Turboden ORC: a proven technology for Biomass cogeneration
International Conference - Energy Efficiency Through Cogeneration
RenExpo - Bucharest, Romania - November 20\textsuperscript{th}, 2014

Marco Di Prima – Sales Area Manager
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, Professor of Energy at the Politecnico di Milano, and today Managing Director of Turboden. His close connection with the university has always ensured the recruitment of highly qualified R&D personnel.

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 30 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

• MHI acquires the majority of Turboden. Italian quotaholders stay in charge of management

2013...

• Today - Over 250 ORC plants in the world, 200 in operation
Mitsubishi Heavy Industries is one of the world’s leading heavy machinery manufacturers, with consolidated sales of over $28 billion (in fiscal 2011). MHI’s products and services encompass shipbuilding, power plants, chemical plants, environmental equipment, steel structures, industrial and general machinery, aircraft, space systems and air-conditioning systems.
Over 30 Years of Experience

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

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

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

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

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

2010 – First plant overseas

2013 – Over 250 ORC plants in the world
What We Do

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

- **standard units** from 200 kW to 10 MW
- **customized solutions** up to 15 MW
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.
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
- No water needed, no water chemical treatment needed

Operational advantages / results

- Simple start-stop procedures
- Automatic and continuous operation
- No operator attendance needed
- Quiet operation
- High Availability (Admont – over 70,000 hours of operation, availability > 98%)
- 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

Turboden ORC plants in the world

AUSTRALIA: 60
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

AUSTRIA: 30
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

BELGIUM: 4
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

BULGARIA: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

CANADA: 5
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

CROATIA: 5
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

CZECH REP: 3
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

DENMARK: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

ESTONIA: 2
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

FINLAND: 2
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

FRANCE: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

GERMANY: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

GREECE: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

INDONESIA: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

ITALY: 6
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

JAPAN: 8
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

LATVIA: 13
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

MOROCCO: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

NETHERLANDS: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

POLAND: 11
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

ROMANIA: 2
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

RUSSIA: 6
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SINGAPORE: 2
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SLOVAKIA: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SLOVENIA: 5
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SPAIN: 7
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SWEDEN: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

SWITZERLAND: 6
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

TURKEY: 2
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

UNITED KINGDOM: 3
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

UNITED STATES: 1
- Biomass: 1
- Heat recovery: 1
- Geothermal: 1

Total plants in operation: 298
- Biomass: 201
- Heat recovery: 16
- Geothermal: 22
- Solar: 6
- Waste to energy: 2

Total under construction: 250
- Biomass: 44
- Heat recovery: 6
- Geothermal: 22
- Solar: 8
- Waste to energy: 2

Total: 548

*Hybrid Heat Recovery and Solar Thermal Power plant
Biomass
Cogeneration plants with Turboden ORC can produce heat and electrical power from biomass with high efficiency and user friendly operation. The generated power usually ranges between 200 kW and 15 MW electric.
ORC Plants – Performances

- Gross electric efficiency: up to 24%
- Overall energy efficiency: 98%

100 %
Thermal power from thermal oil (or other heat carrier)

80 to 74%
Thermal power to heat users

18 to 24 %
Gross electric power

2 %
Thermal losses (insulation and generator losses)
ORC Plant in a Process of Cogeneration from Biomass

* Turboden ORC units can be also fed with saturated vapor or superheated water.
Combined Heat & Power (CHP) with Split System Standard Sizes and Typical Performances

<table>
<thead>
<tr>
<th>INPUT - Thermal Oil</th>
<th>TURBODEN 6 CHP</th>
<th>TURBODEN 7 CHP</th>
<th>TURBODEN 10 CHP</th>
<th>TURBODEN 14 CHP</th>
<th>TURBODEN 18 CHP</th>
<th>TURBODEN 22 CHP</th>
<th>TURBODEN 26 CHP</th>
<th>TURBODEN 28 CHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal temperature &quot;HT&quot; loop (in/out) °C</td>
<td>312/252</td>
<td>312/252</td>
<td>310/250</td>
<td>310/250</td>
<td>312/252</td>
<td>309/249</td>
<td>310/250</td>
<td>310/245</td>
</tr>
<tr>
<td>Thermal power input &quot;HT&quot; loop kW</td>
<td>3056</td>
<td>3572</td>
<td>4685</td>
<td>6130</td>
<td>8935</td>
<td>10975</td>
<td>12948</td>
<td>14302</td>
</tr>
<tr>
<td>Thermal power input &quot;LT&quot; loop kW</td>
<td>283</td>
<td>328</td>
<td>450</td>
<td>585</td>
<td>855</td>
<td>1045</td>
<td>1225</td>
<td>1386</td>
</tr>
<tr>
<td>Overall thermal power input kW</td>
<td>3339</td>
<td>3810</td>
<td>5135</td>
<td>6715</td>
<td>8790</td>
<td>12020</td>
<td>14171</td>
<td>15688</td>
</tr>
<tr>
<td>Nominal temperature &quot;HT&quot; loop (in/out) °F</td>
<td>594/486</td>
<td>594/486</td>
<td>590/482</td>
<td>590/482</td>
<td>594/486</td>
<td>590/480</td>
<td>590/480</td>
<td>590/473</td>
</tr>
<tr>
<td>Thermal power input &quot;HT&quot; loop MMBtu/h</td>
<td>16.43</td>
<td>12.19</td>
<td>15.99</td>
<td>20.92</td>
<td>30.49</td>
<td>37.45</td>
<td>44.15</td>
<td>48.76</td>
</tr>
<tr>
<td>Nominal temperature &quot;LT&quot; loop (in/out) °F</td>
<td>486/270</td>
<td>486/270</td>
<td>482/266</td>
<td>482/266</td>
<td>486/270</td>
<td>480/269</td>
<td>482/273</td>
<td>473/268</td>
</tr>
<tr>
<td>Thermal power input &quot;LT&quot; loop MMBtu/h</td>
<td>0.96</td>
<td>1.15</td>
<td>1.54</td>
<td>2.00</td>
<td>2.92</td>
<td>3.57</td>
<td>4.17</td>
<td>4.73</td>
</tr>
<tr>
<td>Overall thermal power input MMBtu/h</td>
<td>11.06</td>
<td>13.02</td>
<td>17.52</td>
<td>22.91</td>
<td>33.41</td>
<td>41.01</td>
<td>48.57</td>
<td>53.53</td>
</tr>
</tbody>
</table>

| OUTPUT - Hot Water |  |
|---------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Hot water temperature (in/out) °C | 60/90 | 60/80 | 60/90 | 60/80 | 60/90 | 60/80 | 60/90 | 60/90 |
| Thermal power to hot water circuit kW | 2629 | 3146 | 4095 | 5341 | 7843 | 9688 | 11589 | 12908 |
| Hot water temperature (in/out) °F | 140/176 | 140/176 | 140/176 | 140/176 | 140/194 | 140/194 | 140/194 | 140/194 |
| Thermal power to hot water circuit MMBtu/h | 9.18 | 10.73 | 13.97 | 18.22 | 26.76 | 32.75 | 39.51 | 44.04 |

| PERFORMANCES |  |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Gross active electric power kW | 619 | 729 | 1000 | 1317 | 1862 | 2319 | 2632 | 2833 |
| Gross electric efficiency | 18.5% | 18.6% | 19.5% | 19.6% | 19.0% | 19.3% | 18.5% | 18.1% |
| Captive power consumption kW | 32 | 40 | 51 | 62 | 87 | 98 | 155 | 166 |
| Net active electric power kW | 587 | 689 | 949 | 1255 | 1775 | 2221 | 2476 | 2667 |
| Net electric efficiency | 17.6% | 17.6% | 18.5% | 18.5% | 18.5% | 18.5% | 18.5% | 17.0% |
| Electric generator** | 50Hz, 400V | 50Hz, 400V | 50Hz, 400V | 50Hz, 400V | 50Hz, 660V | 50Hz, 660V | 50Hz, 660V | 50Hz, 660V |
| Plant size | Single Skid | Single Skid | Multiple Skid | Multiple Skid | Multiple Skid | Multiple Skid | Multiple Skid | Multiple Skid |
| Biomass consumption*** | kg/h | 1459 | 1709 | 2244 | 2935 | 4279 | 5263 | 8194 |

* 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 efficiency is reduced of about 1.5%.

***Assuming a low heating value of biomass = 2.6 kWh/kg and boiler efficiency = 0.88. The thermal oil boiler is not included in the Turboden scope of supply.

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

HRS for electricity generation and cogeneration from biomass

The Turboden HRS turbogenerators guarantee a high total electrical efficiency: 24% of the thermal power to the ORC

100% thermal Power from Thermal Oil

Gross Performance of the Turboden HRS Modules at Various Condensation Water Temperatures

Value of gross electrical efficiency calculated as the ratio of electric power output at generator terminals to the thermal power input to the ORC at the design point

26% 24% 22%
20% 18% 16%
14%

24%
22%
20%
18%
16%
14%

15 20 25 30 35 40 45 50 55 60 65

Water outlet temperature from condenser (°C)

Design Point
HRS – High Electrical Efficiency Units

* Turboden CHP and HRS ORC units can also be fed with saturated vapor.
## 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 ‘HT’ loop kW</td>
<td>3817</td>
<td>4043</td>
<td>4425</td>
<td>4817</td>
</tr>
<tr>
<td>Nominal temperature ‘LT’ loop (in/out) °C</td>
<td>206/130</td>
<td>-</td>
<td>216/130</td>
<td>-</td>
</tr>
<tr>
<td>Thermal power input ‘LT’ loop kW</td>
<td>33</td>
<td>-</td>
<td>392</td>
<td>-</td>
</tr>
<tr>
<td>Overall thermal power input kW</td>
<td>4155</td>
<td>4043</td>
<td>4817</td>
<td>4817</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>77/95</td>
<td>77/95</td>
<td>77/95</td>
<td>77/95</td>
</tr>
<tr>
<td>Thermal power to the cooling water circuit kW</td>
<td>10.75</td>
<td>10.75</td>
<td>12.5</td>
<td>12.39</td>
</tr>
</tbody>
</table>

### PERFORMANCES

<table>
<thead>
<tr>
<th>Gross electric power kW</th>
<th>1000</th>
<th>1000</th>
<th>1156</th>
<th>1188</th>
<th>2270</th>
<th>2336</th>
<th>3109</th>
<th>3193</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross electric efficiency %</td>
<td>24.1%</td>
<td>24.7%</td>
<td>24.0%</td>
<td>24.7%</td>
<td>23.6%</td>
<td>24.2%</td>
<td>23.8%</td>
<td>24.4%</td>
</tr>
<tr>
<td>Captive power consumption kW</td>
<td>36</td>
<td>36</td>
<td>46</td>
<td>49</td>
<td>87</td>
<td>92</td>
<td>119</td>
<td>125</td>
</tr>
<tr>
<td>Net active electric power output kW</td>
<td>964</td>
<td>964</td>
<td>1110</td>
<td>1139</td>
<td>2183</td>
<td>2244</td>
<td>2960</td>
<td>3067</td>
</tr>
<tr>
<td>Net electric efficiency %</td>
<td>23.2%</td>
<td>23.8%</td>
<td>23.0%</td>
<td>23.6%</td>
<td>22.7%</td>
<td>23.3%</td>
<td>22.9%</td>
<td>23.5%</td>
</tr>
<tr>
<td>Electric generator*** 50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
<td>50Hz, 400V</td>
</tr>
<tr>
<td>Plant size Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
<td>Multiple skid</td>
</tr>
<tr>
<td>Biomass consumption**** kg/h</td>
<td>1816</td>
<td>1944</td>
<td>2105</td>
<td>2316</td>
<td>4211</td>
<td>4632</td>
<td>5715</td>
<td>6286</td>
</tr>
<tr>
<td>Net solar collector surface***** m²</td>
<td>-</td>
<td>10000-13000</td>
<td>-</td>
<td>13000</td>
<td>-</td>
<td>24000</td>
<td>-</td>
<td>33000</td>
</tr>
</tbody>
</table>

* 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 efficiency 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 CHP with split, = 0.80 in case of CHP 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.

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

<table>
<thead>
<tr>
<th></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></td>
<td>Range of Operation</td>
<td>Range Case</td>
<td>Range Case</td>
<td>Range Case</td>
</tr>
<tr>
<td><strong>INPUT - Thermal Oil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Oil inlet temp</td>
<td>°C</td>
<td>300 - 320</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Thermal Oil outlet temp</td>
<td>°C</td>
<td>170 - 200</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Overall thermal power input</td>
<td>kW</td>
<td>18000 - 40000</td>
<td>20000</td>
<td>25380</td>
</tr>
<tr>
<td>Thermal Oil inlet temp</td>
<td>°F</td>
<td>572 - 608</td>
<td>599</td>
<td>599</td>
</tr>
<tr>
<td>Thermal Oil outlet temp</td>
<td>°F</td>
<td>356 - 382</td>
<td>374</td>
<td>374</td>
</tr>
<tr>
<td>Overall thermal power input</td>
<td>MMBtu/hr</td>
<td>614.4 - 136.5</td>
<td>68.3</td>
<td>86.6</td>
</tr>
<tr>
<td><strong>OUTPUT - Cooling System (1)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling source</td>
<td>Water / air</td>
<td>water</td>
<td>water</td>
<td>water</td>
</tr>
<tr>
<td>Design cooling system temp (2)</td>
<td>°C</td>
<td>0 - 40</td>
<td>25/35</td>
<td>24/34</td>
</tr>
<tr>
<td>Thermal power to the cooling system</td>
<td>kW</td>
<td>13000 - 30000</td>
<td>14911</td>
<td>19376</td>
</tr>
<tr>
<td>Design cooling system temp (2)</td>
<td>°C</td>
<td>32 - 104</td>
<td>77/65</td>
<td>75/63</td>
</tr>
<tr>
<td>Thermal power to the cooling system</td>
<td>MMBtu/hr</td>
<td>44.4 - 102.4</td>
<td>48.6</td>
<td>64.7</td>
</tr>
<tr>
<td><strong>PERFORMANCES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross electric power</td>
<td>kW</td>
<td>4500 - 11000</td>
<td>5286</td>
<td>6348</td>
</tr>
<tr>
<td>Gross electric efficiency</td>
<td></td>
<td>23 - 27%</td>
<td>26.4%</td>
<td>25.0%</td>
</tr>
<tr>
<td>Captive power consumption (3)</td>
<td>kW</td>
<td>180 - 500</td>
<td>212</td>
<td>348</td>
</tr>
<tr>
<td>Net active electric power output</td>
<td>kW</td>
<td>4500 - 10000</td>
<td>5074</td>
<td>6000</td>
</tr>
<tr>
<td>Net electric efficiency (4)</td>
<td></td>
<td>22 - 28%</td>
<td>25.4%</td>
<td>23.6%</td>
</tr>
<tr>
<td>Electric generator</td>
<td>50Hz / 60Hz, MV</td>
<td>50Hz, 60Hz</td>
<td>60Hz, 4160V</td>
<td>50Hz, 60Hz</td>
</tr>
<tr>
<td>Biomass consumption (5)</td>
<td>kg/h</td>
<td>1000 - 20000</td>
<td>9610</td>
<td>12200</td>
</tr>
<tr>
<td>Net solar collector surface (6)</td>
<td>m²</td>
<td>45000 - 100000</td>
<td>50000</td>
<td>65000</td>
</tr>
<tr>
<td>Typical delivery time (FW) (7)</td>
<td>Months</td>
<td>10 - 15</td>
<td>10 - 15</td>
<td>10 - 15</td>
</tr>
</tbody>
</table>

1. Cooling water/air temperatures are selected considering specific site requirements, e.g. average air temperature, water availability.
2. Use either dry or wet heat dissipation system, possibility of CHP mode (with hot water generation at ORC condensers).
3. IN/OUT water temperatures for water cooling.
4. Including working fluid pump and auxiliaries consumptions. Excluding heat dissipation system and thermal oil circulation consumptions.
5. 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).
6. Assuming a low heating value of biomass = 2.5 kWh/Kg and boiler efficiency = 0.80. The thermal oil boiler is not included in the Turboden scope of supply.
7. Assuming solar radiation is 800 W/m², design solar collector efficiency is 0.6 and solar multiple is 1.2. The Solar field is not included in the Turboden scope of supply.
8. Delivery time is defined at the moment of order considering specific project features (e.g. customer standards) and Turboden production load at the moment of order.
9. For heat recovery applications direct heat exchange can be available.

DISCLAIMER NOTE: Data provided herein are not binding and might change without prior notice.
Biomass – Fuels & Applications

**Fuels**
- Wood biomass: sawdust, woodchips, bark, treated wood
- Other biomass: dried sewage sludge, green cuttings, rice husk, vinasse and vine cuttings, wood industry waste material etc ...
- Waste material

**Heat Consumers**
- District Heating networks
- Timber drying in sawmills
- Sawdust drying in wood pellet factories
- MDF/PB Producers
- Air pre-heating in MDF industry
- Refrigeration
- Greenhouses
- Wine industry
Case Study – Some References

Case studies
<table>
<thead>
<tr>
<th>project</th>
<th>location</th>
<th>start-up date</th>
<th>type</th>
<th>details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sortilemn</strong>&lt;br&gt;Gherla&lt;br&gt;<strong>1.3 MWel Cogeneration project</strong> from wooden biomass in the Sortilemn sawmill</td>
<td></td>
<td>October 2012</td>
<td>Cogeneration</td>
<td>from wooden biomass in the Sortilemn sawmill</td>
</tr>
<tr>
<td><strong>Holcim Romania – Holcim Group</strong>&lt;br&gt;Aleșd&lt;br&gt;<strong>4 MWel Heat recovery project</strong> from cement production in the Holcim Romania cement plant</td>
<td></td>
<td>July 2012</td>
<td>Heat recovery</td>
<td>from cement production in the Holcim Romania cement plant</td>
</tr>
<tr>
<td><strong>Carpatcement Holding – Heidelberg Group</strong>&lt;br&gt;Fieni, Dâmbovița County&lt;br&gt;<strong>4 MWel heat recovery project</strong> from cement production in the Heidelberg/Carpaticement cement plant</td>
<td></td>
<td>Under construction</td>
<td>Heat recovery</td>
<td>from cement production in the Heidelberg/Carpaticement cement plant</td>
</tr>
<tr>
<td><strong>Forestar</strong>&lt;br&gt;Tarcau&lt;br&gt;<strong>1.3 MWel cogeneration project</strong> from wooden biomass in the Forestar (Romanel Group) sawmill</td>
<td></td>
<td>Under construction</td>
<td>Cogeneration</td>
<td>from wooden biomass in the Forestar (Romanel Group) sawmill</td>
</tr>
</tbody>
</table>
District Heating Networks

WITHOUT ORC

BIOMASS

BIOMASS POWERED BOILER

HEAT USER

cold water

hot water

WITH ORC

BIOMASS

BIOMASS POWERED BOILER

ORC

HEAT USER

Electric power

cold water

hot water

Thermal oil
First Turboden biomass plant in Italy

T.C.V.V.V. - The first in Italy!

Customer: T.C.V.V.V. spa
Application: District Heating
Location: Tirano (SO) Italy
ORC model: T1100 CHP
Started up in: June 2003
Installed Electrical Power: 1,1 MWel
Thermal Power: 4,8 MWth
Water Temperature: 62°- 92°C
Biomass used: wood chips
District heating network extension: 31 km
Number of utilities connected: 716
Served population (estimation): 7000 inhabitants

➢ 13.000 t/year of CO₂ avoided
➢ exploitation of local resources and renewable sources

www.tcvvv.it
Sawmills

- **SELECTION**
- **BARKING**
- **PROCESSING**
- **PACKAGING**
- **DRYING**

**Flow Diagram:**
- **TRUNKS** → **SELECTION** → **BARKING** → **PROCESSING** → **PACKAGING** → **DRYING**
- **Bark** and **sawdust** inputs:
  - **Bark** from **BARKING**
  - **Sawdust** from **PACKAGING**

**Energy Sources:**
- **Thermal oil** from **BIOMASS POWERED BOILER**
- **Electric power** from **ORC**
- **Cold water**
- **Hot water**

**Clean Energy:**
- **TURBODEN**
- **Mitsubishi Heavy Industries, Ltd.**
Sortilemn SA – First Turboden plant in Romania

Customer: Sortilemn SA (www.sortilemn.ro)
Application: sawmill/drying
Location: Gherla (Romania)
ORC model: Turboden 14 CHP split
Start up: September 2012
Installed Electrical Power : 1,24 MWel
Thermal Power: 6,7 MWth
Water temperature: 70°- 90°C
Biomass type: wood chips/wood waste from the process
Thermal users: drying chambers/sawmill internal processing/buildings heating

- green energy from the sawmill
- local wood used
Wood Pellet Production

- BIOMASS POWERED BOILER
- ORC
- Electric power
- Suitable granulometry UR 40%
- Suitable granulometry UR < 13%
- Thermal oil
- hot water
- cold water

- TRUNKS
- BARKING
- CHIPPING
- MILLING
- SELECTION/SORTING
- AIR COOLING/DEDUSTING
- PELLET MAKING PRESS
- DEDUSTING/SELECTION/REFINING

- Pellet
- Pellet ready to be packaged
Lika Energo Eko – First Turboden plant in Croatia

Customer: Lika Energo Eko
Application: pellet production
Location: Udbina - Lika region - Croatia
ORC model: Turboden 10 CHP split
Started up: January 2012
Installed Electrical Power: 999 kWel
Thermal Power: 4.1 MWth
Water temperature: 70° - 90°C
Biomass type: wood chips/wood waste from the process
Thermal users: belt dryier used for pellet production
Yearly pellet production: 32,000 t/y

- green energy from the process waste wood
- local wood used
- very high plant efficiency – total integration of the ORC in the process
Figure: Proposed scheme for MDF plant with ORC cogeneration unit
CCHP – Combined Cooling Heating Power

- BIOMASS POWERED BOILER
- ORC

- Thermal oil
- hot water
- cold water

- ELECTRIC POWER
- DISTRICT HEATING
- COOLING SYSTEM

- USE IN PUBLIC BUILDING, HOTEL, ...

- cold water

- clean energy ahead TURBODEN

- Copyright © – Turboden S.r.l. All rights reserved
Greenhouses

- Green cuttings
- BIOMASS POWERED BOILER
- ORC
- Electric power
- Thermal oil
- Cold water
- Hot water
- Hot water

Greenhouses powered by biomass and thermal oil, producing hot water and electric power.
Wine Production

- **Vine Growing**
- **Grape production**
- **Land yearly upkeeping → cutting**

- **Rasping**
  - **Grape stalks**

- **Pressing**
  - **White**
  - **Red**

- **Fermentation**

- **Fermented Vinasse** → **Distilling**
  - **Grappa and Alcohol**
  - **Skins Vinasse**
  - **Exhaust Vinasse**

- **BIOMASS TO ENERGY PRODUCTION**
  - **Fermentation**
  - **Pressing**
**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)
Heat Recovery In 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.
Cement: Alesd – Holcim Romania Project

**Project:** Holcim Romania  
**Heat Source:** cement production process

- Heat source: exhaust gas @ 360°C (PRS) and hot air @ 250 °C (CC)  
- Thermal oil (PRS) and pressurised water (CC) heat recovery loops  
- **ORC electric power:** ~ 4 MWe

**Client:** Holcim Romania – Holcim Group (Romania)  
**In operation since July 2012**
Turboden at a Glance
## Turboden strong points

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

For further information please contact me:
Marco Di Prima – Sales Area Manager
Email: marco.diprima@turboden.it
Phone: +39 030 3552001