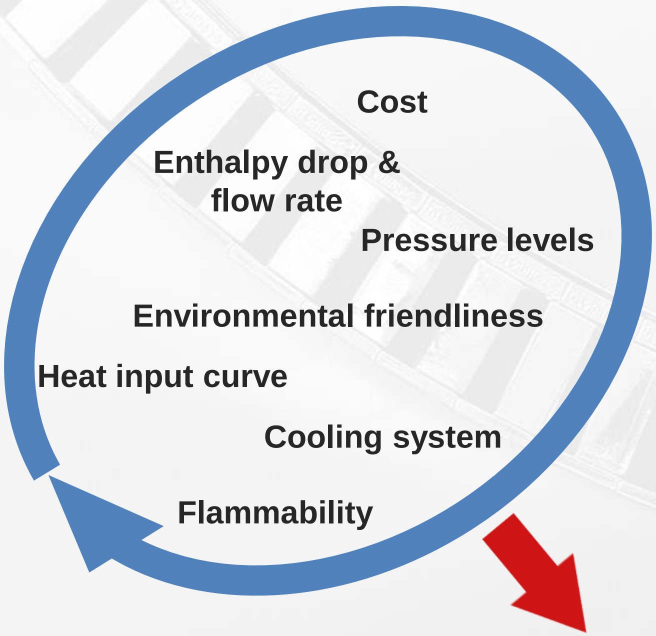


- Larger footprint
- Efficient in cold climate
- Lower own consumption
- No water needed
- Virtually no environmental impact and operating costs

Critical issues

- Investment costs: initial / overall
- Generated yearly output, linked to gross power and parasitic loads

Working fluid selection is influenced by many factors



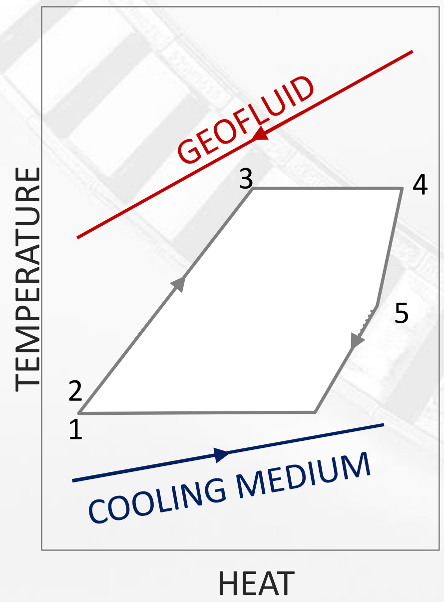
OPTIMAL FLUID

Option to select a non flammable fluid

- Fluid flammability is critical in urban areas & for insurance costs
- Turboden identified and studied a number of fluids
- Turboden tested a non flammable fluid in Altheim, being used ever since
- Lab tests under way to check compatibility & behavior in wider range
- Possibility to place the unit inside a building or shelter (protection from atmospheric agents and mitigation of noise emissions)


The Altheim plant building

Combined Heat and Power



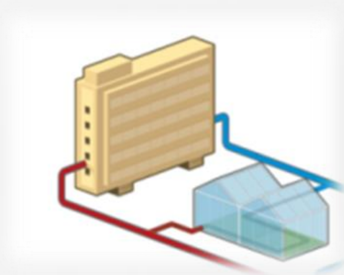
The uses of geothermal energy cover a wide spectrum from low-temperature, such as green houses heating and aquaculture, to high-temperature applications, including power generation.

Electricity is regarded as the highest grade and most useful form of energy.

Nonetheless selling the heat is remunerative, environmental friendly and is being incentivized (Heating Fund in France, incentives in UK).

Various schemes are possible:

- in parallel (Altheim, Mirom)
- in series (cascade uses, New Mexico)
- from the condensation heat (classic cogeneration concept, LowBin)



Reference Plant - Sauerlach

Plant type: two-level cycle geothermal unit

Customer: SWM - StadtWerke München (public utilities company)

Site: Sauerlach, Munich, Germany

Start-up: December 2012

Heat source: geothermal fluid at 140°C

Cooling device: air condensers

Total power: 5+ MW_e plus 4 MW_{th} decoupling for district heating

Working fluid: refrigerant 245 fa (non flammable)

Reference Plant - Dürrnhaar

Plant type: two-level cycle geothermal unit

Customer: Hochtief Energy Management GmbH

Site: Dürrnhaar (Munich), Germany

Start-up: December 2012

Heat source: geothermal fluid at 138°C

Cooling device: "dry & spray" condenser

Total electric power: 5.6 MW

Scope of supply: EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant

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Reference Plant - Kirchstockach

Plant type: two-level cycle geothermal unit

Customer: Hochtief Energy Management GmbH

Site: Kirchstockach (Munich), Germany

Start-up: March 2013

Heat source: geothermal fluid at 138°C

Cooling device: air condensers

Total electric power: 5.6 MW

Scope of supply: EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant

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Reference Plant - Traunreut



Plant type: ORC geothermal unit

Customer: Geothermische Kraftwerksgesellschaft Traunreut GmbH

Site: Traunreut, Germany

Start-up: January 2016

Heat source: geothermal fluid at 118°C

Cooling device: air condensers

Total electric power: 4.1 MW

Total thermal power: 12 MW (to the district heating)

Scope of supply: Supply of the complete ORC unit, including the Air Cooled Condenser and control system of geothermal site

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Reference Plant - Afyon Jeotermal

Model: TURBODEN 30 HR

Client: Afyon Jeotermal (Afjet)

Start-up: May 2016 (expected)

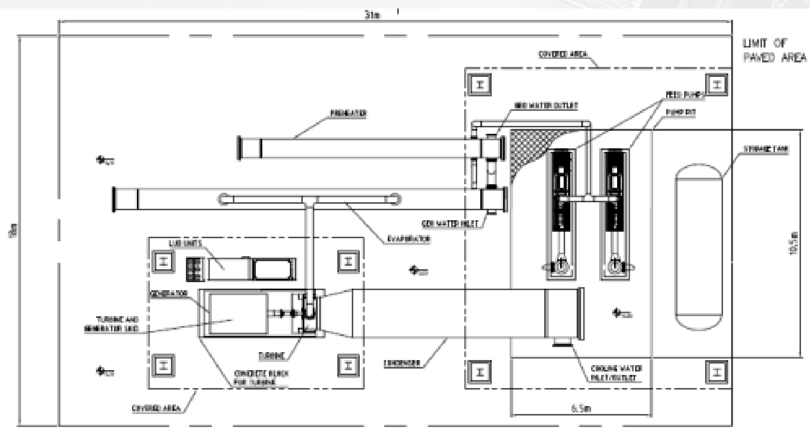
Location: Afyonkarahisar, Turkey

Heat source: geothermal brine at 110°C

Total electric power: 3 MW

ORC working fluid: refrigerant

Water temperature (in/out): 25 - 35°C



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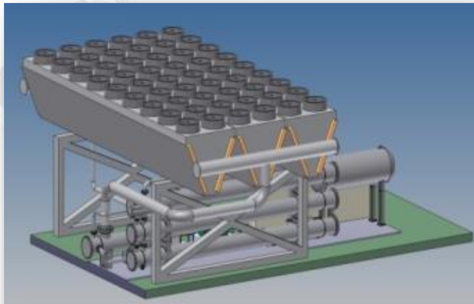
Reference Plant - Enel Supercritical



Plant type: geothermal prototype with supercritical cycle

Customer: Enel Green Power

Site: Livorno, Italy

Start-up: March 2012

Heat source: hot water at 150°C nominal

Cooling device: ‘dry & spray’ condenser

Total electric power: 500 kW

Working fluid: refrigerant (non flammable)

Reference Plant - Velika Ciglena

Plant type: ORC geothermal unit

Customer: MB Holding

Site: Velika Ciglena, Bjelovar, Croatia

Start up: Q1 2017

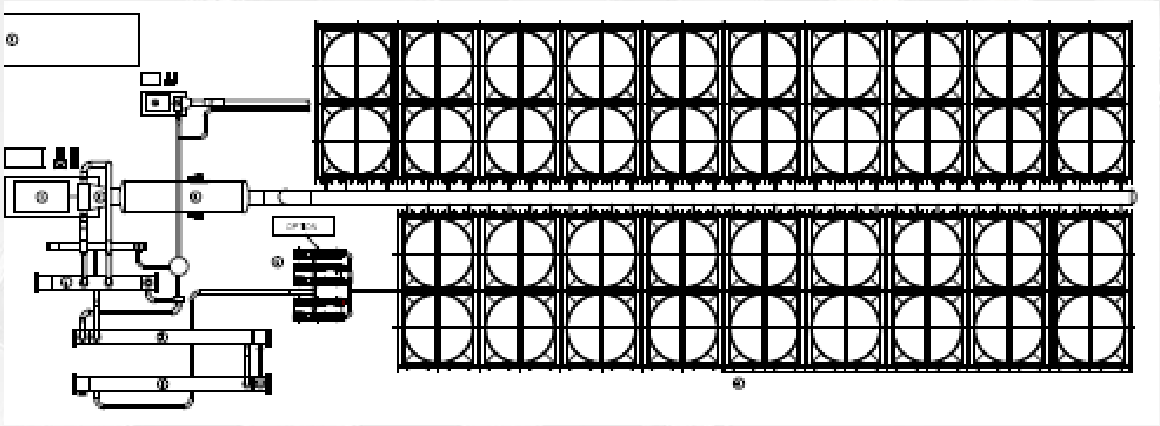
Heat source: geothermal brine and steam @170°C

Cooling device: Air Cooled Condenser

Total power: 16,5 MWe on a single turbine (including a 1.5 MW NCG expansion turbine)

Working fluid: Isobutane

Scope of supply: Engineering, procurement and Construction of the full ORC power plant, including civil and steam-field engineering



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Reference Plant - The Philippines

Plant type: 4 X Turboden 10 MW (net) ORC units

Customer: undisclosed

Site: The Philippines

Start-up: under construction (first 10 MW foreseen for Q3/Q4 2017)

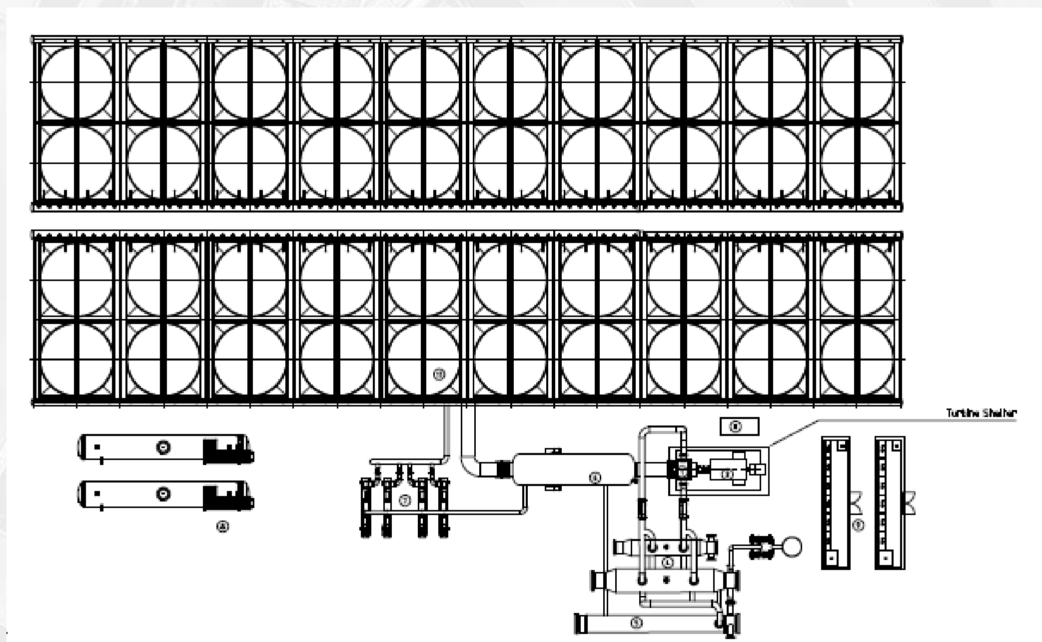
Heat source: geothermal fluid at 159°C

Cooling device: air condensers

Total electric power: 40 MW net

Working fluid: Isopentane

Scope of supply: Turboden in consortium with TSK will provide the turnkey plant



Reference Plant - Sugawara

Plant type: brine + steam ORC geothermal unit

Customer: Mitsubishi Heavy Industries

Location: Japan

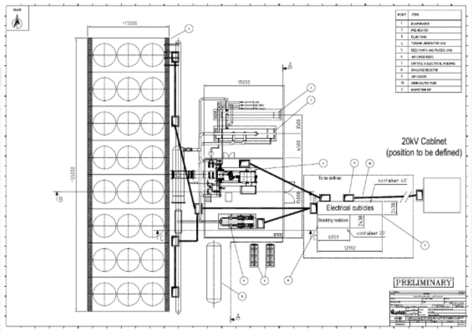
Status: in operation since June 2015

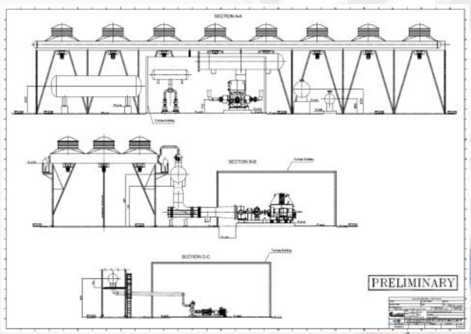
Heat source: geothermal brine/steam 140°C

Cooling device: air condensers

Total electric power: 5+ MW

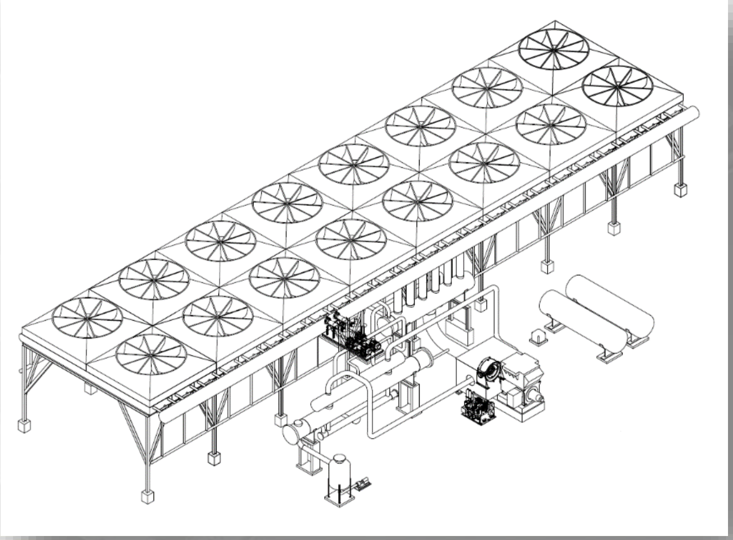
Working fluid: n-pentane





Reference Plant - Nevis

- **Plant type:** Single turbine ORC geothermal unit
- **Turbine type:** Turboden Multi-stage axial type
- **Customer:** Nevis Renewable Energy International
- **Site:** Nevis, Federation of Saint Kitts and Nevis, Lesser Antilles
- **Start up:** COD before end of 2017
- **Heat source:** high enthalpy geothermal brine and steam @179 °C
- **Cooling device:** Air Cooled Condenser
- **Total power:** 9 MW net
- **Working fluid:** Pentane
- **Scope of supply:** Engineering procurement and construction of the entire powerplant



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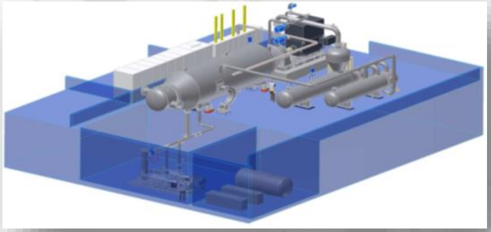
Reference Plant - Mirom

Water temperature similar to Geothermal



Plant type: heat recovery from pressurized water boiler in waste incinerator

Customer: MIROM, Spie Belgium SA

Site: Roeselare, Belgium

Start-up: April 2008

Availability: > 98%

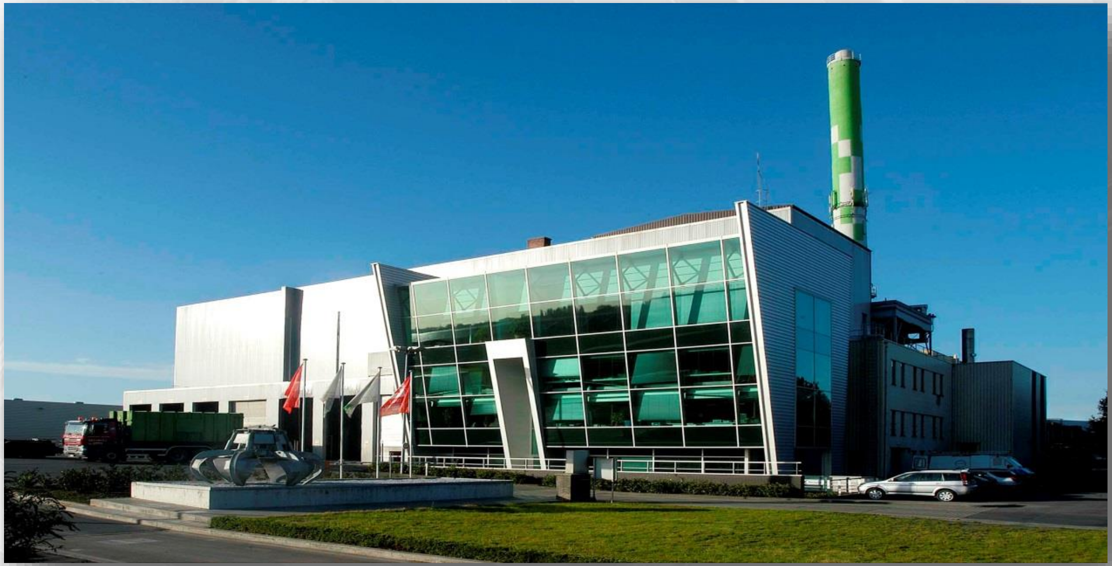
Heat source: hot water at 180°C (return at 140°C)

Cooling source: water/air

Total electric power: 3 MW

Net electric efficiency: 16.5%

Non-flammable working fluid: to meet customer’s requirement



MIROM MILIEUZORG ROESELARE EN MENEN

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Early Demonstration Projects

Site: Kapisha, Zambia

Year: 1988

Heat source: Geothermal fluid at 88°C

Total electric power: 2 x 100 kW

Plant type: geothermal – experimental for Enel

Site: Castelnuovo di Val di Cecina, Italy

Year: 1992

Heat source: Geothermal fluid at 114°C (return at 102°C)

Cooling source: water/air

Total electric power: 1.3 MW

Net electric efficiency: 9%

EU Funded Demonstration Projects

Plant type: geothermal low enthalpy, coupled with a geothermal district heating system

Site: Marktgemeinde, Altheim, Austria

Start-up : March 2001

Heat source: hot water at 106°C

Cooling source: cold water from a nearby river (cooling temperature 10/18°C)

Design electric power: 1 MW (normally operated by the owner at ~ 500 kW)

Plant type: geothermal, 1st EU operating plant on EGS (Enhanced Geothermal System)

Site: Soultz-sous-Forêts, Alsace, France

Start-up: June 2008

Heat source: hot water at 180°C

Cooling source: air condenser

Total electric power: 1.7 MW

Net electric efficiency: 11.5%

Plant type: geothermal low enthalpy, coupled with a geothermal district heating system

Site: Simbach – Braunau, German-Austrian border

Start-up: August 2009

Heat Source: hot water at 106°

Cooling source: air/water

Design electric power: 200 kW

LOW-BIN GEOTHERMAL POWER

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Turboden at a Glance

Turboden strong points

R&D	Sales/marketing	Design	Operations & manufacturing	Aftermarket service
• Participation in national & EU research programs • Cooperation with EU Universities and Research Centres • Thermodynamic cycle optimization • Working fluid selection & testing • Thermo-fluid-dynamic design and validation • Implementation & testing of control/supervision software • Many patents obtained	• Pre-feasibility studies: evaluation of technical & economical feasibility of ORC power plants • Customized proposals to maximize economic & environmental targets	• Complete in-house mechanical design • Proprietary design and own manufacturing of ORC optimized turbine • Tools - Thermo-fluid-dynamic programs - FEA - 3D CAD-CAM - Vibration analysis	• Outsourced components from highly qualified suppliers • Quality assurance & project management • In-house skid mounting to minimize site activities	• Start-up and commissioning • Maintenance, technical assistance to operation and spare parts service • Remote monitoring & optimization of plant operation

EPC capability *

Full Power Plant EPC

Single point responsibility

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