PWPS acquired a majority stake in Turboden in 2009

Turboden
Organic Rankine Cycle (ORC)
Industry Leader

- Leading provider of ORC’s
- 400 kW to 10 MW
- Customized for >10 MW
- 249 plants in 27 countries

**Biomass**
- 2012E sales: 67%
- Simple and efficient generation of electric power and heat from biomass
- 213 plants, 228 MW

**Geothermal**
- 2012E sales: 26%
- Electricity production from medium-to-low temperatures (90°C to 180°C)
- 7 plants, 20 MW

**Heat recovery**
- 2012E sales: 7%
- Electricity production from sources such as industrial waste heat and reciprocating engine sources
- 25 plants, 41 MW

**Solar thermal**
- Conversion of heat harnessed by solar collectors into electricity through an efficient thermodynamic cycle
- First plant (6 MW) currently under construction in Hawaii
GLOBAL INSTALLATIONS

Turboden ORC plants in the world

Turboden together with Pratt & Whitney Power Systems currently has about 330 ORC units all over the world.

*Biomass, Heat Recovery, Geothermal, Solar

**Hybrid Heat Recovery and Solar Thermal Power plant
HEAT TO ELECTRICITY GENERATION

Cooling: Air conditioner

- Electricity

Heat: PureCycle® Power System

- Electricity

Combustion, Emissions, Fuel Cost are prohibited.
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.
<table>
<thead>
<tr>
<th>EFFICIENCY</th>
<th>APPLICATION</th>
<th>HEAT CARRIER</th>
<th>HEAT RELEASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-27%</td>
<td>Biomass / Heat Recovery / CSP</td>
<td>Thermal Oil 310°C</td>
<td>Water 25°C</td>
</tr>
<tr>
<td>19%</td>
<td>Biomass (CHP)</td>
<td>Thermal Oil 310°C</td>
<td>Water 80°C</td>
</tr>
<tr>
<td>19%</td>
<td>Heat Recovery</td>
<td>Thermal Oil 275°C</td>
<td>Water 25°C</td>
</tr>
<tr>
<td>16%</td>
<td>Geothermal / Heat Recovery</td>
<td>Water 180°C</td>
<td>Water 30°C</td>
</tr>
<tr>
<td>10%</td>
<td>Geothermal</td>
<td>Water 100°C</td>
<td>Water 10°C</td>
</tr>
<tr>
<td>7.5%</td>
<td>Geothermal / Heat Recovery</td>
<td>Water 90°C</td>
<td>Air 15°C</td>
</tr>
</tbody>
</table>
MAIN COMPONENTS

- Evaporator
- Preheater
- Condenser-Recuperator
- Electric cubicles
- ORC turbine
- Electric generator
- Feed Pump
- ORC heat input (thermal oil)
- ORC heat output (hot water)
- 1 MWe modular ORC unit

1 MWe modular ORC unit
## HEAT RECOVERY APPLICATIONS

<table>
<thead>
<tr>
<th>Industry</th>
<th>Gas</th>
<th>Liquid</th>
<th>Steam/Vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil &amp; Gas</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Chemicals</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Steel / Nonferrous</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Pulp &amp; Paper</td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Food</td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Waste Treatment</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Thermal Oxidizers</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Generation</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
IC ENGINES: UP TO 10 % ADD’L PWR

- Heat recovery exchanger gas/thermal oil
- Filters / Chimney
- Heat dissipation system (dry or wet)
- Cooling water circuit
- ORC TURBODEN
- Exhaust gas
- Thermal oil circuit
- ELECTRIC POWER
GAS TURBINES: 25-30% ADD’L PWR

- Gas Turbine
- Heat recovery exchanger
- Cooling circuit
- Heat dissipation system (dry or wet)
- Electrical power
- Thermal oil / Steam / Pressurised water circuits
- Silencer/Exhaust
**NOTE:** Estimated values assuming ambient air temperature of 15°C, nominal load operation
HEAT RECOVERY APPLICATIONS
Exhaust gas streams:
- Kiln pre-heater gas
- Clinker cooler gas

Exhaust Gas:
- High dust content
- Different operating conditions depending on mill operation, season, etc
STEEL INDUSTRY

- Rolling, forging
- Heat treatment
- Strip processing

- Sinter
- Blast furnace
- BOF
- EAF

- Relatively clean exhaust gas at moderate temperature
- Cost effective for ORC ≥ ~ 1 MW

- Interface between process and energy recovery unit is critical
- Exhaust gas:
  - high flow
  - high temperature
  - high dust content
  - large variations in operating cycle
  - environmental constraints
25% - 30% of the power input to the furnace is lost in the exhaust.

70% of the lost power recoverable.

Target: 3-5% of the EAF consumed power.
Biomass – Fuels & Apps.

**Biomass fuels**
- Wood biomass: sawdust, woodchips, bark, treated wood
- Other biomass: dried sewage sludge, straw, green cuttings, rice husk
- Waste material
- Waste recycling wood

**Applications**
- Timber drying in sawmills
- Saw dust drying in wood pellet factories
- Air pre-heating in MDF industry
- District Heating networks
- Refrigeration / air conditioning

**Standard Units**
- CHP or HRS
- Cogeneration and/or trigeneration
- Up to 25% efficiency
HIGH OVERALL EFFICIENCIES

100 %
Thermal power from thermal oil

73% to 78%
Thermal power to heat users

20% to 25%
Gross electric power

2%
Thermal losses (insulation and generator losses)
TYPICAL SAWMILL APPLICATION

- **Selection**
- **Barking**
- **Processing**
- **Packaging**
- **Drying**
- **ORC (Organic Rankine Cycle)**

**Power Sources**
- **Electric Power**
- **Biomass Powered Boiler**
  - Thermal oil
- **Cold Water**
- **Hot Water**

**Processes**
- Bark to sawdust

**Outputs**
- **Product**
Key issues:

- Corrosion – need special (costly) materials for heat exchangers
- Scaling leads to limits in cooling the geothermal brine
- Fouling - need removable covers / straight cleanable tubes
- Working fluid flammability: critical in urban areas & for insurance cost
- Vapour plume and need for makeup water in case of evaporative cooling systems
- Larger footprint and noise emissions from the fans in case of air cooling
**ORC DESIGN CONSIDERATIONS**

Evaluation of the proper cooling system: Wet vs Dry

- **Evaporative towers**
  - Smaller footprint
  - Lower noise emissions
  - Fresh water consumption
  - Chemical water treatment → operation cost, environment

- **Air condensers**
  - Larger footprint
  - Higher noise emissions
  - No water needed
  - Virtually no environmental impact and low operating costs

**Critical issues**
- Investment costs: initial / overall
- Generated yearly output, linked to gross power and parasitic loads
- Which is best then?
SOLAR THERMAL + ORC

Emission Free Electricity

Hot thermal oil

Cold thermal oil

SOLAR FIELD

THERMAL STORAGE

BIOMASS BOILER

TURBODEN ORC

AIR COOLER
1 MW SOLAR THERMAL + ORC

Power output: $1 \text{ MW}_{\text{el}}$

Conceptual rendering of an hybrid solar thermal system based on a Turboden 12 HRS
## ORC VERSUS STEAM

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Steam Turbine</th>
<th>ORC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need to Superheat the Vapor</td>
<td>Yes: Steam turbine operates at temperatures of 450°C.</td>
<td>No: ORC operates at much lower temperatures with saturated organic fluid vapor.</td>
</tr>
<tr>
<td>Control of Steam Quality</td>
<td>Yes: System required to continuously monitor &amp; control the salt &amp; acidity content of the water. Blow down is also required.</td>
<td>No: System with organic fluid/vapor in a closed loop with pressure higher than atmospheric pressure.</td>
</tr>
<tr>
<td>Requirement of Qualified/Specially Trained Personnel</td>
<td>Yes: 24 hr supervision of a qualified operator is required.</td>
<td>No: ORC is completely automated and does not typically require supervision by a certified operator.</td>
</tr>
<tr>
<td>Complex/Costly Maintenance</td>
<td>Yes: Expensive maintenance and major overhauls at 5 year intervals.</td>
<td>No: The costs are minimal. No major overhauls.</td>
</tr>
<tr>
<td>Turbine Corrosion/Erosion</td>
<td>Yes: with non-optimal steam quality and in case of condensation in turbine.</td>
<td>No: Organic fluid is lubricant, non corrosive, no condensation risk in turbine.</td>
</tr>
<tr>
<td>Turn-Down Capability</td>
<td>Limited with steep efficiency drop.</td>
<td>Yes: Excellent turn-down (10%) with very good partial load efficiency.</td>
</tr>
<tr>
<td>Electric Power and electric Generator</td>
<td>Potentially greater electric power produced compared to the ORC, depending upon the heat source temperatures</td>
<td>Lower electric power output produced compared to the steam turbine.</td>
</tr>
</tbody>
</table>
ORC Part Load Efficiency

Part load operation down to 10% of nominal load. Maintains 90% of the cycle efficiency down to 50% loading.
THANK YOU!

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