Turboden Waste to Energy Solutions
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.

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

- Turboden installs ORC biomass plants, especially in Austria, Germany and Italy
  - 1980–1999
  - 2000–2009
  - 2009–2013
  - 2016...

- Turboden plans to enter new markets, with focus on North America
  - First heat recovery applications

- 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 300 ORC plants in the world, over 240 in operation

- 1980 – Prof. Mario Gaia founds Turboden to design and manufacture ORC turbogenerators
  - 1980–1999

- Turboden develops research projects in solar, geothermal and heat recovery applications
  - 1998 – First ORC biomass plant in Switzerland (300 kW)

- 1980–1999
35 Years of Experience

1984 – 40 kW\textsubscript{e} ORC turbo-generator for a solar plant in Australia

1987 – 3 kW\textsubscript{e} ORC turbo-generator for a biomass plant in Italy

1988 – 200 kW\textsubscript{e} ORC geothermal plant in Zambia

2008 – 3 MW\textsubscript{e} ORC turbo-generator for heat recovery on a waste incinerator in Belgium

2009 – First 100 plants and first installed 100 MW\textsubscript{e}

2010 – First plant overseas

2016 – Over 300 ORC plants in the world
Turboden – a Group Company of MHI

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 and develops 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.

➢ **Turboden solutions** from 200 kW to 15 MW electric per single unit
The turbogenerator uses the heat carrier (e.g. hot temperature thermal oil) to pre-heat and vaporize a suitable organic working fluid in the evaporator (8→3→4). The organic fluid vapor powers the turbine (4→5), which is directly coupled to the electric generator through an elastic coupling. The exhaust vapor flows through the regenerator (5→9) where it heats the organic liquid (2→8). The vapor is then condensed in the condenser (cooled by the water flow or other) (9→6→1). The organic fluid liquid is finally pumped (1→2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.
Water vs High Molecular Mass - Working Fluid

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

High molecular mass fluid
- Large flow rate
- Larger diameter turbine with high efficiency of the turbine (85-90%)
- No wear of blades and metal parts
- Slow rotation speed and few stages (2-6)
ORC provides significant advantages as compared to steam

Steam Rankine Cycle

- High enthalpy drop
- Superheating needed
- Risk of blade erosion

Organic Rankine Cycle (ORC)

- Small enthalpy drop
- No need to superheat
- No supercritical pressure
- No risk of blade erosion

Thermodynamic features and consequences

- Water treatment required
- Highly skilled personnel needed
- High pressures and temperatures in the cycle

Operation and maintenance costs

- Convenient for large plants and high temperatures
- Low flexibility with significantly lower performances at partial load

Other features

- Non-oxidizing working fluid with no corrosion issues
- Minimum personnel and O&M (1)
- Completely automatic (2)
- No blow down

Operation and maintenance costs

- High flexibility and good performances at partial load
- High availability (average >98%)
- Possibility to work at low temperatures (90+°C)

(1) Standard maintenance: 2-3 days per year
(2) Fast start-stop procedure (ca. 20 min), partial load operation (down to 10% of nominal load)
Flexible and automatic

"One of the key points in the success of ORC technology is the capability to adapt to load variation easily and quickly."

**ORC Partial Load Efficiency**

Part load operation down to 10% of nominal load.

Mantains 90% of cycle efficiency down to 50% of loading.

**Cooling water temperature effect on cycle efficiency**

Turboden ORC units automatically adapt the cycle at the ambient temperature variations.
Layout – Some Examples

TURBODEN 7 layout

TURBODEN 10 layout

TURBODEN 18 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** 12

**Solar in operation** 1
**under construction** 1
**TOTAL** 2

**Total Plants** 265

*Hybrid Heat Recovery and Solar Thermal Power plant*
ORC Applications - Waste to Energy

Waste to Energy
Turboden ORC technology can be profitably and efficiently used to produce electric energy from waste to energy recovery processes.
The power of Turboden turbogenerators in this application ranges from 200 kW to 15 MW electric.
Waste to Energy

Product Cycle
- Material
- Product
- Waste

Waste Hierarchy
1. Prevent & Reduce
2. Reuse
3. Recycling
4. Energy Recovery
5. Disposal

Energy Recovery
- Incinerator Boilers
- Solid Waste Gasification
- Landfill Gas
- Other

Heat
Electricity

Waste should first be prevented & reduced, then reused and recycled.

What about unrecyclable waste?

Efficient Waste to Energy plants perform a recovery operation (step 4 of the hierarchy), providing energy that avoids the use of fossil fuels and reduces greenhouse gas emissions.

Waste to Energy handles waste that cannot be recycled and would otherwise be landfilled.

Waste to Energy

**What waste?**
Waste-to-Energy plants are designed to incinerate:

- **Municipal Solid Waste (MSW)**
- Similar waste from *industry and commerce* can be treated as well
- **Sewage sludge** and **medical waste** can be co-incinerated in certain percentages, but they need special storage and handling facilities
- **No pre-treatment** is needed, except that very large pieces (more than 1 m) and bulky items have to be shredded
- **Hazardous and radioactive waste** is not permitted, it has to be treated in dedicated facilities

**Source:** ESWET handbook

---

**Waste production**
500 kg/person/year

**Recycling rate**
50%

**Still 250 kg of waste to be treated**

**Example:**
0.5 million people city needs a 125,000 tons WTE plant

**Size**
- Convenience for at least 40,000 t/yr
- Largest plants size: 1Mt/yr
- Individual line capacity: 2.5 – 50 t/h
  usually 5-30 t/h
- At least 8,000 operating hours per year (94%)

**How much**
- Tailor made plants, depending on very specific local requirements
- Typical EU value:
  500 - 700 € per t/yr installed capacity

**Note:**
1) EU citizen average
2) Today’s EU average is 40%
3) Not including cost for the site and for project development

**Source:** ESWET handbook
Waste to Energy - General scheme

- Heat source
  - Heat carrier loop
    - Pressurized water
    - Saturated steam
    - Thermal oil
    - Direct exchange
  - Municipal solid waste incineration
  - Landfill gas
  - Waste syngas
  - Hot stream in WTE
  - Other

- Heat exchangers
- Turbo expander
  - Electric power (or mechanical)
  - Organic Rankine Cycle
  - Steam Rankine Cycle
  - Other

- Heat rejection system
- Cooling tower
- Water cooled condenser
- Air cooled condenser
- ... 

- Potential thermal users
  - Process
  - District heating
  - Absorption chiller
  - ...

Note: 1) to be evaluated depending on exhaust gases composition
ORC finds many applications in the Waste to Energy sector

A. Steam or hot water from incinerator boiler
   1. Revamping of existing WTE plants
   2. New units

B. Municipal Solid Waste gasification

C. Landfill engines exhaust gas

D. Primary heat conversion system - alternative to steam turbine
Waste to Energy applications

A  Steam or hot water from incinerator boiler

1. in existing plant as second user to existing district heating network
2. for new installation also in power only configuration

1. Bunker
2. Furnace
3. Heat recovery Steam generator
3a. Economizer
3b. District Heating Network
3c. ORC
4a. ESP
4b. Chemical Reactor
4c. Bag Filter
4d. Denox
5. Chimney
Waste to Energy applications

A Hot water from WTE – Mirom, Belgium

**Plant type:**
62,000 t/yr MSW plant
Plant in operation since 1976
2 boilers of 8 MW$_{th}$ each

**Customer:**
MIROM

**In operation since:**
April 2008

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

**Cooling source:**
water/air dissipation

**Total electric power:** 3 MW

**Net electric efficiency:** 16.5%

**Availability:** > 98%

---

Use of heat: hot water at 180°C

1. District heating from 1986:
   - 21 customers, 12 km network
2. ORC from 2006
   - in parallel of district heating use

- Example of *Turboden 30 HR* ORC plant for heat recovery from district heating waste to energy plant: 3 MW$_e$ installation in *Roeselare (Belgium)*
- Good performances in a **very fluctuating conditions**
- Plant overall efficiency increased
**Waste to Energy applications**

**A  Hot water from WTE – Nantes, France**

- **Plant type:** Heat recovery from pressurized water boiler in waste incinerator
- **Incinerator:**
  - 2 lines of 9.5 t/h → 150,000 t/yr
  - FGT: FF+DRY+CA+SCR
  - Production of superheated water at 200°C → 130 GWh/yr for district heating, ORC in parallel
- **Customer:** Seche Environnement Usine – Alcea (Nantes - France)
- **In operation since:** October 2014
- **Heat source:** hot water at 200°C (back 130°C)
- **Cooling source:** water/air
- **Total electric power:** 2.7 MW
- **Net electric efficiency:** 16.5%

Example of **Turboden 30 HR Low temperature** ORC plant for heat recovery from hot water: 2.7 MW installation in Nantes (France)
**Waste to Energy applications**

**A** Low-pressure steam – Lons le Saunier, France

**Plant type:**
Heat recovery from low pressure steam in waste incinerator

**Incinerator:**
A grate furnace of 5 t/hr (PCI = 2,200 kcal/kg)
A recovery boiler: 14 t/h steam at 350°C, 29.5 bar
A back pressure turbine of 1MW
A district heating fed by steam at 4 bar with a steam exchanger hot water boiler of 7 MW

**End user:** UVE du SYDOM (operated by VEOLIA propreté Rhin Rhone) – Lons le Saunier, France

**In operation since:** August 2015

**Heat source:** low pressure steam at 4.5 bars 180°C (back 78°C)

**Cooling source:** air

**Total electric power:** 750 kW

**Net electric efficiency:** 13.6%
Waste to Energy applications

B Municipal Solid Waste gasification

- Municipal Solid Waste gasifier + syngas cleaning
- Internal combustion engine
  - Syngas combustion boiler
  - Syngas Turbine
- Heat exchanger
  - Direct exchange
  - Thermal oil
- Organic Rankine Cycle
  - 25 ÷ 35% additional power (1)
- Mechanical/electric power
- Cooling tower
  - Water cooled condenser
  - Air cooled condenser

Note: 1) Percent of the prime mover nominal power referring to gas turbines
Waste to Energy applications

B Municipal Solid Waste gasification

Notes:
Turboden ORC turbogenerator sizes range between 200 kw and 15 MW

Up to 35% additional power
### Waste to Energy applications

#### B Municipal Solid Waste gasification

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pro</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal combustion engine</td>
<td>• High conversion efficiency</td>
<td>• Syngas cleaning system required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Frequent maintenance</td>
</tr>
<tr>
<td>Syngas turbines</td>
<td>• Good reliability</td>
<td>• Medium conversion efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Few references</td>
</tr>
<tr>
<td>Syngas combustion boiler</td>
<td>• Simplicity</td>
<td>• Lower conversion efficiency</td>
</tr>
<tr>
<td></td>
<td>• Lower O&amp;M costs</td>
<td></td>
</tr>
</tbody>
</table>
Plant type: Industrial waste synthesis gas burned in a thermal oil boiler

Customer: ITC-KA Enerji Uretim Sanayi VE Ticaret A.S., Mamak (Ankara), Turkey

Status: first unit in operation since February 2014, second unit in operation since May 2015

Heat source: thermal oil at 315°C from 2 boilers of 20 MW$_{th}$ each

Cooling source: cooling towers

Total electric power: 2 units of 5.5 MW each

Net electric efficiency: 25%

Availability: > 98%

Example of Turboden tailor-made ORC plant for heat recovery from waste gasification: 5.5 MW$_e$ installation in Ankara (Turkey)
Waste to Energy applications

C Landfill engines exhaust gas

- Landfill gasification
- Internal combustion engine
- Mechanical/electric power
- Heat exchanger
  - Direct exchange
  - Thermal oil
- Organic Rankine Cycle
  - 7 ÷ 10% additional power
- Cooling tower
- Water cooled condenser
- Air cooled condenser

Note: 1) Percent of the prime mover nominal power
C. 7%-10% of the prime move nominal power output is recovered through ORC.
Plant type: 15 MWₐ engine power plant utilizing landfill gas (one of the largest facilities in Europe) 49,000 t/yr of biowaste composting

Customer: Helsinki Region Environmental Services Authority (HSY)

In operation since: October 2011

Heat source: thermal oil at 275°C from 4 MWM engines of 4 MWₐ each

Cooling source: air coolers

Total electric power: 1.3 MW

Net electric efficiency: 20.6%

Availability: > 98%

Example of Turboden 14 HR ORC plant for heat recovery from landfill gasification: 1.3 MWₑ installation in Espoo (Finland)
Waste to Energy applications

Primary heat conversion system alternative to steam turbine

<table>
<thead>
<tr>
<th></th>
<th>Steam</th>
<th>ORC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working fluid temperature</td>
<td>&gt;400°C</td>
<td>100 - 320°C</td>
</tr>
<tr>
<td>Working fluid pressure</td>
<td>&gt;30 bar</td>
<td>&lt; 15 bar</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Operators needed</td>
<td>At least 1 licensed operator 24/7</td>
<td>1 low-skilled 1 hour/day</td>
</tr>
<tr>
<td>Water treatment</td>
<td>necessary</td>
<td>not present</td>
</tr>
<tr>
<td>Turbine overhaul and/or replacement</td>
<td>5 – 7 years</td>
<td>20 years</td>
</tr>
<tr>
<td>Gross Electric Efficiency</td>
<td>20 – 30%</td>
<td>18 - 25%</td>
</tr>
</tbody>
</table>
Plant type: Heat recovery from dried sewage sludge incineration (Sewer District water treatment plant)

End user: Albany County Sewer District

Site: Albany County, Menands, NY

Start-up in operation since March 2013

ORC electric power: 0.9 MW

Heat source: thermal oil at 285°C

Electrical efficiency: 19.3%

Cooling source: water/air dissipation

Process features:

- Multiple-hearth incineration for sewage-sludge produced in a 35 million gallon per day waste water treatment plant
- Operation: 106 hours/week
- 1.5 dry tons per hour of sewage sludge
- Exhaust gas from sludge incinerators: 538 - 677 °C
- Incinerator flue gas volumetric flow rate: 17 tonnes/sec– 21 tonnes/sec
Turboden at a Glance
Turboden strong points

- 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