Organic Rankine Cycle
Power Generation

Pratt & Whitney Power Systems ORC Power Solutions
Diverse Product Portfolio

Large Engines

Organic Rankine Cycle

EPC Service

Power Systems

After market

Mobile Power

Marine
Acquisition by MHI

- Acquisition announced Dec. 2012
- Regulatory approvals underway
- Planned completion in 2Q13
ORC Applications

- PWPS / Turboden designs & manufactures Organic Rankine Cycle (ORC) turbogenerators
- 30 years of ORC experience
- Sizes from 1MW to 10 MW an up.
The Organic Rankine Cycle (ORC)

Key:
- Red = hot water
- Green = working fluid
- Blue = cold water

Heat In – Power Out
<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Application</th>
<th>Heat Carrier</th>
<th>Heat Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>Biomass / Heat Recovery / CSP</td>
<td>Thermal Oil 590°F Water 80°F</td>
<td></td>
</tr>
<tr>
<td>19%</td>
<td>Biomass (CHP)</td>
<td>Thermal Oil 590°F Water 170°F</td>
<td></td>
</tr>
<tr>
<td>19%</td>
<td>Heat Recovery</td>
<td>Thermal Oil 530°F Water 80°F</td>
<td></td>
</tr>
<tr>
<td>16%</td>
<td>Geothermal / Heat Recovery</td>
<td>Water 355°F Water 85°F</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>Geothermal</td>
<td>Water 220°F Water 50°F</td>
<td></td>
</tr>
<tr>
<td>7.5%</td>
<td>Geothermal / Heat Recovery</td>
<td>Water 195°F Air 60°F</td>
<td></td>
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</tbody>
</table>
TD UNITS – MAIN COMPONENTS

- Condenser-Recuperator
- Electric cubicles
- Feed Pump
- Electric generator
- Preheater
- Evaporator
- ORC turbine
- ORC heat input (thermal oil)
- ORC heat output (hot water)
Heat Recovery Applications (HR & HRS)

Example of ORC Waste Heat to Power Applications

Sources of Waste Heat
(Reciprocating Engine and Gas Turbine Exhaust, Cement, Steel, Glass Industries, Etc.)

External Heat Exchanger

Heat Carrying Loop

Electric Power Output

Air Cooler or Cooling Towers
IC Engine – TYPICAL OUTPUTS

Notes:
1. Smallest PWPS/Turboden HR ORC Turbogenerator produces 609 kW.e
2. Largest PWPS/Turboden HR ORC Turbogenerator produces 11,500 kW.e

Pe-ORC/Pe-RE = 10%
Pe-ORC/Pe-RE = 7%
GAS TURBINES – TYPICAL OUTPUTS

NOTE: Indicative values assuming ambient air temperature of 15°C, Gas Turbines operating at nominal load; calculations based on Gas Turbine exhaust gas properties as reported in specific suppliers' websites.
SYSTEM ADVANTAGES

• Completely automated – no operator in most case
• Do not consume water
• Remotely monitored and controlled
• Very low O&M Costs
• No effect on main power plant operation
• Maintains good efficiency at partial load
• Turn-down to 10% of nominal power
• Low turbine RPM, low mechanical stress
• Simple Start/Stop procedures
• Can reach efficiencies up to 25%
• Quiet Operation
Installed Cost

- Installed cost varies widely
- ~$1800 – $3000/kW
- Depends on:
  - Heat quality and Accessibility
  - Cooling: air/temp, water/humidity
  - Electrical interconnect
  - Project location
  - Labor rates
Electricity Price for 5yr Payback

Notes:
5 year Payback
6% Cost of Money
Favorable Case Availability @ 8300 h/yr
Unfavorable Case Availability @ 6100 h/yr

Minimum Electricity Price for Payback (€/kWh)

10
9
8
7
6
5
4
3
2
1
0
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.00

ORC Electrical Power (MWe)

Unfavorable
Favorable
THANK YOU!