Converting Low Temperature Waste Heat in Electricity using ORC Technology

Cleenewerck Tyndo
AGENDA

→ Company introduction
→ ORC introduction
→ Typical ORC applications
→ Case study:
  → district heating
  → biogas
→ Double/triple wins
→ Maximising IRR
→ Conclusion
→ Project references
• Established in 1953 (Grand Rapids, MI)

• Provides complex machinery globally (Automotive, Industrial, Glass, Aerospace, Energy)

• Global sales and service organization (24 hour support – Global Reach)

• Proven track record of quality machinery installed with long reliability records (generally 20-30 years in operation)

• Sales Turnover - $165 Million USD +

• Headcount – 562 Direct, 90+ Contract, 100+ Agent (Sales & Service)

• Nearly 100 CNC machining centers (vertically integrated)

• 8 Manufacturing Facilities globally positioned in the Americas, Europe, UK, and Asia
GLOBAL ORGANIZATION

BEP Owned Locations

North America (12,500 sqm)
- Grand Rapids, MI
- Three Rivers, MI
- Troy, MI
- Shelby Twp., MI

Europe (16,500 sqm)
- Brugge, Belgium
- Laatzen, Germany
- Bydgoszcz, Poland (2 locations)

UK (2,000 sqm)
- Bristol, UK
- Stroud, UK
- Gosport, UK

Asia (9,000 sqm)
- Wuxi, China
- Yokohama, Japan
- Seoul, South Korea (Tech Ctr.)

South America
- Sao Paulo, Brazil

Sales Agent & Service Locations

Beijing, Shanghai, Changchun, Chongqing, Wuhan, China
- Jakarta, Indonesia
- Bangkok, Thailand
- Pune, Delhi, Chennai, India
- Kuala Lumpur, Maleysia
BURKE PORTER PRODUCTS

DVT or Roll Brake

Lab Products (Chassis Dynos)

NCA – Non Contact Aligner

MIM – Motor in the Middle, NVH – Noise Vibration Harshness, HD, Other

HLA – Headlight Aim

DAS – Driver Assistance

Powertrain Test Stands

Simulates driving without full vehicle assy. NVH is the Primary Test

Wheel & Tire Asy. Systems

End of Line (EOL)

Build to Print (Machining)

Specialty Machines
BURKE PORTER PRODUCTS

Balancing Products (Universal Balancing, CIMAT)

- Drive Shafts / Prop Shafts
- Aerospace, Meters, Turbo-Chargers
- Brake Rotors, Fans, Large Axles

Powertrain Test Stands (NVH)
- Simulates driving without full vehicle assy. NVH is the Primary Test

Gage Based Assembly Systems – Powertrain (EPIC Equipment & Engineering)
E-RATIONAL PRODUCTS

ORC (E-Rational)

ORC 55-132 kWe
- Indoor, noise isolated skid
- Outdoor, 20 feet container

ORC 160-740 kWe
- Outdoor, 40 feet container
GLOBAL ENERGY CONCERN

• Today’s society is still heavily based on fossil fuel
• Due to limited resources, increasing demand, air quality issues and volatile prices:

  ➔ Improvement of technology
  ➔ Renewable energy sources: wind, solar,...
  ➔ Sustainable energy production: inexhaustible resources
  ➔ Energy management
**ORC: ENERGY MANAGEMENT**

- **Resource conservation**
  - Reuse of waste heat
  - Huge amounts of waste heat available, compared with solar or wind potential

- **Climate protection**
  - Zero emissions
  - No SMOG

- **Cost savings**
  - Reduction on electricity bill
  - Elimination of the costs for waste heat dumping

Significant financial & ecological benefits
Average Belgian consumption = 4 MWh / household

Windturbine 2MW
- 2200 h / year
- 4400 MWh / year
- 1100 households

ORC 400kWe
- 8000 h / year
- 3200 MWh / year
- 800 households

Soccer field Solar power
- 480 MWh / year
- 120 households
Simple Payback calculation:

- ORC, 315kWe, installed on gensets
  - Running hours: 8500 hrs
  - Electricity price: 100€/MWh
  - Net production: 275kW
  - Total yearly production: 2337,5 MWh
  - Yearly O&M cost: 27,500€

 donc, Simple ROI < 3 years

So, ORC makes economic sense if:
1. Running hours are high (>6000h/y)
2. Integration is not too complex
3. Electricity value is not too low (>70€/MWh)
Ir. William Macquorn Rankine

• **Steam cycle = Rankine Cycle**
  - High temperatures & pressures
  - Water is the medium
  - Production of work or electricity

• **Organic Rankine Cycle**
  - Water replaced by organic fluid or refrigerant
  - Lower temperatures required
  - Production of work or electricity
ORC TECHNOLOGY
Cycle
E-Rational ORC machine

• Recover waste heat between 80°C and 150°C

• Power range from 50kWe up to 740kWe

• Optimized efficiency full & part load

• Larger heat applications multiple units can be installed
ORC 50 to 132kWe

- Input between 80°C & 150°C
- Generator module 55 up to 132 kWe
- Hot water, steam or thermal oil
- Table for 1MW of hot water below
- Skid or 20 ft container

<table>
<thead>
<tr>
<th>$T_{\text{hot water}}$</th>
<th>$T_{\text{cold water}} = 20°C$</th>
<th>$T_{\text{cold water}} = 30°C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°C</td>
<td>72 kWe</td>
<td>65 kWe</td>
</tr>
<tr>
<td>100°C</td>
<td>84 kWe</td>
<td>74 kWe</td>
</tr>
<tr>
<td>110°C</td>
<td>91 kWe</td>
<td>81 kWe</td>
</tr>
<tr>
<td>120°C</td>
<td>101 kWe</td>
<td>91 kWe</td>
</tr>
<tr>
<td>130°C</td>
<td>111 kWe</td>
<td>101 kWe</td>
</tr>
<tr>
<td>140°C</td>
<td>121 kWe</td>
<td>112 kWe</td>
</tr>
</tbody>
</table>
**ORC 160 to 740 kWe**

- Input temperature between 80°C & 150°C
- Generator module 250 up to 2x370 (=740) kWe
- Hot water, steam or thermal oil
- Table for 4MW hot water below
- Standard in 40 ft container

<table>
<thead>
<tr>
<th>$T_{\text{hot water \ In}}$</th>
<th>$T_{\text{cold water}}$</th>
<th>OUT = 20°C</th>
<th>$T_{\text{cold water}}$</th>
<th>OUT = 30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°C</td>
<td>288 kWe</td>
<td></td>
<td>260 kWe</td>
<td></td>
</tr>
<tr>
<td>100°C</td>
<td>336 kWe</td>
<td></td>
<td>300 kWe</td>
<td></td>
</tr>
<tr>
<td>110°C</td>
<td>364 kWe</td>
<td></td>
<td>324 kWe</td>
<td></td>
</tr>
<tr>
<td>120°C</td>
<td>404 kWe</td>
<td></td>
<td>364 kWe</td>
<td></td>
</tr>
<tr>
<td>130°C</td>
<td>444 kWe</td>
<td></td>
<td>404 kWe</td>
<td></td>
</tr>
<tr>
<td>140°C</td>
<td>484 kWe</td>
<td></td>
<td>448 kWe</td>
<td></td>
</tr>
</tbody>
</table>
MAIN COMPONENTS

→ Refrigerants
→ Expander
→ Control Unit
→ Safety
ORC Refrigerant

Refrigerants applied

- R245fa (Honeywell)
- Solkatherm (Solvay)
- Novec (3M)

→ Selection depends on temperature and legislation

→ Zero ODP
→ Low GWP
→ Non-toxic
→ Non-flammable
SINGLE SCREW EXPANDER

- The heart of the machine
- Expander vs turbine
  → Robust
  → Performance at part load
  → Highly reliable
  → Lower operating cost
- Single Screw: connected to asynch. generator
CONTROL UNITS

- Siemens PLC
  - Monitor multiple parameters
  - Adapt to process conditions

- Touch panel
  - Visualization for operator

- Remote connection
  - Upload of new program version
SAFETY CONTROL

• CE compliant
  ➔ Pressure & Equipment Directive
  ➔ Hazop

• Manual for maintenance & operation
  ➔ Good Operating Practice

• Safety valves
  ➔ Prevent high pressures
Typical Applications

• Industrial waste heat
• Stationary Engines
• Geothermal Heat
• Biomass/Waste incineration
INDUSTRIAL WASTE HEAT

Waste heat from:
• Cooling processes
• Steel Industry: Walking beam furnaces 85°C → 75°C
• Chemical Industry: Exothermal reactions → Low P Steam
**STATIONARY ENGINES**

- Biogas, natural gas, diesel or HFO fueled
- ~40% conversion to electricity
- ~60% heat
- ORC: 5 – 10% electricity gain
STATIONARY ENGINES

- Jacket heat from engine cooling
- Heat from exhaust gas
- More heat to recuperate
- More electricity production by ORC
Geothermal Heat

- Low temperature heat sources
- Geothermal brine: salts & solids
- Secondary circuit necessary
Biomass/Waste Incinerators

- Can be in combination with district heating:
  - Heat excess: summer - winter
  - Typical Input temperature: 90°C
  - Typical Return temperature: 70°C
ORC HEAT SINK

• Lower cooling temperatures = higher production
  → Small amount of heat = to be dumped
• Reuse in low temperature heating (greenhouses)
  → Heat sink temperature = increased (max. 60°C)
  → Heat source temperature = high enough
  → High performant application
CASE: NETWORK BALANCING FOR DISTRICT HEATING
Case: Network Balancing for District Heating

Holzheizkraftwerk, Hövelhof, Germany

- Wood fired boiler 5 MWth / 17.6 MMBTU
- 1 MWe Turboden High temperature ORC (300°C/ 572°F)
- Cooling of Turboden is heat input for District Heating/E-Rational ORC

- ORC Project Type: ORC-315 kWe
  - Hot water 90°C-70°C/ 194°F-158°F
  - Thermal load max 4MW, typical 3MW
  - Cooling water circuit: Air cooled condensers
  - Power production max 315 kWe, typical 220kWe
- Delivery done April 2014, started up in June 2014
CASE: NETWORK BALANCING FOR DISTRICT HEATING
CASE : NETWORK BALANCING FOR DISTRICT HEATING
Holzheizkraftwerk, Hövelhof, Germany

Economics

- Total produced power: 1572 MWh
- Running hours: 8002
  - Average hourly production = 196.5 kWh
- Total Revenue: 251,520€ (total Electricity value: 160€/MWh)
- Total investment: 800,000€
- Simple Payback: 3.18 years

BUT: Now, also the wood boiler can run the whole year at full load, burning the waste wood AND the high temperature ORC can run the whole year at full load!
Holzheizkraftwerk Hövelhof

- **Holzheizkraftwerk Germany, Hövelhof**
  - Biomass (wood) boiler
  - 5MWth

- **Turboden**
  - High temperature ORC
  - Oil: >300°C
  - 1 MWe production

- **District heating net**
  - 90°C

- **ORC**
  - 315kWe production
  - Hot water 4MWth
  - 315 kWe production

- **E-RATIONAL**
  - Value for Heat

- **Air cooled condensers**

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**Sources:**
- E-RATIONAL
- Turboden
- BURKE PORTER GROUP
Vanheede Environmental Services, Quévy Belgium

- Anaerobic Digestion of waste biomass + 3 Biogas CHP Engines
  - Waste heat recovery from Engines (2 x 716 kWe + 1 x 1000 kWe)
  - Hot water 88°C (190°F)
    - Heating of Digesters
    - Building heating
    - Water for showers,...
  - Remaining heat goes to ORC (300-600 kW/h)
- Cooling: air condenser
- Power production: 40 kWe net
  - Yearly production > 340 MWhe
  - > 240 Tonnes CO2 reduction per year
- Type: E-Rational 55kWe
- Operational since July 2012
Waste heat recovery in biomass installations
BIOGAS APPLICATION - 1
BIOGAS APPLICATION - 1
DOUBLE AND TRIPLE WINS

Double Wins:

• Hövelhof: producing extra electricity + process stabilisation
• Jacket cooling of stationary engines (gensets)
  • Instead of using electricity to cool the jacket water, producing electricity
• Condensing waste steam
  • Producing electricity
  • Recuperating demineralised water
    • E.g. Proviron:
      • producing ~1500MWh electricity/year
      • Saving 27,000 m³/y of demi water
      • >1000 tonnes CO2 reduction
DOUBLE AND TRIPLE WINS

Triple Wins:

- Centre Aquatique Virton:
  - Biomass Pellet burner
  - producing electricity
  - Using condensor heat for floor heating/swimming pool heating
- Pontipool, UK:
  - Biomass burner
  - Producing electricity
  - Using condensor heat for biomass drying
- Greenhouses, France:
  - Biomass burner
  - Producing electricity
  - Using condensor heat at 60°C for greenhouse heating
MAXIMISING IRR

Using leverage:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>equity portion</td>
<td>0,25</td>
</tr>
<tr>
<td>cost/mach + installation</td>
<td>€ 500,000,00</td>
</tr>
<tr>
<td>total machines installed</td>
<td>1</td>
</tr>
<tr>
<td>Heat availability hours/year</td>
<td>8500</td>
</tr>
<tr>
<td>Machine availability (%)</td>
<td>96%</td>
</tr>
<tr>
<td>Net E production (kWh)</td>
<td>210</td>
</tr>
<tr>
<td>prod/mach/y (MWh)</td>
<td>1713,6</td>
</tr>
<tr>
<td>Electricity value (€/MWh)</td>
<td>100,0</td>
</tr>
<tr>
<td>Yearly gross revenu/machine (€)</td>
<td>€ 171,360,00</td>
</tr>
<tr>
<td>rental rate (%)</td>
<td>4,00%</td>
</tr>
<tr>
<td>loan duration (years)</td>
<td>5</td>
</tr>
<tr>
<td>ORC lifetime (years)</td>
<td>20</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>5,00%</td>
</tr>
<tr>
<td>WACC</td>
<td>6,75%</td>
</tr>
<tr>
<td>NPV</td>
<td>€ 1,092,533,08</td>
</tr>
<tr>
<td>IRR</td>
<td>92%</td>
</tr>
</tbody>
</table>

E-value has high impact on NPV, IRR. But even at 60€/MWh there is still a NPV of 352k€ and an IRR of 21%
## Maintenance

### Monthly Tasks
- Inspect. leakages @ flanges/valves/bolts
- Inspect. oil levels
- Inspect. mech. damages
- Clean filter cooling fan electrical cabinet
- Inspect. electrical cabinet

### 3-Monthly Tasks
- Inspect. oil levels
- Inspect. mech. damages

### 6-Monthly Tasks
- Clean magn. filter
- Inspect. mechanical cabinet
- Inspect. electrical cabinet

### 9-Monthly Tasks
- Clean magn. filter
- Inspect. electrical cabinet
- Refill generator lubricant
- Inspect. cold water side*

### Yearly Tasks
- Inspect. piping wall thickness*
- Overhaul of expander*
- Refill of the machine*

### 2-Yearly Tasks
- Overhaul of expander*
- Refill of the machine*

---

**Low Maintenance & Operation Cost**

(*) maintenance to be performed by BEP Europe or local partner
<table>
<thead>
<tr>
<th>Country</th>
<th>Client</th>
<th>Installed Power</th>
<th>#</th>
<th>Commissioning</th>
<th>Project Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>HoWest</td>
<td>11 kWc</td>
<td>1</td>
<td>2011</td>
<td>Test unit for simulation and R&amp;D in UGent University</td>
</tr>
<tr>
<td>Belgium</td>
<td>Proviron</td>
<td>250 kWc</td>
<td>1</td>
<td>2011</td>
<td>Recovery of waste heat from LP steam in chemical plant. Additional savings on steam condensate.</td>
</tr>
<tr>
<td>Belgium</td>
<td>Vanheeide</td>
<td>55 kWc</td>
<td>1</td>
<td>2012</td>
<td>Recovery of jacket water in biogas plant</td>
</tr>
<tr>
<td>Germany</td>
<td>Holzheizkraftwerk</td>
<td>90 kWc</td>
<td>1</td>
<td>2013</td>
<td>Recovery of heat excess in district heating. Heat delivered by biomass boiler (wood).</td>
</tr>
<tr>
<td>Norway</td>
<td>Alstom</td>
<td>90 kWc</td>
<td>1</td>
<td>2013</td>
<td>Recovery of heat from exhaust gases in anode baking furnace through Alstom's patented heat exchanger.</td>
</tr>
<tr>
<td>Germany</td>
<td>Holzheizkraftwerk</td>
<td>315 kWc</td>
<td>1</td>
<td>2014</td>
<td>Recovery of heat excess in district heating. Heat train with biomass boiler, high temperature ORC and district heating with E-Rational ORC.</td>
</tr>
<tr>
<td>Belgium</td>
<td>Delta Themic</td>
<td>22 kWc</td>
<td>1</td>
<td>2014</td>
<td>Heat recovery to electricity combined with heating of public swimming pool at ORC cold side. Heat delivered by wood chip boiler.</td>
</tr>
<tr>
<td>Japan</td>
<td>Tokyo Sangyo</td>
<td>260 kWc</td>
<td>1</td>
<td>2014</td>
<td>Power production with geothermal heat. Delivery of first machine in project.</td>
</tr>
<tr>
<td>Japan</td>
<td>Tokyo Sangyo</td>
<td>260 kWc</td>
<td>2</td>
<td>2015</td>
<td>Power production with geothermal heat. Delivery of 2 additional machines on same project as previous.</td>
</tr>
<tr>
<td>Belgium</td>
<td>Beneens</td>
<td>110 kWc</td>
<td>1</td>
<td>2016</td>
<td>Recovery of heat from biomass boiler (wood). Cold side of the machine is connected to the local heating network.</td>
</tr>
</tbody>
</table>
# References

<table>
<thead>
<tr>
<th>Country</th>
<th>Company</th>
<th>Size (kWe)</th>
<th>Years</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>Dordtech</td>
<td>90</td>
<td>2015</td>
<td>Recovery of waste heat from a biomass boiler. The cooling side of the ORC is used for low temperature drying processes.</td>
</tr>
<tr>
<td>France</td>
<td>TREDI</td>
<td>370</td>
<td>2016</td>
<td>Recovery of waste heat from industrial waste incinerator.</td>
</tr>
<tr>
<td>UK</td>
<td>Dordtech</td>
<td>110</td>
<td>2016</td>
<td>Recovery of waste heat from a biomass boiler. The cooling side of the ORC is used for low temperature drying processes.</td>
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<tr>
<td>Romania</td>
<td>Energy Serv</td>
<td>200</td>
<td>2016</td>
<td>Recovery of waste heat from wood fired boiler. E-RATIONAL ORC connected to cooling side of a Turboden high temperature ORC.</td>
</tr>
<tr>
<td>UK</td>
<td>Crossfieds Farm</td>
<td>220</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
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<tr>
<td>UK</td>
<td>Stuart skelton</td>
<td>160</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
</tr>
<tr>
<td>South Korea</td>
<td>LSIB Gyeonggannyun</td>
<td>160</td>
<td>2016</td>
<td>Recovery of waste heat in the form of steam into electrical power.</td>
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<tr>
<td>UK</td>
<td>IEC Solutions</td>
<td>220</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
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<tr>
<td>UK</td>
<td>Tudor Griffits Group</td>
<td>185</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
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<tr>
<td>UK</td>
<td>Barden Biomass</td>
<td>180</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
</tr>
<tr>
<td>UK</td>
<td>Isembard Ltd</td>
<td>90</td>
<td>2016</td>
<td>Recovery of waste heat from biomass boiler.</td>
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<td>Barden Biomass</td>
<td>90</td>
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<td>Recovery of waste heat from biomass boiler. The cooling side is used for drying processes.</td>
</tr>
</tbody>
</table>
CONCLUSION

We are committed to the interests of our Clients = Add value to the Clients operations with our ORC machines

Sustainable energy solutions: NO HEAT TO WASTE!

Rational and logical approach

Low temperature waste heat

Creating green energy

E-RATIONAL

High quality standards

Reliable ORC machines

Attractive pay-backs

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