The Company and the Geothermal Applications
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.

• 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

• 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

• 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

• 2016...
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
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

*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

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 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.
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
Turboden ORC Plants in the World

**Biomass**
- In operation: 230
- Under construction: 43
- Total: 273

**Geothermal**
- In operation: 7
- Under construction: 3
- Total: 10

**Heat Recovery**
- In operation: 19
- Under construction: 7
- Total: 26

**Waste to Energy**
- In operation: 9
- Under construction: 3
- Total: 4

**Solar**
- In operation: 1
- Under construction: 0
- Total: 1

**Total Plants**
- In operation: 265
- Under construction: 56
- Total: 321

*Hybrid Heat Recovery and Solar Thermal Power plant*
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
No standard heat/cooling sources → highly customized solutions
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

** AVAILABLE **

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

** MAKE UP WATER **

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

** NOT AVAILABLE **

** Critical issues **
- Investment costs: initial / overall
- Generated yearly output, linked to gross power and parasitic loads
Geothermal ORC Design

Working fluid selection is influenced by many factors

- Cost
- Enthalpy drop & flow rate
- Pressure levels
- Environmental friendliness
- Heat input curve
- Cooling system
- Flammability

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)

OPTIMAL FLUID

changes from case to case

The Altheim plant building
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
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
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
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
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
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
Reference Plant - Mirom

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
Early Demonstration Projects

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%

Site: Kapisha, Zambia
Year: 1988
Heat source: Geothermal fluid at 88°C
Total electric power: 2 x 100 kW
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°C  
**Cooling source:** air/water  
**Design electric power:** 200 kW
Turboden at a Glance
Turboden strong points

R&D

- 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

Sales/marketing

- Pre-feasibility studies: evaluation of technical & economical feasibility of ORC power plants
- Customized proposals to maximize economic & environmental targets

Design

- 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

Operations & manufacturing

- Outsourced components from highly qualified suppliers
- Quality assurance & project management
- In-house skid mounting to minimize site activities

Aftermarket service

- 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