Waste Heat Recovery using Organic Rankine Cycle turbines
**Heat balance, fuel furnace, permanent regime**

- **Fuel** 100%
- **Useful heat** 100%
- **Fumes loss** 25 to 60%
- **Loss due to openings** 3 to 10%
- **Loss due to walls** 3 to 10%
- **Loss due to conveyors** 3 to 10%

Source: ADEME (2014)
Waste Heat Recovery using ORC turbines

Industrial waste heat: the example of France (2)

Typically: agro, paper, chemical industry

Typically: steel mill, cement & glass factories

Source: ADEME (2014)
Waste Heat Recovery using ORC turbines

Industrial waste heat: the example of France (3)

- Heating networks
- Electricity production

Energy efficiency actions on site

Waste heat avoided

Waste heat recovered and exported

Waste heat recovered on site

Recoverable waste heat

Waste heat definitely lost

Useful heat for production

Waste heat

Fuel consumption

Source: ADEME (2014)
Waste Heat Recovery using ORC turbines

Industrial waste heat: the example of France (4)

Figures in brief
319 TWh:
- 275 TWh (industry)
- 44 TWh (refineries)

Process: furnaces, dryer, boilers
Temperature > 100°C: fumes, vaporized fluids

Losses from boilers’ fumes
- 28%
- 40%
- 32%

Losses from furnaces’ fumes
- 11%
- 7%
- 14%

Remaining heat from dryers
- 78%

Industrial waste heat > 100°C
- 51 TWh

Source: ADEME (2014)
1,1 TWh
250 sites
1,400 MWe potential

Fuel consumption: ~287 TWh, ~37 000 sites (> 10 salariés)

Waste heat: ~26 TWh, ~37 000 sites

Gross power production: ~300 GWh, ~164 MWe, ~1 060 sites

Net power production: ~120 GWh, ~140 MWe, ~250 sites

Source: ADEME (2014)
Waste Heat Recovery using ORC turbines

Industrial Waste Heat Recovery

Purchased fuels (oil, gas, biomass, etc.)

Heat generation (boilers, fired heaters/furnaces, etc.)

Genset

ST, ORC

Electricity generated (engine, ST, ORC, etc.)

Electricity purchased (oil, gas, biomass, etc.)

Process

ORC

Cooling system (cooling towers, closed loop cooling, etc.)

Surroundings (rivers, air, etc.)

Electricity

Heat

Cold
Expanding heat to power scope of possibilities

- no fuel
- no combustion
- no emissions

- no chemicals*
- no need for high pressure
- suitable with temperatures as low as 80°C

* hot loop
Waste Heat Recovery using ORC turbines

In operations for 35 years, producing more than 3,000 MW worldwide!

Source: orc-world-map.org (2015)

More players since the years 2000
Waste Heat Recovery using ORC turbines

WhR using ORC technology : types of activities

- Diesel engine or gas turbine: 66.8%
- Other applications: 0.3%
- Waste to energy: 5.8%
- Pulp & paper: 0.4%
- Primary or fabricated metals: 7.2%
- Petroleum and coal products: 1.4%
- Other landfill gas engine: 0.7%
- Chemical industry: 0.9%
- Cement & lime: 8.3%
- Biogas: 1.0%
- LNG: 1.4%

Source: orc-world-map.org (2015)
Waste Heat Recovery using ORC turbines

Reminder of Organic Rankine Cycle (ORC) technology

- thermal oil
- superheated water
- (hot gas)

Working fluid vaporized (vapor phase)

Working fluid condensed (liquid phase)

- water
Waste Heat Recovery using ORC turbines

Figures for a very low enthalpy waste heat recovery
### Comparative table between ST and ORC solutions (1)

<table>
<thead>
<tr>
<th></th>
<th>Steam turbines</th>
<th>ORC turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot loop</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fluid</td>
<td>purified water steam</td>
<td>thermal oil or superheated water</td>
</tr>
<tr>
<td>pressure</td>
<td>20 to 300 bar</td>
<td>5-20 bar</td>
</tr>
<tr>
<td>temperature</td>
<td>250-550°C</td>
<td>80-330°C</td>
</tr>
<tr>
<td>chemicals</td>
<td>yes (water purification)</td>
<td>no</td>
</tr>
<tr>
<td>reheating device</td>
<td>yes (water purification)</td>
<td>no</td>
</tr>
<tr>
<td><strong>Working fluid loop</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fluid</td>
<td>dry purified water steam (HP)</td>
<td>« organic » fluid</td>
</tr>
<tr>
<td></td>
<td>possible droplets at LP stages</td>
<td></td>
</tr>
<tr>
<td>water consumption</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>pressure inlet turbine</td>
<td>20 to 300 bar</td>
<td>5-20 bar</td>
</tr>
<tr>
<td>temperature inlet turbine</td>
<td>250-550°C</td>
<td>80-330°C</td>
</tr>
<tr>
<td>pressure outlet turbine</td>
<td></td>
<td>&lt; 2 bar</td>
</tr>
<tr>
<td>temperature outlet turbines</td>
<td>100-45°C</td>
<td>~60°C</td>
</tr>
<tr>
<td>CHP</td>
<td>possible</td>
<td>possible</td>
</tr>
<tr>
<td><strong>Turbine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blades</td>
<td>up to tens of stages</td>
<td>1 to ~15</td>
</tr>
<tr>
<td>diameter</td>
<td>up to several meters</td>
<td>10 to 60 cm</td>
</tr>
<tr>
<td>rotation speed</td>
<td>1800-3600 rpm</td>
<td>up to 1800 rpm</td>
</tr>
</tbody>
</table>

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## ORC versus steam turbines technologies

<table>
<thead>
<tr>
<th></th>
<th>ST</th>
<th>ORC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>80-90%</td>
<td>98%</td>
</tr>
<tr>
<td>Load variation</td>
<td>-5/+5%</td>
<td>-60/+120</td>
</tr>
<tr>
<td>Pressure, temperature</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Corrosion (efficiency decrease)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Lifetime</td>
<td>15</td>
<td>20-25</td>
</tr>
<tr>
<td>Water consumption, chemicals</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maintenance, OPEX</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

## Financial benefits choosing ORC tech.

<table>
<thead>
<tr>
<th></th>
<th>ST</th>
<th>ORC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Installation and commissioning</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Exploitation, availability (incomes)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Maintenance, OPEX</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Value and options at the end of the PPA</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Overall benefits at the end of the PPA</strong></td>
<td><strong>-</strong></td>
<td><strong>+</strong></td>
</tr>
</tbody>
</table>
Steam and ORC turbines

**Steam turbine**

- **HP stages**
- **LP stages**

**ORC turbine**

**Turbo expander**: combination of a micro turbine with an integrated generator

Potential applications are not only ORC but also CO2 cycle, natural gas expansion, process gas expansion, hot air energy recovery

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Waste Heat Recovery using ORC turbines

Various ORC applications

Biogas, landfill gas
- Enhancement of biogas engine via exhaust, water jacket or both
- Direct biogas to electricity conversion with boiler

Solar
- Solar CHP with CSP field
- Solar CHP with CSP and heat storage

Biomass
- Biomass to electricity
- Biomass CHP
- Isolated site

Geothermal
- Natural hot sources
- Medium temperature wells (from 80°C)

Renewable Energies

Industrial Waste Heat Recovery
- Process Heat
- Exhaust gases
- Waste steam

Diesel and gas gensets
- Efficiency enhancement via exhaust, water jacket or both

Transportation
- Vessels
- Railroad
- Heavy Duty Trucks

Education and research
- With boiler simulating heat source

Energy Efficiency

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Waste Heat Recovery using ORC turbines

Industrial waste heat recovery

- fumes
- industrial process
- excess steam

- cement factories
- still mills
- foundries
- glass furnaces
- refineries
- aluminium smelters
- incinerators
- plants treating sewage through incineration
- paper factories
- agro-industry
- etc.
Waste Heat Recovery using ORC turbines

Case study: cement factory (1)

- Flue gas outlet temperature from all sources: 180°C

Thermal oil loop data:
- Thermal oil mass flow: 79.1 kg/s
- Thermal power recovered: 26.713 kW
- Electrical consumption: 20 kW

Recuperators (Heat exchanger on flue gas)

High temperature loop inlet temperature: 290°C
High temperature loop outlet temperature: 140°C

2 x ATM-3000H
- 6 266 kW gross (Efficiency: 23.45%)
- 5 952 kW net (Efficiency: 22.28%)

Flue gas data from hot source 1:
- Mass flow: 25.4 kg/s
- Available temperature: 377°C
- Recovered heat: 5 220 kW
- Flue gas pressure loss in the heat exchanger: <1.5 kPa

Flue gas data from hot source 2:
- Mass flow: 123.2 kg/s
- Available temperature: 339°C
- Recovered heat: 20 315 kW
- Flue gas pressure loss in the heat exchanger: <1.5 kPa

Flue gas data from hot source 3:
- Mass flow: 7.1 kg/s
- Available temperature: 339°C
- Recovered heat: 1 178 kW
- Flue gas pressure loss in the heat exchanger: <1.5 kPa

Net power solution: 5 742 kW
Efficiency: 21.49%

Cold source data:
- Thermal power dissipated: 20 402 kW
- Water mass flow rate: 487.9 kg/s
- Ambient temperature (annual average): 25 °C
- Electrical consumption of the circulation pump: 58 kW
- Electrical consumption of the dry coolers: 134 kW

Cooling water loop
Outlet temperature: 45°C
Inlet temperature: 35°C

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Waste Heat Recovery using ORC turbines

Case study: cement factory (2)

Scope / Investment

2x ATM-3000H (2 x ORC 3000 kWe)

Estimated CAPEX for turnkey PP: 20 MUSD
Incentives: 0
Annual OPEX: 0.5 MUSD

Performance

Net production: 5742 kWe
ORC availability: 8500 h (97%)
Global availability: 8000 h (91%)
Annual production: 45,936 GWh

Profitability

TRI (80 USD/MWh): 6 years
TRI (100 USD/MWh): 5 years
LCOE (10 years): 54 USD/MWh
LCOE (20 years): 32 USD/MWh

Electricity tariff of 80 USD/MWh

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Charcoal and pelets factory: recovering excess heat from the dryer

Waste Heat Recovery using ORC turbines

2,5 MW recovered thermal power

Heat exchanger

200 kW Electricity Production

Evaporator

Condenser

Pump

2,5 MW recovered thermal power

130°C

Hot water loop 30 kg/s

110°C

200°C Hot air

50°C

Cold water 19 kg/s

30°C

ORC (Scope of the pre-quotation)
Waste Heat Recovery using ORC turbines

Case study: WHR from biomass dryer (1)

Scope / Investment

1x ENO-200LT (ORC 200 kWe)

Estimated global CAPEX: 600 kUSD
Incentives: 0
Annual OPEX: 15 kUSD

Performance

Net production: 180 kWe
ORC availability: 8670 h (99%)
Global availability: 8500 h (97%)
Annual production: 1,530 MWh

Profitability

TRI (100 USD/MWh): 4- years
LCOE (10 years): 92,5 USD/MWh

Electricity tariff of 0.1 USD/kWh
Waste Heat Recovery using ORC turbines

Internal Combustion Engines (ICE) heat recovery

- Diesel, HFO, gas, biogas
- Exhaust gases and possibly jacket water heat the thermal oil with a heat exchanger
- Approximately 10% additional electricity is produced
Waste Heat Recovery using ORC turbines

Case study: WHR from a biogas engine

With a Jenbacher biogas engine
Waste Heat Recovery using ORC turbines

- ORC technology provides a solution to reduce flaring and venting
- Low quality gases from well are diverted to a boiler (Thermal Oil Heater).

The new ranking – top 30 flaring countries (2013-15)

Source: NOAA/OGFR
The estimated recoverable:
- heat output is 1580 kW\text{th}
- net power output is 88 kW\text{e}
Waste Heat Recovery using ORC turbines

Case study: oil wells conversion -> geothermal (2)

Scope / Investment
ENO-100LT (ORC 100 kWe)
Estimated global CAPEX : 350 kUSD
Incentives : 0
OPEX : 30 kUSD

Performance
Gross production : 98 kWe
Net production : 88 kWe
ORC availability : 8670 h (99 %)
Global availability : 8500 h (97%)
Annual production : 748 MWh

Profitability
TRI (100 USD/MWh): 6+ years
TRI (200 USD/MWh): 3- years
LCOE (10 years) : 87 USD/MWh
LCOE (20 years) : 63,5 USD/MWh
Estimate of electricity production for various flow rates and temperatures of the source

**Ambient temperature : 31°C**

![Graph showing electricity production vs mass flow rate for different temperatures (90°C, 100°C, 110°C).](image)
Waste Heat Recovery using ORC turbines

Ship’s diesel engine heat recovery (1)
Ship’s diesel engine heat recovery (2)

Waste Heat Recovery using ORC turbines

Evaporator: 2600 kg/h, 385°C, <120°C, 160°C, 1.02 bar

Regenerator: 1.47 kg/s

Condenser: 8 m³/h, 15.94 bar, 15°C

Sea water

From engine’s exhaust gases

Turbine expander

Evaporator

Organic fluid cycle

Condenser

Feed-pump

Electricity

Cooling

Waste heat

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Waste Heat Recovery using ORC turbines

Ocean Thermal Energy Conversion (OTEC)

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Waste Heat Recovery using ORC turbines

Thank you for your attention!

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