Turboden Solar Thermal Power Applications
Turboden is a leading European company in development and production of ORC (Organic Rankine Cycle) turbogenerators. This state-of-the-art equipment generates heat and power from renewable sources and heat recovery in industrial processes.

The company was founded in 1980 in Milan by Mario Gaia, Associate Professor at Politecnico di Milano, teaching Thermodynamics, Renewable Energy and specifically studying ORC systems. At present Prof. Gaia is Honorary Chairman. A number of his former students are key persons in the Company and the whole Company is permeated by innovative and research oriented spirit.

Turboden has always had a single mission: to design ORC turbogenerators for the production of heat and electrical power from renewable sources, while constantly striving to implement ORC technical solutions.

In 2009, Turboden became part of UTC Corp., a worldwide leader in development, production and service for aero engines, aerospace drive systems and power generation gas turbines, to develop ORC solutions from renewable sources and waste heat worldwide.

In 2013 UTC exits the power market forming strategic alliance with Mitsubishi Heavy Industries.

In 2013 Mitsubishi Heavy Industries acquires from UTC Pratt & Whitney Power Systems (now PW Power Systems, Inc.) and the affiliate Turboden. Today Turboden S.r.l. and PW Power Systems, Inc. are MHI group companies to provide a wider range of products and services for thermal power generation systems.

• Prof. Mario Gaia makes experience in the field of ORC within his research group at Politecnico di Milano

• 1976 – First prototype of a solar thermodynamic ORC

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

• Turboden develops research projects in solar, geothermal and heat recovery applications

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

• 1980 – First prototype of a solar thermodynamic ORC

• Turboden installs ORC biomass plants, especially in Austria, Germany and Italy

• Turboden plans to enter new markets, with focus on North America

• First heat recovery applications

• 2009 – 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

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35 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

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

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**Energy & Environment**

Providing optimal solutions in the energy-related fields of thermal power, nuclear energy and renewable energy in different environmental areas and for Chemical plants & other industrial infrastructures elements.

**Machinery, Equipment & Infrastructure**

Providing a wide range of products that form the foundation of industrial development, such as machine tools, material handling, construction machinery, air-conditioning and refrigeration systems.

**Commercial Aviation & Transport Systems**

Delivering advanced land, sea and air transportation systems, including civilian aircraft, commercial ships and transit networks.

**Integrated Defense & Space Systems**

Providing advanced land, sea and air defense systems, including naval ships, defense aircraft, launch vehicles and special vehicles, as well as space-related services.
What We Do

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

➢ **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: 6
- Under construction: 0
- Total: 6

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

*Hybrid Heat Recovery and Solar Thermal Power plant*
Solar Thermal Power
Turboden units allow to convert the heat collected by solar collectors into electricity through an efficient thermodynamic cycle. Concentrating Solar Power systems with ORC Turboden can be cost-effective in the range between 200 kW and 15 MW electric.
Solar energy can be harnessed by different technologies. Each of the technologies covers the part of the market where it can bring the highest cost-effectiveness rate.

Turboden ORC mostly finds its place in industrial scale sector from 1 to 10 MWel.
Feed in tariff is paid for 25 years from date of commercial operation of the plant.

Plants will also be paid the market price for electricity sold.

Feed in tariff in table are referred to plants that will be started up by 31st December 2015.

<table>
<thead>
<tr>
<th>Integration rate</th>
<th>Up to 0.15</th>
<th>Between 0.15 and 0.50</th>
<th>Above 0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tariff added to the price of sale for plants with collecting surface up to 2500 m²</td>
<td>0.36</td>
<td>0.32</td>
<td>0.30</td>
</tr>
<tr>
<td>Tariff added to the price of sale for plants with collecting surface above 2500 m²</td>
<td>0.32</td>
<td>0.30</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Feed in tariff will be reduced by 5% in 2016 and a further 5% in 2017.

A minimum thermal storage capacity is required:
- 1.5 kWhth/m² of collecting surface (for plants with a collecting surface bigger than 50,000 m²)
- 0.4 kWhth/m² of collecting surface (for plants with a collecting surface between 10,000 and 50,000 m²)

In those plants where hybridization source is renewable, integration rate is conventionally zero.
The ORC power block uses **organic fluid to drive the turbine** instead of a traditional high pressure steam. This results in a **reliable, efficient and user friendly** solar thermal power plant.

**Turboden ORC strenghts in CSP plants**

- Electrical efficiency up to 26%
- Capability to adapt to load variation easily and quickly
- Partial load operation down to 10% of the nominal load
- Direct air condenser. No water consumption
- Synchronous or asynchronous generation
- Remote Control operation
  - No operator needed on site
- Low O&M requirements
- Ease of hybridization with biomass or heat recovery plants
- Possibility to couple to low cost/medium scale solar collectors
- Possibility to use mineral/synthetic oils or saturated steam as heat transfer fluid
Different Heat Transfer Fluids

Th. oil parabolic trough system

Th. oil linear Fresnel reflectors

Turboden solution

- Thermal oil (mineral or synthetic) between 250-300°C feeds
- **Turboden HR** (20% electrical efficiency) or
- **Turboden HRS** units (24% electrical efficiency).

- Partial load down to 10% of thermal power input

→ Non-harmful mineral or synthetic oil
→ Thermal oil also as storage medium
→ Higher equivalent working hours considering storage
→ Heat transfer fluid working at ambient pressure
→ High ORC efficiency
Different Heat Transfer Fluids

DSG linear Fresnel reflectors

Figure 3: AUSRA Fresnel collectors

DSG parabolic trough system

Figure 4: Solarlite solar collectors

Turboden solution

Saturated steam at ~20 bar\text{A} can feed Turboden HR units (20% electrical efficiency)

Saturated steam at ~60-70 bar\text{A} can feed Turboden HRS units (25% electrical efficiency)

→ Lean configuration
→ Lower CAPEX
→ Environment friendly
→ Partial load with saturated steam inlet even below 5 bar\text{A}
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.
- Maintains 90% of cycle efficiency down to 50% of loading.

Cooling water temperature effect on cycle efficiency (HRS Units)

- Turboden ORC units automatically adapt the cycle at the ambient temperature variations.

Design Point

- Water outlet temperature from condenser [°C]
- Gross electric efficiency
# Turboden Solutions: HR Units

## INPUT* - Thermal Oil

<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>Range of Operation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*°C</td>
<td>*°F</td>
<td>*°C</td>
<td>*°F</td>
<td>*°C</td>
</tr>
<tr>
<td><strong>Reference Case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 6 HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 10 HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 22 HR SPLIT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 40 HR SPLIT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 70 HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thermal Oil inlet temperature</strong></td>
<td>240-300</td>
<td>240-300</td>
<td>240-310</td>
<td>250-315</td>
<td>240-310</td>
</tr>
<tr>
<td><strong>Thermal Oil outlet temperature</strong></td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
<td>170-120</td>
</tr>
<tr>
<td><strong>Thermal power input</strong></td>
<td>2.5-4.0</td>
<td>3.0</td>
<td>5.0-7.0</td>
<td>8.0-12.0</td>
<td>13.0-22.0</td>
</tr>
<tr>
<td><strong>Thermal Oil inlet temperature</strong></td>
<td>464-572</td>
<td>464-500</td>
<td>464-590</td>
<td>482-590</td>
<td>484-590</td>
</tr>
<tr>
<td><strong>Thermal Oil outlet temperature</strong></td>
<td>338-248</td>
<td>338-248</td>
<td>338-248</td>
<td>338-248</td>
<td>338-248</td>
</tr>
<tr>
<td><strong>Thermal power input</strong></td>
<td>MMBtuhr</td>
<td>8.53-13.65</td>
<td>17.06-23.88</td>
<td>27.30-40.95</td>
<td>44.36-75.07</td>
</tr>
</tbody>
</table>

## OUTPUT** - Cooling Water

<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>Range of Operation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
</tr>
<tr>
<td><strong>Reference Case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 10 HR</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>TD 22 HR SPLIT</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>TD 40 HR SPLIT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TD 70 HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Thermal power to condenser</strong></td>
<td>2.0-3.5</td>
<td>4.0-5.0</td>
<td>6.0-9.5</td>
<td>10.0-15.7</td>
<td>19.2-40.0</td>
</tr>
<tr>
<td><strong>Typical cooling water temperature (in/out)</strong></td>
<td>77/95</td>
<td>77/95</td>
<td>77/104</td>
<td>77/104</td>
<td>77/104</td>
</tr>
<tr>
<td><strong>Thermal power to condenser</strong></td>
<td>6.82-11.94</td>
<td>13.65-17.06</td>
<td>20.47-32.42</td>
<td>34.12-59.71</td>
<td>65.51-136.49</td>
</tr>
</tbody>
</table>

## 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>Gross electric power</strong></td>
<td>kW</td>
<td>kW</td>
<td>kW</td>
<td>kW</td>
<td>kW</td>
</tr>
<tr>
<td><strong>Gross electric efficiency</strong>*</td>
<td>17%-20%</td>
<td>17%-22%</td>
<td>17%-22%</td>
<td>17%-22%</td>
<td>17%-22%</td>
</tr>
<tr>
<td><strong>Captive power consumption</strong></td>
<td>18-36</td>
<td>36-70</td>
<td>60-100</td>
<td>80-100</td>
<td>200-300</td>
</tr>
<tr>
<td><strong>Net active electric power output</strong></td>
<td>480-760</td>
<td>850-1550</td>
<td>1650-2400</td>
<td>2500-4000</td>
<td>4500-9800</td>
</tr>
<tr>
<td><strong>Net electric efficiency</strong>*</td>
<td>16%-19%</td>
<td>19%</td>
<td>16%-21%</td>
<td>18%</td>
<td>16%-20%</td>
</tr>
<tr>
<td><strong>Electric generator</strong>**</td>
<td>50Hz, 400V / 60Hz, 480V</td>
<td>50Hz, 400V / 60Hz, 480V</td>
<td>50Hz, 400V / 60Hz, 480V</td>
<td>50Hz, 400V / 60Hz, 480V</td>
<td>50Hz, 400V / 60Hz, 480V</td>
</tr>
</tbody>
</table>

## Cooling systems

<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>Closed loop water cooling or wet tower</strong></td>
<td>9-11</td>
<td>9-11</td>
<td>9-11</td>
<td>11-13</td>
<td>12-14</td>
</tr>
</tbody>
</table>

* Turboden 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 ORC).

*** Electric efficiency depends on several factors, primarily Heat and Cooling Source Temperatures and thermal media. Our sales specialists will support you to optimise the evaluations, specifying 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.
## Turboden Solutions: HRS 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>208/130</td>
<td>-</td>
<td>210/130</td>
<td>-</td>
</tr>
<tr>
<td>Thermal power input &quot;LT&quot; loop kW</td>
<td>339</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>77/86</td>
<td>77/86</td>
<td>77/86</td>
<td>77/86</td>
</tr>
<tr>
<td>Thermal power to the cooling water circuit MMBl/hr</td>
<td>10.75</td>
<td>10.37</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>2338</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>2590</td>
<td>2907</td>
</tr>
<tr>
<td>Net electric efficiency</td>
<td>23.2%</td>
<td>23.8%</td>
<td>23.0%</td>
<td>23.8%</td>
<td>22.7%</td>
<td>23.3%</td>
<td>22.9%</td>
<td>23.5%</td>
</tr>
<tr>
<td>Electric generator**</td>
<td>50Hz, 400V 60Hz, 480V</td>
<td>50Hz, 400V 60Hz, 480V</td>
<td>50Hz, 400V 60Hz, 480V</td>
<td>50Hz, 400V 60Hz, 480V</td>
<td>50Hz, 560V 60Hz, 4160V</td>
<td>50Hz, 880V 60Hz, 4160V</td>
<td>50Hz, 560V 60Hz, 4160V</td>
<td>50Hz, 880V 60Hz, 4160V</td>
</tr>
<tr>
<td>Plant size</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***</td>
<td>kg/h</td>
<td>1816</td>
<td>1944</td>
<td>2105</td>
<td>2316</td>
<td>4211</td>
<td>4632</td>
<td>5715</td>
</tr>
<tr>
<td>Net solar collector surface****</td>
<td>m²</td>
<td>-</td>
<td>10000-13000</td>
<td>-</td>
<td>13000</td>
<td>-</td>
<td>24000</td>
<td>-</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 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.

For heat recovery applications direct heat exchange can be available.

DISCLAIMER NOTE: Data provided herein are not binding and might change without prior notice.
# Turboden Solutions: HRS 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>Thermal Oil inlet temperature °C</td>
<td>300 - 320</td>
<td>315</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Thermal Oil outlet temperature °C</td>
<td>170 - 200</td>
<td>190</td>
<td>190</td>
<td>180</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 inlet temperature °F</td>
<td>572 - 808</td>
<td>599</td>
<td>599</td>
<td>599</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>

<table>
<thead>
<tr>
<th>OUTPUT - Cooling System (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling source</td>
</tr>
<tr>
<td>Design cooling system temperature °C</td>
</tr>
<tr>
<td>Thermal power to the cooling system kW</td>
</tr>
<tr>
<td>Design cooling system temperature °F</td>
</tr>
<tr>
<td>Thermal power to the cooling system MMBtu/hr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PERFORMANCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross electric power kW</td>
</tr>
<tr>
<td>Gross electric efficiency</td>
</tr>
<tr>
<td>Captive power consumption (3) kW</td>
</tr>
<tr>
<td>Net active electric power output kW</td>
</tr>
<tr>
<td>Net electric efficiency (4)</td>
</tr>
<tr>
<td>Electric generator</td>
</tr>
<tr>
<td>Biomass consumption (5) kg/h</td>
</tr>
<tr>
<td>Net solar collector surface (6) m²</td>
</tr>
<tr>
<td>Typical delivery time (B/W) (7) Months</td>
</tr>
</tbody>
</table>

---

(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 solution, 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 kW/h and boiler efficiency = 0.80. 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.

For heat recovery applications direct heat exchange can be available.

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Reference Plants

Customer:
Italcementi Group

Site:
Ait Baha, Morocco

DNI:
2,400 kWh/m²_year

Turboden unit:
Turboden 18 HR (2 MWₑ)

Plant type:
hybrid – heat recovery from waste heat of cement factory plus solar collectors with pebble stone thermal storage

Solar field area:
Aperture area: 6,159 m²
Nr. of string: 3
String length: 215 m
Thermal power: 4 MWₜₜ
Storage capacity: 12 h
HTF: hot air

Figure 5: Turboden 18 HR in Ait Baha plant

Figure 6: Airlight concrete solar collector structure

Figure 7: View of Italcementi cement factory in Ait Baha with solar field
ENAS project

- **Final Customer**: ENAS (Ente acque della Sardegna)
- **EPC**: CEIF Soc. Coop. (Cooperativa Elettricisti Installatori Forlivesi)
- **Site**: Ottana (Nuoro, Sardegna)
- **Size**: 650 kW_e
- **Turboden unit**: Turboden 6 HR (Nominal working conditions: thermal oil 260/150°C, cooling water 25/35°C, gross efficiency 21%)
- **Plant type**: pure solar plant with 6 loops FERA Fresnel solar collectors (about 10,000 m²) and a direct two-tanks thermal oil storage with thermal capacity of almost 5 equivalent working hours

*Figure: FERA Fresnel solar collectors.*
Archimede project

• **Final Customer:** Archimede S.r.l. Società di Ingegneria

• **EPC:** Archimede S.r.l. Società di Ingegneria

• **Site:** Melilli (Siracusa, Sicilia)

• **Size:** 1180 kW<sub>el</sub>

• **Turboden unit:** Turboden 12 HRS (Nominal working conditions: thermal oil 305/204°C, cooling water 25/35°C, gross efficiency 25%)

• **Plant type:** hybrid solar plant with about 8.000 m<sup>2</sup> solar collectors coupled to a 3 MW<sub>th</sub> natural gas boiler.

*Figure: Turboden 12 HRS*
R&D solar projects

SOLAR project

Public-Private laboratory for the development of innovative technologies for distributed power production from Solar energy. DM 593/00 art.12 DM 19447

Description:
- Study and development of new-designed concentrated solar collectors
- Study of innovative thermal fluids with nanoparticles
- Realization of a prototype scale ORC connected to solar collectors
- Master studies for qualified energy technicians

Beneficiaries:
- Università del Salento (Coordinator)
- Università degli Studi di Catania
- CNR-IMM
- Costruzioni solari Srl
- Politecnico di Bari
- STC Srl
- TCT Srl
- Turboden Srl

Budget: 12,3 Meuro - Grant: 9,1 MEuro

EUROSUNMED project

Euro-Mediterranean cooperation on research & training in sun based renewable energies. FP7-ENERGY-2013-1

Description:
- Developing new technologies in 3 energy areas: PV, CSP and grid integration,
- Establishing strong networking between EU and MPC
- Disseminating the results of the projects

Beneficiaries:
- France: CNRS, EMRS
- Norway: Sintef, Sintef Energy
- Spain: Cener, IK4 Tekniker
- Belgium: EUREC
- Italy: Turboden
- Morocco: CNESTEN, CNRST, MASCIR, Agdal University, Al Akhawayn University, MASEN
- Egypt: Helwan University, Alexandria University, Nile Valley Engineering
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