Turboden ORC plants for Industrial Heat Recovery

The proven way to address environmental sustainability
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.

### ’60-’70
- 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).

### 1980-1999
- 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.

### 2000-2009
- 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.

### 2009-2013
- 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.

### 2016...
- Today - Over 300 ORC plants in the world, over 240 in operation.
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 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
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 15 MW electric per single unit
The turbogenerator uses the 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) (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.
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

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

Heat Recovery
Turboden ORC can produce electricity by recovering heat from industrial processes, reciprocating engines and gas turbines. The power of Turboden turbogenerators in this application generally ranges between 200 kW and 15 MW electric.
HR – Applications / Energy Sources

Gaseous sources:
- **Internal combustion engines exhaust gas** (ORC as bottom cycle to Diesel and gas reciprocating engines, gas turbines)
- **Steel furnaces exhaust gas**
- **Cement, Glass and other non ferrous metal furnaces exhaust gas**
- **Exhaust Gas from waste incineration** (civil/industrial)

Liquid sources:
- **Refineries hot streams**
- **Cooling water (or other fluids) loops in industrial processes**
- **Jacket cooling water of reciprocating engines**

Condensing sources:
- **Refineries organic vapours to be condensed**
- **Surplus steam from production process** (i.e. paper production process)
- **Steam from cooling loops in industrial processes** (i.e. steel)


### HR Units - Typical Range of Operation and Performances

<table>
<thead>
<tr>
<th></th>
<th>TURBODEN 6/7 HR DE</th>
<th>TURBODEN 10 to 14 HR DE</th>
<th>TURBODEN 18 to 24 HR DE</th>
<th>TURBODEN 27 to 40 HR DE</th>
<th>TURBODEN 50 to 100 HR DE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT</strong> - Thermal Oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Oil inlet temperature °C</td>
<td>240-300</td>
<td>240-310</td>
<td>240-310</td>
<td>250-315</td>
<td>240-310</td>
</tr>
<tr>
<td>Thermal Oil outlet temperature °C</td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
</tr>
<tr>
<td>Thermal power input MW</td>
<td>2.5-4.0</td>
<td>3.0</td>
<td>5.0-7.0</td>
<td>5.5</td>
<td>8.0-12.0</td>
</tr>
<tr>
<td><strong>OUTPUT</strong> - Cooling Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal power to condenser MW</td>
<td>2.0-3.5</td>
<td>4.0-5.0</td>
<td>6.0-9.5</td>
<td>10.0-17.5</td>
<td>19.2-40.0</td>
</tr>
<tr>
<td>Typical cooling water temperature (in/out) °F</td>
<td>77/95</td>
<td>77/95</td>
<td>77/95</td>
<td>77/104</td>
<td>77/104</td>
</tr>
<tr>
<td>Thermal power to condenser MMBtu/hr</td>
<td>8,558-13,655</td>
<td>17,062-23,880</td>
<td>27,300-40,950</td>
<td>44,357-75,077</td>
<td>81,801-170,811</td>
</tr>
</tbody>
</table>

### PERFORMANCES

<table>
<thead>
<tr>
<th></th>
<th>kW</th>
<th>kW</th>
<th>kW</th>
<th>kW</th>
<th>kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross electric power</td>
<td>500-800</td>
<td>600</td>
<td>900-1600</td>
<td>1108</td>
<td>1700-2500</td>
</tr>
<tr>
<td>Gross electric efficiency***</td>
<td>17%-22%</td>
<td>20%</td>
<td>17%-22%</td>
<td>17%-22%</td>
<td>19%</td>
</tr>
<tr>
<td>Captive power consumption</td>
<td>18-36</td>
<td>25</td>
<td>36-70</td>
<td>46</td>
<td>60-100</td>
</tr>
<tr>
<td>Net active electric power output</td>
<td>480-760</td>
<td>575</td>
<td>850-1550</td>
<td>1062</td>
<td>1650-2400</td>
</tr>
<tr>
<td>Net electric efficiency***</td>
<td>16%-19%</td>
<td>19%</td>
<td>16%-21%</td>
<td>18%</td>
<td>16%-21%</td>
</tr>
<tr>
<td>Electric generator****</td>
<td>50Hz 60/480V</td>
<td>50Hz 60/480V</td>
<td>50Hz 60/480V</td>
<td>50Hz 60/480V</td>
<td>50Hz 60/480V</td>
</tr>
<tr>
<td>Cooling systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical delivery time (EDW)</td>
<td>9-11</td>
<td>9-11</td>
<td>9-11</td>
<td>11-13</td>
<td>12-14</td>
</tr>
</tbody>
</table>

* Turbocharger units up to TURBODEN 40 HR can be equipped with the "Split System", a heat exchanger allowing additional low temperature heat recovery to increase the power production. The "Split System" heat exchanger may use thermal oil / pressurized water as heat transfer fluid.

** Cooling water temperatures are selected keeping into account specific site requirements, e.g. average air temperature, water availability (to use either dry or wet heat dissipation system), possibility of CHP mode (in this specific case water up to 90°C can be generated by the OCR).

*** Electric efficiency depends on several factors, primarily Heat and Cooling Source Temperatures and thermal media. Our sales specialists will support you to optimise the solutions, evaluating specific heat source features (thermal oil, steam, pressurized water, exhaust gas) and cooling devices (dry/wet water loops, CHP, air condensing).

**** Induction or synchronous, medium voltage available upon request. If reduction gear is required, electric power is reduced of about 1.5%.

DE: Available Direct Heat Exchange for direct heat recovery from internal combustion engines exhaust gas.

DISCLAIMER NOTE: Data provided herein are not binding and might change without prior notice.
## HRS – High Electrical Efficiency Units

<table>
<thead>
<tr>
<th>INPUT - Thermal Oil</th>
<th>TURBODEN 12 HRS - 1MW</th>
<th>TURBODEN 12 HRS</th>
<th>TURBODEN 24 HRS</th>
<th>TURBODEN 32 HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with split*</td>
<td>without split</td>
<td>with split*</td>
<td>without split</td>
</tr>
<tr>
<td>Thermal power input &quot;HT&quot; loop kW</td>
<td>3617</td>
<td>4043</td>
<td>4425</td>
<td>4817</td>
</tr>
<tr>
<td>Nominal temperature &quot;LT&quot; loop (in/out) °C</td>
<td>208/198</td>
<td>-</td>
<td>210/198</td>
<td>-</td>
</tr>
<tr>
<td>Thermal power input &quot;LT&quot; loop kW</td>
<td>338</td>
<td>-</td>
<td>392</td>
<td>-</td>
</tr>
<tr>
<td>Overall thermal power input kW</td>
<td>4115</td>
<td>4043</td>
<td>4817</td>
<td>4817</td>
</tr>
<tr>
<td>Nominal temperature &quot;HT&quot; loop (in/out) °F</td>
<td>581/405</td>
<td>581/399</td>
<td>581/410</td>
<td>581/403</td>
</tr>
<tr>
<td>Thermal power input &quot;HT&quot; loop MMBtu/hr</td>
<td>13.02</td>
<td>13.00</td>
<td>15.08</td>
<td>15.44</td>
</tr>
<tr>
<td>Nominal temperature &quot;LT&quot; loop (in/out) °F</td>
<td>408/266</td>
<td>-</td>
<td>410/266</td>
<td>-</td>
</tr>
<tr>
<td>Thermal power input &quot;LT&quot; loop MMBtu/hr</td>
<td>1.15</td>
<td>-</td>
<td>1.34</td>
<td>-</td>
</tr>
<tr>
<td>Overall thermal power input MMBtu/hr</td>
<td>14.18</td>
<td>13.30</td>
<td>16.44</td>
<td>16.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT - Cooling Water</th>
<th>TURBODEN 12 HRS - 1MW</th>
<th>TURBODEN 12 HRS</th>
<th>TURBODEN 24 HRS</th>
<th>TURBODEN 32 HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with split*</td>
<td>without split</td>
<td>with split*</td>
<td>without split</td>
</tr>
<tr>
<td>Thermal power to the cooling water circuit kW</td>
<td>3151</td>
<td>3040</td>
<td>3662</td>
<td>3632</td>
</tr>
<tr>
<td>Cooling water temperature (in/out) °F</td>
<td>77/53</td>
<td>77/53</td>
<td>77/53</td>
<td>77/53</td>
</tr>
<tr>
<td>Thermal power to the cooling water circuit MMBtu/hr</td>
<td>10.75</td>
<td>10.37</td>
<td>12.5</td>
<td>12.39</td>
</tr>
</tbody>
</table>

### PERFORMANCES

- **Gross electric power** kW
- **Gross electric efficiency** %
- **Captive power consumption** kW
- **Net active electric power output** kW
- **Net electric efficiency** %
- **Electric generator**
  - 50Hz, 400V
  - 60Hz, 480V
- **Plant size**
  - Multiple skid
  - Multiple skid
  - Multiple skid
  - Multiple skid
  - Multiple skid
  - Multiple skid
  - Multiple skid
  - Multiple skid
- **Biomass consumption*** kg/h
- **Net solar collector surface**** m²
- **Typical delivery time (EWH)** Months

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* The Turboden split system allows maximisation of electric power production for a given biomass consumption.

** Induction or synchronous, medium voltage available upon request. If reduction gear is required, electric power is reduced of about 1.5%.

*** Assuming a low heating value of biomass = 2.6 kWh/kg and boiler efficiency = 0.88 in case of ORC with split, = 0.80 in case of ORC without split. The thermal oil boiler is not included in the Turboden scope of supply.

**** Assuming design solar radiation = 800 W/m², design solar collector efficiency = 0.6 and solar multiple = 1.2. The Solar field is not included in the Turboden scope of supply.

For heat recovery applications direct heat exchange can be available.

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# HRS – High Electrical Efficiency Units

<table>
<thead>
<tr>
<th>INPUT - Thermal Oil</th>
<th>TURBODEN 50-110 HRS</th>
<th>TURBODEN 55 HRS</th>
<th>TURBODEN 65 HRS</th>
<th>TURBODEN 110 HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of Operation</td>
<td>300 - 320</td>
<td>315</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Thermal Oil inlet temperature °C</td>
<td>170 - 200</td>
<td>315</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Overall thermal power input kW</td>
<td>18000 - 40000</td>
<td>20000</td>
<td>25380</td>
<td>40023</td>
</tr>
<tr>
<td>Thermal Oil outlet temperature °F</td>
<td>356 - 392</td>
<td>374</td>
<td>374</td>
<td>374</td>
</tr>
<tr>
<td>Overall thermal power input MMBtu/hr</td>
<td>81.4 - 136.5</td>
<td>68.3</td>
<td>86.6</td>
<td>134.9</td>
</tr>
</tbody>
</table>

| OUTPUT - Cooling System (1) | | | | |
| Cooling source | water / air | water | water | water |
| Design cooling system temperature (2) °C | 0 - 40 | 25/35 | 24/34 | 25/35 |
| Thermal power to the cooling system kW | 13000 - 30000 | 14911 | 13376 | 29750 |
| Design cooling system temperature (2) °F | 39 - 104 | 77/95 | 75/97 | 77/95 |
| Thermal power to the cooling system MMBtu/hr | 44.4 - 162.4 | 48.6 | 64.7 | 97.7 |

| PERFORMANCES | | | | |
| Gross electric power kW | 4500 - 11000 | 5266 | 6348 | 10512 |
| Gross electric efficiency | 23 - 27% | 28.4% | 25.0% | 26.3% |
| Captive power consumption (3) kW | 180 - 500 | 212 | 346 | 512 |
| Net active electric power output kW | 4500 - 10000 | 5074 | 6000 | 10000 |
| Net electric efficiency (4) | 22 - 26% | 25.4% | 23.6% | 25.0% |
| Electric generator 50Hz/60Hz, MV | 50Hz, 6kV | 60Hz, 1160V | 50Hz, 8kV | 1060 |
| Biomass consumption (5) kg/h | 9000 - 20000 | 9610 | 12200 | 19010 |
| Net solar collector surface (6) m² | 45000 - 100000 | 50000 | 63500 | 98900 |
| Typical delivery time (ExW) (7) Months | 10 - 15 | 10 - 15 | 10 - 15 | 10 - 15 |

(1) Cooling water/air temperatures are selected considering specific site requirements; e.g., average air temperature, water availability (to use either dry or wet heat dissipation system), possibility of CHP mode (with hot water generation at ORC condenser).

(2) IN/OUT water temperatures for water cooling.

(3) Including working fluid pump and auxiliaries consumption. Excluding heat dissipation system and thermal oil circulation consumptions.

(4) Electric efficiency depends on several factors, primarily Heat and Cooling Source Temperatures and thermal media. Our sales specialists will support you to optimize the solutions, evaluating specific heat source features (thermal oil, steam, pressurized water, exhaust gas) and cooling devices (dry/wet water loops, CHP, air conditioning).

(5) Assuming a low heating value of biomass = 2.6 kWh/kg and boiler efficiency = 0.60. The thermal oil boiler is not included in the Turboden scope of supply.

(6) Assuming design solar radiation = 800 W/m², design solar collector efficiency = 0.6 and solar multiple = 1.2. The Solar field is not included in the Turboden scope of supply.

(7) Delivery time is defined at the moment of order considering specific project features (e.g., customer standards) and Turboden production lead at the moment of order.

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## Turboden 200/300 kW Units – Typical Performances

<table>
<thead>
<tr>
<th>THERMAL INPUT</th>
<th>TURBODEN 2 (Dual mode*)</th>
<th>TURBODEN 3 (Dual mode*)</th>
<th>TURBODEN 3 CHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated steam / Thermal Oil inlet temperature <em>HT</em> Loop (in) °C</td>
<td>200</td>
<td>220</td>
<td>310</td>
</tr>
<tr>
<td>Water condensate / Thermal Oil outlet temperature <em>HT</em> Loop (out) °C</td>
<td>181</td>
<td>201</td>
<td>221</td>
</tr>
<tr>
<td>Overall thermal power input kW</td>
<td>1234</td>
<td>1708</td>
<td>1817</td>
</tr>
<tr>
<td>Heat source flow rate**) L/h</td>
<td>2.2</td>
<td>3.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Saturated steam / Thermal Oil inlet temperature <em>HT</em> Loop (in) °F</td>
<td>352</td>
<td>428</td>
<td>590</td>
</tr>
<tr>
<td>Water condensate / Thermal Oil outlet temperature <em>HT</em> Loop (out) °F</td>
<td>353</td>
<td>394</td>
<td>437</td>
</tr>
<tr>
<td>Overall thermal power input MMMBtu/hr</td>
<td>4.21</td>
<td>5.83</td>
<td>6.21</td>
</tr>
<tr>
<td>Heat source flow rate**) Lb/min</td>
<td>81</td>
<td>118</td>
<td>309</td>
</tr>
</tbody>
</table>

### THERMAL OUTPUT – Hot water

<table>
<thead>
<tr>
<th>Hot water temperature (in/out) °C</th>
<th>35/55</th>
<th>75/95</th>
<th>35/55</th>
<th>55/75</th>
<th>60/80</th>
<th>75/90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power to the cooling water circuit kW</td>
<td>1002</td>
<td>1402</td>
<td>1300</td>
<td>1647</td>
<td>1491</td>
<td>1505</td>
</tr>
<tr>
<td>Water flow rate (in/out) °F</td>
<td>95/131</td>
<td>167/203</td>
<td>95/131</td>
<td>131/167</td>
<td>140/176</td>
<td>167/194</td>
</tr>
<tr>
<td>Thermal power to the cooling water circuit MMMBtu/hr</td>
<td>3.42</td>
<td>4.71</td>
<td>5.09</td>
<td>5.13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PERFORMANCES

<table>
<thead>
<tr>
<th>Gross active electric power kW</th>
<th>200</th>
<th>200</th>
<th>300</th>
<th>300</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captive consumption kW</td>
<td>12</td>
<td>22</td>
<td>18</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Net active electric power kW</td>
<td>188</td>
<td>178</td>
<td>282</td>
<td>274</td>
<td>280</td>
</tr>
<tr>
<td>Gross electric efficiency %</td>
<td>16.2</td>
<td>12.3</td>
<td>17.5</td>
<td>15.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Electric generator Asynchr.; 400V; 50Hz</td>
<td></td>
<td></td>
<td>Asynchr.; 400V; 50Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass consumption*** Kg/h</td>
<td>558</td>
<td>735</td>
<td>775</td>
<td>880</td>
<td>825</td>
</tr>
<tr>
<td>Typical delivery time (EXW) Months</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

* Dual mode: the same ORC module (fed with saturated steam) can be operated either in “max electric efficiency” mode or in “CHP” mode.

** In case of thermal oil the flow rate was calculated assuming “Therminol 66” properties.

*** Assuming a low heating value of biomass = 2.6 kWh/kg and a boiler efficiency = 0.85.

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HR from Reciprocating Engines: up to 10% add’l Power

NOTE: Indicative values assuming ambient ISO conditions, Engines operating at nominal load; calculations based on Engines exhaust gas properties as reported in specific suppliers’ web sites.
Turboden's ORC modules for heat recovery have a power output between 200 kWe up to 15 MWe: the minimum thermal power necessary to employ a Turboden ORC is approximately 1.2 MWt.

**Exhaust gas:** Typically contains between 1/4 and 1/3 of the fuel heat, being released at relatively high temperatures (300 ÷ 500°C).
**ORC production reaches up to 10% of engine power output**
<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 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>
HR from Gas Turbine: 25-35% add’l Power (Gas Compressor Stations)

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.

Notes:
1. Smallest Turboden HR ORC Turbogenerator produces 200 kWe
2. Largest Turboden HR ORC Turbogenerator produces 15 MWe
Heat Recovery from Gas Turbine

**Reference Plant**
Heat recovery from Solar CENTAUR gas turbine in a Gas Compressor station in Canada

- Gas Turbine prime power: 3.5MWe
- Gas Turbine efficiency: 28%

**ORC electric power**: 1MW

*General Contractor: IST (Innovative Steam Technologies)*
*Final Client: TransGas*
*In operation since November 2011*

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**Reference Plant**
Heat recovery from Solar TITAN 130 gas turbine in a Gas Turbine Power Plant (GTPP) in Russia (Moscow region)

- Gas Turbine prime power: 25MWe
- Gas Turbine efficiency: 30%

**ORC electric power**: 3MW - Direct exchange cogenerative solution
**ORC thermal power**: 15 MW of hot water at 90°C

*Customer/Project Developer: Polylimex/Energo development LCC*
*Under construction (start-up foreseen IV quarter 2014)*
Heat Recovery from Cement Production Process

Exhaust gas streams from cement production process:
- Kiln pre-heater gas
- Clinker cooler gas

Main Exhaust Gas Characteristics:
- High dust content
- Different operating conditions depending on mill operation, season, plant upsets, etc.
Heat Recovery from Cement Production Process

**Reference case study**: PRS gas waste heat recovery

**Customer**: Ciments du Maroc – Italcementi Group

**Site**: Ait Baha, Morocco

**Start-up**: in operation since November 2010

**ORC electric power**: ca. 2 MW

- Clinker production capacity: ≈ 5,000 ton/day
- Heat source: exhaust gas @ 330°C
- Gas cooled down to 220°C (extra heat used for raw material pre heating)
Heat Recovery from Cement Production Process

**Customer:** Holcim Romania – Holcim Group  
**Site:** Aleșd, Romania  
**Start-up:** in operation since July 2012  
**Heat Source:** cement production process  
**ORC electric power:** ca. 4 MW

- Clinker production capacity: ≈ 4,000 ton/day  
- Heat source: exhaust gas @ 360°C (PRS) and hot air @ 250°C (CC)  
- Thermal oil (PRS) and pressurized water (CC) heat recovery loops
Heat Recovery from Cement Production Process

Reference case study: PRS and CC gas waste heat recovery
Customer: Holcim Slovakia – Holcim Group
Site: Rohožník, Slovakia
Start-up: in operation since February 2014
ORC electric power: ca. 5 MW

- Clinker production capacity: ≈ 3,600 ton/day
- Heat source: exhaust gas @ 360°C (PRS) and hot air @ 310°C (CC)
- Thermal oil heat recovery loops
Heat Recovery from Cement Production Process

Reference case study: PRS and CC gas waste heat recovery
Customer: Carpatcement Holding – Heidelberg Group
Site: Fieni, Dâmbovița County, Romania
Start-up: in operation since July 2015
ORC electric power: ca. 3.8 MW

- Clinker production capacity: ~ 3,500 ton/day
- Heat source: exhaust gas @ 370°C (PRS) and hot air @ 290°C (CC)
- Thermal oil heat recovery loops
- Cooling with ACC
Heat Recovery from Refractory Production Process

**Reference case study**: Refractory ovens exhaust gas heat recovery

**Customer**: RHI Group

**Site**: Radenthein, Austria

**Start-up**: in operation since February 2009

**ORC electric power**: ca. 1 MW

- Refractory production capacity: ≈ 250 ton/day
- Heat source: exhaust gas @ 500°C
- Gas cooled down to ca. 150°C
Heat Recovery in Steel Industry

Main exhaust gas streams available:

- Rolling, forging
- Strip processing
- Heat treatment
- Annealing
- Blast oxygen furnaces
- Sinter
- Coke ovens
- Electric Arc Furnace

- Relatively clean exhaust gas at moderate temperature
- Cost effective for ORC ≥ 600/800 kW
- Exhaust gas: high flows, high temperatures, high dust content, large variations in operating cycle, environmental constraints
- Interface between process and energy recovery unit is critical
Reference case study: rolling mill reheating furnace waste heat recovery
Customer: Natsteel – Tata Group
Site: Singapore
Start-up: in operation since February 2013
ORC electric power: ca. 0.7 MW

- Heat source: exhaust gas from LFO burning, @ 400°C
- Direct exchange between exhaust gas and working fluid
Heat Recovery from Electric Arc Furnace

25% ÷ 30% of the power inserted in the furnace is lost in the exhaust.

70% of the lost power could be recovered.

Target: 3-5% of the EAF installed power.
PROJECT IN A GERMAN IRON&STEEL FACTORY
Exhaust gas from EAF (100 t) with steam production

Primary heat source: exhaust gas from EAF

Steam production:
The steam is produced from two different heat sources:
1. Pipe to pipe duct, modified to work with pressurized water at the boiling point
2. Substitution of the quenching tower with a shell and tubes heat exchanger which produces steam.

Steam produced: ~ 30 t/h of steam at 27 bar - 245°C

Start-up: in operation since December 2013

Steam available for the ORC unit:
~ 20 t/h of steam at 27 bar and 245°C (10 t/h is delivered to an industrial process)

Gross power output ORC unit: ~ 3 MWe

High flexibility of the heat recovery system: the ORC properly operates with a steam flow rate between 2 and 22 t/h, automatically adapting its operation to the different operating conditions

⇒ THE SYSTEM AUTOMATICALLYfollows THE EAF MELTING CYCLE
Heat Recovery from Glass Production Process

Heat source main properties:

- High exhaust gas temperature
- Constant operating conditions
- Exhaust gas with moderate dust content
- Exhaust gas must be cooled not below 200°C

High temperature ORC cycle employed:

→ ORC electrical efficiency up to 25%
Heat Recovery from Glass Production Process

**Reference case study**: Float glass production process  
**Customer**: AGC Glass Europe  
**General contractor**: GEA Bischoff  
**Site**: Cuneo, Italy  
**Start-up**: in operation since February 2012  
**ORC electric power**: ca. 1.3 MW

- Glass production capacity: ≈ 600 ton/day  
- Heat source: exhaust gas at approximately 500°C
Heat Recovery from waste incinerator plant

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

Customer: MIROM (Roeselare, Belgium)

In operation since: April 2008

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

Cooling source: water/air

Total electric power: 3 MW

Net electric efficiency: 16.5%

Availability: > 98%

Example of Turboden tailor-made ORC plant for heat recovery from hot water 3 MWe installation in Roeselare, Belgium
Heat Recovery Data Collection Sheet

<table>
<thead>
<tr>
<th>Title: Heat recovery data collection sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date: ........................................</td>
</tr>
<tr>
<td>Company: .....................................</td>
</tr>
<tr>
<td>Reference person: ................................</td>
</tr>
<tr>
<td>e-mail ........................................</td>
</tr>
<tr>
<td>tel. ...........................................</td>
</tr>
<tr>
<td>Examined process/es: ..........................</td>
</tr>
</tbody>
</table>

Note: (*) data are mandatory for a preliminary evaluation

### Technical data:

<table>
<thead>
<tr>
<th>(*)T-1 Heat Source:</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>(* )T-2 Temperature:</td>
<td>...... °C</td>
<td></td>
</tr>
<tr>
<td>(*)T-3 Flow rate:</td>
<td>...... kg/s</td>
<td>.......... Nm³/hr</td>
</tr>
</tbody>
</table>

### T-4a Heat source characteristics

- Composition:
  - CO₂: ........ %
  - CO: ........ %
  - H₂O: ........ %
  - N₂: ........ %
  - Other: ........ %

- Dust content: ........ mg/Nm³

### T-4c Presence of compounds potentially aggressive for the heat recovery system:

### T-5 Minimum temperature achievable for the waste heat source: ........ °C

Notes: ..............................................................................................................................

### T-6 If possible, enclose a PFD

### T-7 Average temperature at installation site: ........ °C

### T-8 Height above sea level: ........ m

### T-9 Availability of cooling water (well, river, ...)

- Temperature: ........ °C
- Flow rate: ........ kg/s | ........ m³/h

### T-10 If possible, enclose a typical daily operation diagram (flow rates and temperatures)

### Economical data

<table>
<thead>
<tr>
<th>(*)E-1 Operating time:</th>
<th>........ hours/day</th>
<th>........ hours/year</th>
</tr>
</thead>
</table>

### E-3 Energy sources:

- **E-3a Electricity**
  - Average cost: ........ €/MWh

- **E-3b Methane / natural gas**
  - Yearly consumption: ........ Nm³

- **E-3c Other fuels**
  - Yearly consumption: ........ [………..]
  - Average cost: ........ [€ / ……..]

### E-4 Possible co-generative use:

- Temperatures: ........ / ........ °C

### Additional notes:

- ..............................................................................................................................
- ..............................................................................................................................
- ..............................................................................................................................
- ..............................................................................................................................
- ..............................................................................................................................
- ..............................................................................................................................
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