Turboden Solutions in the Oil&Gas Industry
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.

Over 35 Years of Experience

1980 - Founded by Mario Gaia, professor at Politecnico di Milano

1998 – First ORC biomass plant in Switzerland (300 kW)

1990’s – First ORC projects in solar, geothermal and heat recovery applications

2000’s - ORC biomass plants in Europe

2009 - United Technologies Corp. (UTC) acquires the majority of Turboden’s quotas. PW Power Systems supports Turboden in new markets beyond Europe. 100 plants sold

2013 - MHI acquires the majority of Turboden. Italian shareholders stay in charge of management

Today - Over 300 plants in the world, over 270 in operation
Over 35 Years of Experience

1984 – 40 kW_e ORC turbo-generator for a solar plant in Australia

1987 – 3 kW_e ORC turbo-generator for a biomass plant in Italy

1988 – 200 kW_e ORC geothermal plant in Zambia

2008 – 3 MW_e ORC turbo-generator for heat recovery on a waste incinerator in Belgium

2009 – First 100 plants and first installed 100 MW_e

2010 – First plant overseas

2016 – Over 300 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

**Turboden – a Group Company of MHI**

**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.
Turboden has currently more than 300 reference plants worldwide

### Turboden Plants

<table>
<thead>
<tr>
<th>Application</th>
<th>Size</th>
<th>Plant in Operation</th>
<th>Under Construction</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MW</td>
<td>no.</td>
<td>MW</td>
<td>no. MW</td>
</tr>
<tr>
<td>Wood Biomass</td>
<td>0.2 – 8.0</td>
<td>238</td>
<td>280.5</td>
<td>45** 87,1</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.5 – 16.5</td>
<td>8</td>
<td>29.3</td>
<td>2 19.5</td>
</tr>
<tr>
<td>Solar thermal power</td>
<td>0.1 – 3.8</td>
<td>1*</td>
<td>2</td>
<td>4** 5.5</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>0.5 – 5.0</td>
<td>20*</td>
<td>35.3</td>
<td>7 22.2</td>
</tr>
<tr>
<td>Waste to Energy</td>
<td>0.5 - 5.3</td>
<td>9</td>
<td>20.3</td>
<td>0 0</td>
</tr>
<tr>
<td><strong>Total Turboden Plants</strong></td>
<td></td>
<td>275</td>
<td>367.4</td>
<td>57 134.3</td>
</tr>
</tbody>
</table>

* Hybrid heat recovery and solar plant
** Hybrid biomass and solar plant

### Country

<table>
<thead>
<tr>
<th>Country</th>
<th>plants</th>
<th>Country</th>
<th>plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>94</td>
<td>Russia &amp; CIS</td>
<td>10</td>
</tr>
<tr>
<td>Italy</td>
<td>82</td>
<td>Rest of the World</td>
<td>8</td>
</tr>
<tr>
<td>Austria</td>
<td>31</td>
<td>Turkey</td>
<td>6</td>
</tr>
<tr>
<td>Rest of Europe</td>
<td>92</td>
<td>North America</td>
<td>9</td>
</tr>
</tbody>
</table>

*Last Update: August 2016*
Waste heat from industrial processes can be recovered and converted into power.
Waste heat to power

- Gas turbines
- Internal combustion engines
- Hot streams from industrial processes
- ...

- Direct exchange
- Heat carrier loop
  - Thermal oil
  - Pressurized water
  - Saturated steam
  - ...

- Organic Rankine Cycle
- Steam Rankine Cycle
- Other

- Cooling towers
- Water cooled condensers
- Air cooled condensers
- ...

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

- Electric power (or mechanical)

- Heat source
- Heat exchanger
- Turbo expander
- Heat rejection system

(Turboden S.r.l. All rights reserved)
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.

➢ Turboden solutions from 200 kW to 20 MW electric per single shaft
## Organic Rankine Cycle: concept

<table>
<thead>
<tr>
<th>Cycle</th>
<th>it is a thermodynamic cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rankine</td>
<td>it is theoretically given by 2 isobar and 2 adiabatic thermodynamic transformations</td>
</tr>
<tr>
<td>Organic</td>
<td>it exploits an organic working fluid</td>
</tr>
</tbody>
</table>

**The principle** is based on a turbogenerator working as a normal steam turbine to transform thermal energy into mechanical energy and finally into electric energy through an electric generator. **Instead of** the water steam, the ORC system **vaporizes an organic fluid**, characterized by a **molecular mass higher than water**, which leads to a **slower rotation** of the turbine and to **lower pressure and erosion** of the metallic parts and blades.

**Efficiency:** 98% of incoming thermal power is transformed into **electric power** (around 20%) and **heat** (78%), with extremely limited thermal leaks, only 2% due to thermal isolation, radiances and losses in the generator. The electric efficiency obtained in **non-cogeneration** cases is much higher (more than 24% of the thermal input).
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

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

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

**Organic Rankine Cycle (ORC)**

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

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

- 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)
ORC performance at partial load
Waste heat to power ORC plant

Source of waste heat
(reciprocating engines and gas turbine exhausts, industrial process exhausts, etc.)

External heat exchanger (2)

Heat-carrying loop (1)

ORC battery limit

Cooling system or cogeneration (3)

Mechanical/electric power output

Note
1) Heat-carrying loop may be filled with verse media e.g. thermal oil, saturated steam, pressurized water or it can be replaced by a direct exchange between the exhaust and the organic fluid
2) Possibility to exploit multiple thermal sources
3) Cooling tower, water cooled condenser, air cooled condenser, other
ORC finds many applications in the Oil&Gas sector

A. Gas turbines exhaust gas
   Gas compressor stations, natural gas liquefaction, oil pumping stations, etc.

B. Hot water from exhausted/unused oil wells

C. Associated Petroleum Gas (APG)

D. Refinery hot streams
   Distillation columns, Oil/Gasoline/Kerosene production, etc.
**Oil&Gas applications**

**A) Gas turbines exhaust gas**

- Gas turbines
  - Gas compressor stations
  - Gas storage GTs
  - Oil pumping stations
  - Sea water injection systems
  - ...
- Internal combustion engines

**Turboden References**

- **TransGas – Canada**
  - GT power: 3.5 MWe
  - ORC power: 1 MWe
  - Thermal oil circuit
  - In operation since Q4 2011

- **Polyimpex – Russia**
  - GT power: 25 MWe
  - ORC power: 3 MWe
  - CHP th. power: 15 MWth
  - Direct Exchange
  - Status: under construction

(1) Percent of the prime mover nominal power
25% - 35% of the prime mover nominal power output is recovered through ORC

NOTE: Indicative values assuming ambient ISO conditions.
Gas Turbines operating at nominal load; calculations based on Gas Turbine exhaust gas properties as reported in specific suppliers web sites.

Up to 35% additional power
**Thermal oil heat carrier loop**

**ORC-based heat recovery solution:**

- Thermal oil / pressurized water / steam heat recovery exchangers with exhaust gas
- Silicon-based fluids, hydrocarbons or refrigerants used as working fluids
- Water cooled or air cooled condensers employable

**TURBODEN ORC UNIT**

**HEAT EXCHANGERS**

Typically not included in Turboden scope of supply
Direct exchange

**ORC direct exchange solution:**

The thermal energy contained in the exhaust gas is transferred directly, through direct exchange between exhaust gas and the working fluid, to the ORC plant.

For this solution the primary exchanger (exhaust gas / ORC working fluid) is included in the Turboden scope of supply.
CCGT Schemes

1 turbine, 1 ORC

Thermal Oil

Direct Exchange

Multiple Heat Sources

Separated thermal oil heat recovery exchangers

Exhaust gas conveyed to a single heat recovery exchanger
CCGT multiple recovery example

Exhaust gas
Outlet temperature = 170°C

Thermal oil loop
T = 300°C

GE LM 2500
ON

GE LM 2500
ON

GE LM 2500
OFF / SB

HR TO exchanger

TURBODEN ORC
Pel= 15 MW

Exhaust gas
T = 525°C
m = 63.9 kg/s

HR TO exchanger

Thermal oil loop
T = 140°C

AIR CONDENSER

Dry bulb average air temperature at 15°C
A huge potential resides in WHR on Oil&Gas infrastructures

Reference case

**Germany Gas Transmission System Operator**

- **28** Gas Compressor Stations on **11,550 km** network (1)

  - Capacity factor considered: **45%** (2)
  - Total mechanical drive installed capacity: **990 MW**

  - Equivalent power considered: **445 MW**
  - ORC recovery factor: **30%**
  - ORC potential: **135 MWe**

  - Equivalent operating hours: **6,000 h/y** (3)
  - Energy savings: **800 GWh → 48 M€/y** (4)
  - or **208 million cubic meter of natural gas** (5)
  - Emission avoided: **320,000 t CO₂/y** (6)

Example: Germany midstream application

---

(1) Source ENTSOG Ten Year Network Development Plan 2011-2020
(2) Assuming 3 gas turbine per site. Average power: 1 nominal (100%) + 1 partial load (35%) + 1 backup (0%)
(3) Assuming seasonal fluctuations in GCS operation, ORC availability > 95%
(4) Assuming an electricity value of 60 €/MWh
(5) Assuming a consumption of 260 mc of natural gas per MWh of power generated
(6) Assuming an average emission factor of EU power generation plants of 400 t CO₂ per GWh (source IEA 2013)
Natural Gas Compressor Stations: a big opportunity for Heat Recovery

- World natural gas yearly consumption: about 3,000 billion m³
- Compressor stations usually placed at 40 to 100 miles intervals along the pipelines
- Dozens of GW of compression capacity to move natural gas from production sites to users
- Most compressor stations are operating on an open cycle (efficiency about 30-35%)

Dozens of GW of thermal power (in form of hot exhaust gas) are wasted into the atmosphere
Oil&Gas applications

1. Hot water from exhausted oil wells

- Geothermal water in oil fields
- Associated hot water
- 100 - 180°C

- Organic Rankine Cycle
  Efficiency up to 16%

- Electric power

- Cooling towers
- Water cooled condensers
- Air cooled condensers

Turboden references

48.8 MW in 10 geothermal plants
Oil&Gas applications

Associated Petroleum Gas (APG)

- Boilers
- Gas turbines*

Exhaust gases of flare gas burners in petrochemical plants

- Heat exchanger
  - Thermal oil

- Organic Rankine Cycle
  - Efficiency up to 25%

- Electric power

- Cooling towers
- Water cooled condensers
- Air cooled condensers

Turboden references

Russian Oil&Gas company
Flare gas: 3.5 MWe
ORC power: 1.8 MWe
Burner + thermal oil circuit
Start up: Q1 2015

* Low heating value gas turbine
Turboden reference – APG exploitation

Site: Perm, Russia
Customer/End user: LabNT/LUKoil
Status: in operation since September 2015
Heat source: flare gas burning (boiler designed to burn gas with a minimum lower calorific value of 4,500 kcal/Nm3
Heat source temperature: thermal oil at 300 °C
Inlet/Outlet water temperature: 65/95 °C
Electric power: ~1.8 MW
Net electric efficiency: ~18%

Project description
Flare gas from oil extraction wells is burned to heat up thermal oil which is used to feed up an ORC CHP unit. The electricity produced reduces the plant consumptions, whereas the hot water produced is exploited in oil refinery processes including warming up of refined products to be pumped.
APG exploitation – Further development

As a further development of the solution a low calorific value gas turbine can be employed and the ORC can be configured in direct exchange mode, exploiting the exhaust gases of the gas turbine.

Direct heat exchanger between the ORC working fluid and the flue gas

Organic Rankine Cycle Efficiency up to 25%

- Cooling towers
- Water cooled condensers
- Air cooled condensers

The flare gas feeds a low calorific gas turbine

Exhaust gases of flare gas burners in petrochemical plants

Electric power

Electric power
**Oil&Gas applications**

**Refinery hot streams**

- Hot stream used for treatment and then dissipated
- Thermal oil used in Oil&Gas processes

---

**Organic Rankine Cycle**

Efficiency up to 25+\% \(^{(1)}\)

---

**Turboden case study**

Thermal oil power: 53 MW
ORC electric power: 10 MW

\(^{(1)}\) Heat carrier temperature above 300°C
References – Combined Cycle Gas Turbines

**Gas Compressor Station – TransGas**

Heat recovery from Solar CENTAUR gas turbine in a Gas compressor station in Canada
Gas turbine prime power: 3.5 MWe
Gas turbine efficiency: 28%
**ORC** electric power: 1 MW
General contractor: IST
Final client: TransGas
Start up: in operation since November 2011

**Gas Compressor Station**

Heat recovery from Solar TITAN 130 gas turbine in a Gas Turbine Power Plant (GTPP) in Russia (Moscow region)
Gas turbine prime power: 15 MWe
Gas turbine efficiency: 30%
**ORC** electric power: 3 MW direct exchange cogenerative solution
ORC thermal power: 15 MW of hot water at 90°C
General Contractor: Energo development LCC
Final Client: undisclosed
Status: under construction
## References – Internal Combustion Engines

<table>
<thead>
<tr>
<th>Project</th>
<th>ORC Module</th>
<th>Site</th>
<th>Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pisticci I</td>
<td>18 HR SPLIT (1.8 MWe) Start up: Q2 2010</td>
<td>Pisticci (IT)</td>
<td>3 x 8 MWe Wartsila Diesel engines</td>
</tr>
<tr>
<td>Termoindustriale</td>
<td>6 HR SPLIT (0.6 MWe) Start up: Q4 2008</td>
<td>Pavia (IT)</td>
<td>1 x 8 MWe MAN Diesel engine</td>
</tr>
<tr>
<td>Pisticci II</td>
<td>40 HR SPLIT (4 MWe) Start up: Q2 2012</td>
<td>Pisticci Scalo (IT)</td>
<td>2 x 17 MWe Wartsila Diesel engines</td>
</tr>
<tr>
<td>Cereal Docks</td>
<td>6 HR DIR. EXCH. (0.6 MWe) Start up: Q1 2012</td>
<td>Portogruaro (IT)</td>
<td>1 x 7 MWe Wartsila Diesel engine</td>
</tr>
<tr>
<td>E&amp;S Energy</td>
<td>6 HR SPLIT (0.6 MWe) Start up: Q2 2010</td>
<td>Catania (IT)</td>
<td>2 x 1 MWe JGS/GE gas engines + 3 x 0.8 MWe JGS/GE gas engines + 1 x 0.6 MWe JGS/GE gas engine</td>
</tr>
<tr>
<td>Ulm</td>
<td>10 HR cogenerative (1 MWe) Start up: Q3 2012</td>
<td>Senden (DE)</td>
<td>2 x 2 MWe JGS/GE gas engines (+ additional heat from the process)</td>
</tr>
<tr>
<td>Kempen</td>
<td>6 HR cogenerative (0.6 MWe) Start up: Q1 2012</td>
<td>Kempen (DE)</td>
<td>Gas engines</td>
</tr>
<tr>
<td>Mondopower</td>
<td>10 HR (1 MWe) Start up: Q4 2012</td>
<td>Chivasso (IT)</td>
<td>1 x 17 MWe Wartsila Diesel engine</td>
</tr>
<tr>
<td>HSY</td>
<td>14 HR (1.3 MWe) Start up: Q4 2011</td>
<td>Ämmässuo, Espoo (FIN)</td>
<td>4 x 4 MWe MWM gas engines</td>
</tr>
<tr>
<td>Fater</td>
<td>7 HR DIR. EXCH. (0.7 MWe) Start up: Q2 2013</td>
<td>Pescara (IT)</td>
<td>1 x 8 MWe Wartsila Diesel engine</td>
</tr>
</tbody>
</table>
WHTP with ORC in cement industry

<table>
<thead>
<tr>
<th>Start up year</th>
<th>References in cement plants</th>
<th>Heat source</th>
<th>ORC gross electric power [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Italcementi - Ciment du Maroc, Marocco</td>
<td>PH + CSP</td>
<td>1.5</td>
</tr>
<tr>
<td>2012</td>
<td>Holcim Romania</td>
<td>PH + CC</td>
<td>4</td>
</tr>
<tr>
<td>2014</td>
<td>CRH (ex Holcim Group)</td>
<td>PH + CC</td>
<td>5</td>
</tr>
<tr>
<td>2015</td>
<td>Heidelberg Cement – Cartpacement Romania</td>
<td>PH + CC</td>
<td>4</td>
</tr>
<tr>
<td>2016</td>
<td>Cementi Rossi</td>
<td>PH + CC</td>
<td>2</td>
</tr>
</tbody>
</table>

(PH): preheating system, (CSP): concentrated solar power, (CC): clinker cooler
References – Steel industry

1. Electric Arc Furnace Data

<table>
<thead>
<tr>
<th>Heat source</th>
<th>EAF process off-gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel production</td>
<td>1M tons/year</td>
</tr>
<tr>
<td>Heats per day (average)</td>
<td>32</td>
</tr>
<tr>
<td>EAF hourly production</td>
<td>133 tons/hour</td>
</tr>
<tr>
<td>Tapping weight</td>
<td>100 tons</td>
</tr>
<tr>
<td>Tapping temperature</td>
<td>1,600°C</td>
</tr>
<tr>
<td>Charge weight</td>
<td>113 tons</td>
</tr>
<tr>
<td>Average off-gas temperature</td>
<td>1,100°C</td>
</tr>
<tr>
<td>(core temperature ex EAF)</td>
<td></td>
</tr>
<tr>
<td>Average off-gas flow rate</td>
<td>100,000 – 140,000 Nm³/h</td>
</tr>
</tbody>
</table>

2. Heat recovery system Data

<table>
<thead>
<tr>
<th>Nominal steam data at steam drum</th>
<th>247°C – 38 bar(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content cooling system (pipes + tank)</td>
<td>approx. 37 m³</td>
</tr>
<tr>
<td>Capacity of steam accumulation of cooling system</td>
<td>1,442 kg</td>
</tr>
<tr>
<td>Inlet thermal power to the ORC</td>
<td>13,517 kW</td>
</tr>
<tr>
<td>Steam temperature into ORC</td>
<td>228–245°C</td>
</tr>
<tr>
<td>Condensate temperature out from ORC</td>
<td>100°C</td>
</tr>
<tr>
<td>Thermal power to the cooling water</td>
<td>10,640 kW</td>
</tr>
<tr>
<td>Cooling water temperatures (in/out ORC)</td>
<td>26°C / 44°C</td>
</tr>
<tr>
<td>Gross electric power output</td>
<td>2,680 kW</td>
</tr>
<tr>
<td>Net electric power output</td>
<td>2,560 kW</td>
</tr>
</tbody>
</table>

In operation since December 2013
**References – Direct Exchange**

<table>
<thead>
<tr>
<th>Project</th>
<th>Customer</th>
<th>Site</th>
<th>Heat Source</th>
<th>ORC power</th>
<th>Start up</th>
</tr>
</thead>
<tbody>
<tr>
<td>food industry</td>
<td>Cereal Docks</td>
<td>Italy</td>
<td>7 MW diesel engine</td>
<td>700 kW</td>
<td>Q1 2012</td>
</tr>
<tr>
<td>personal care</td>
<td>Alma CIS/Fater</td>
<td>Italy</td>
<td>18V32 diesel engine</td>
<td>700 kW</td>
<td>Q2 2013</td>
</tr>
<tr>
<td>industry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>steel industry</td>
<td>Natsteel/TATA group</td>
<td>Singapore</td>
<td>hot rolling mill reheating furnace</td>
<td>700 kW</td>
<td>Q1 2013</td>
</tr>
<tr>
<td>cogenerative</td>
<td>Polyimpex</td>
<td>Russia</td>
<td>Solar TITAN 130 gas turbine</td>
<td>3,000 kW</td>
<td>Under construction</td>
</tr>
<tr>
<td>cement industry</td>
<td>Cementi Rossi</td>
<td>Italy</td>
<td>clinker cooler</td>
<td>2,000 kW</td>
<td>Under construction</td>
</tr>
</tbody>
</table>

![Image of ORC power plant](image-url)
References – Biomass

236 references in operation, 277 MW installed

Example of large size ORC (thermal oil input): West Fraser Mills Ltd

Site 1: Chetwynd, British Columbia - Canada - 2 x Turboden ORC Units; in operation since March 2015

Site 2: Fraser Lake, British Columbia - Canada - 2 x Turboden ORC Units; in operation since November 2014

- **Fuel**: sawmill scraps, woodchips
- **ORC heat carries**: thermal oil
- **ORC electric power**: 4 x 6.5 MW
References – Geothermal
8 references in operation, 29 MW installed

**Sauerlach**
**Customer:** SWM - StadtWerke München (Munich multi-utility)
**Site:** Sauerlach, Germany
**ORC size:** 5.6 MWe + 4 MWth to district heating
**Start up:** January 2013
**Scope of supply:** Complete ORC supply, air condenser includes

**Dürrnhaar**
**Customer:** Hochtief Energy Management GmbH
**Site:** Dürrnhaar (München), Germany
**ORC size:** 5.6 MWe
**Start up:** December 2012
**Scope of supply:** full EPC for ORC, air condenser and BOP

**Kirchstockach**
**Customer:** Hochtief Energy Management GmbH
**Site:** Kirchstockach (München), Germany
**ORC size:** 5 MWe
**Start up:** January 2013
**Scope of supply:** full EPC for ORC, air condenser and BOP

**Key factors:**
- Close to the Munich urban area (<10 km)
- Coupled with urban district heating network
- Possibility to work on island mode (Sauerlach)
- Medium enthalpy: 140°C
- Non-flammable working fluid
- Small area covered due to houses in the nearby
- Turboden supply all the components except geothermal pump an circuit

8 references in operation, 29 MW installed
References – Low temperature water

**Waste to energy – Mirom, Belgium**

Heat recovery from **pressurized water** boiler in **waste incinerator**

**Customer:** MIROM  
**Location:** Roeselare, Belgium  
**Source:** hot water at 180° C (back at 140° C)  
**Cooling source:** air coolers  
**ORC electric power:** 3 MW  
**Electrical efficiency:** 16.5%  
**Availability:** >98%  
**Start up:** Q2 2008

**Waste to energy – Séché, Francia**

Heat recovery from **pressurized water** boiler in **waste incinerator**

**Customer:** Séché Environnement Usine - Alcea  
**Location:** Nantes, France  
**Source:** hot water at 200° C (back at 130° C)  
**Cooling source:** air coolers  
**ORC electric power:** 2.4 MW  
**Electrical efficiency:** 16.5%  
**Start up:** Q3 2014
Reference case

3 gas turbine (Siemens SGT 600) at full load (100%)

Site: Middle East

Cooling temperature (ambient air): 26°C
Cooling system: Air cooled condenser

ORC Size: 15 MWe
Net Power: 13.2 MWe

Equivalent operating hours: 8,000 h/y (1)
Energy savings: 106 GWhe → 6.3 M€/y (2)

or 22 mcm of natural gas (3)
Emission avoided: 68,900 t CO₂/y (4)

(1) Middle East Gas infrastructures work continuously, ORC availability > 95%
(2) Assuming an electricity value of 80 €/MWhe as barrels of oil savings
(3) Assuming a consumption of 260 mc of natural gas per MWh of power generated
(4) Assuming an average emission factor of EU power generation plants of 650 t CO₂ per GWh (source IEA 2013)
Case study – Heat recovery from GTs (2/2)

- ORC building
- Air cooled condenser
- Thermal oil heat exchangers
- Gas turbines
Conclusion

- ORC technology is a proven way to reduce equivalent fuel consumption and CO₂ emission in Oil&Gas infrastructure equipment

- Turboden ORC technology for waste heat recovery makes Oil&Gas greener

- Turboden has experience in Oil&Gas technical codes and standards

- Provide us with your waste heat data to allow us studying an optimum heat recovery solution
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