ENERGIZE YOUR FUTURE. DON’T WASTE YOUR POWER.
OUR PRODUCTS

ORC SYSTEM

LARGE HEAT PUMP

GAS EXPANDER

Designed for decarbonization.
Turboden Organic Rankine Cycle (ORC) units can produce electricity by recovering residual low-grade heat from industrial processes and from internal combustion engines, gas turbines, and fuel cells operating on open cycle. The generated power ranges up to 20 MW electric per single shaft.

**WHY CHOOSE ORC FOR ENERGY EFFICIENCY?**

- Generate profit by valorising a waste heat source
- Reduce specific production cost by decreasing energy demand
- Improve company sustainability
- Contribute to lower carbonisation and combat climate change
ENERGY EFFICIENCY FOR YOUR BUSINESS

**GAS TURBINES or ICE**
- Gas compressor stations
- Gas storage
- Oil pumping stations
- Sea water injection systems

**PROCESS HOT STREAMS**
- Refinery hot streams
- Thermal oil used in Oil & Gas process
- Geothermal and associated hot water

**ASSOCIATED PETROLEUM GAS**
- Boilers
- Gas turbines or internal combustion engines

**OUTPUT**

**ELECTRIC POWER and/or MECHANICAL POWER**
THE ORC CYCLE – HOW IT WORKS

The ORC turbogenerator uses medium-to-high temperature thermal oil to preheat and vaporize a suitable organic working fluid in the evaporator (4>5).

The organic fluid vapor rotates the turbine (5>6), which is directly coupled to the electric generator, resulting in clean, reliable electric power.

The exhaust vapor flows through the regenerator (6>7), where it heats the organic liquid (2>3) and is then condensed in the condenser and cooled by the cooling circuit (7>8>1).

The organic working fluid is then pumped (1>2) into the regenerator and evaporator, thus completing the closed-cycle operation.

* ORC units can produce electric and/or mechanical power
GAS COMPRESSOR STATION

- Combined cycle configuration with multiple gas turbines
- ORC output from 1 to 20 MW per single turbine
- Combined cycle output 30-40% higher than open cycle output
- Power produced can be exported to the grid or used for internal consumption, especially electrical motor-driven compressors
## OVERALL PLANT PERFORMANCES

### GAS TURBINES

**GT USEFUL POWER**

<table>
<thead>
<tr>
<th><strong>EXHAUST GAS</strong></th>
<th>ORC unit</th>
</tr>
</thead>
</table>

30±40% **ORC additional power***

<table>
<thead>
<tr>
<th>**Useful power *****</th>
<th><strong>Thermal power</strong></th>
<th><strong>Thermal losses</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>18 ± 30%</td>
<td>80 ± 68%</td>
<td>2%</td>
</tr>
</tbody>
</table>

* ORC power output compared to GT or ICE shaft capacity (e.g. 10 MW GT → 3÷4 MWe ORC; 10 MW ICE → approx. 1 MWe ORC).

** Min. flow to ORC: from GT 10-15 kg/s; from ICE 30-40 kg/s.

*** Mechanical and/or electric, calculated on thermal power input to ORC.

### INTERNAL COMBUSTION ENGINES

**ICE USEFUL POWER**

<table>
<thead>
<tr>
<th><strong>EXHAUST GAS</strong></th>
<th>ORC unit</th>
</tr>
</thead>
</table>

10% **ORC additional power***

<table>
<thead>
<tr>
<th><strong>Thermal losses</strong></th>
<th>**Useful power *****</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>18 ± 26%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Thermal power</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>80 ± 72%</td>
</tr>
</tbody>
</table>

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Oil & Gas
GAS TURBINE BOTTOMING WITH ORC

NOTES:

- Indicative values assuming gas turbines operating at nominal load with exhaust gas properties as reported in specific suppliers websites.
- Shaded area represents the potential ORC power output in relation to gas turbine(s) shaft power. ORC performance may vary depending on specific project features.

- Special ORC unit, developed with gas turbine OEM

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Centaur 40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Taurus 70</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>SGT-300</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>SGT-400</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>Mars 100</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Titan 130</td>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>GE10-1</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td>PGT25</td>
<td>14</td>
<td>40</td>
</tr>
<tr>
<td>PT25+G4</td>
<td>12</td>
<td>45</td>
</tr>
<tr>
<td>SGT-750</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>LM6000</td>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>MHPS H-25</td>
<td>14</td>
<td>60</td>
</tr>
<tr>
<td>SGT-A65 TR</td>
<td>16</td>
<td>65</td>
</tr>
<tr>
<td>3 x SGT-300</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>3 x SGT-400</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>3 x SGT-400</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

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INTERNAL COMBUSTION ENGINES BOTTOMING WITH ORC

NOTES:
- Indicative values assuming ICE operating at nominal load with exhaust gas properties as reported in specific suppliers websites.
- Shaded area represents the potential ORC power output in relation to engine(s) nominal power. ORC performance may vary depending on specific project features.
THERMODYNAMIC CYCLE: ORC VS STEAM

**STEAM RANKINE CYCLE**

- Superheating needed
- Risk of blade erosion due to possible liquid formation during the expansion
- High enthalpy drop – turbine with high stage number

**ORGANIC RANKINE CYCLE**

- No need to superheat
- No risk of blade erosion thanks to dry expansion in the turbine
- Small enthalpy drop - turbine with low stage number

### Thermodynamic features and consequences

- **STEAM RANKINE CYCLE**
  - Superheating needed
  - Risk of blade erosion due to possible liquid formation during the expansion
  - High enthalpy drop – turbine with high stage number

- **ORGANIC RANKINE CYCLE**
  - No need to superheat
  - No risk of blade erosion thanks to dry expansion in the turbine
  - Small enthalpy drop – turbine with low stage number

### Operation and maintenance costs

- **STEAM RANKINE CYCLE**
  - Water treatment required
  - Highly skilled personnel needed
  - Periodic major overhaul

- **ORGANIC RANKINE CYCLE**
  - Water-free system
  - Minimum Operation & Maintenance cost
  - No major overhaul
  - Completely automatic

### Other features

- **STEAM RANKINE CYCLE**
  - Low flexibility with significantly lower performances at partial load
  - Convenience for large plants and high temperatures

- **ORGANIC RANKINE CYCLE**
  - High flexibility – Wide operational range from 10% to 110%
  - High availability (average >98%)
EXHAUST GAS HEAT RECOVERY EXCHANGER CONFIGURATION

- EGHEs installed in **by-pass** to the main exhaust gas ducting in order to **avoid any impact on the gas turbines operation** in any circumstance.

- **EGHEs completely isolable** with a diverter prior to the EGHEs and an insulation valve right after it. Diverter equipped with air sealing to ensure 100% insulation. This permits to **insulate the EGHEs, ensuring gas turbines operation** even in case of major issues on the EGHEs.

- Pneumatic **safety-closed diverter** to avoid any impact on gas turbines operation even during emergency situation.

- EGHE equipped with sparking detector, flame detector and thermocouples in different bundle position to **ensure the maximum safety of the system**.

- **False air** fan installed in order to keep the EGHE temperature at acceptable level even in case of gas turbines particular operation cases.
REFINERY HOT STREAMS

HEAT RECOVERY
OF LOW-ENTHALPY STREAMS
(e.g. hot diesel)

O&G FACILITIES PRESENT DIFFERENT LOW-ENTHALPY SOURCES
- Diesel hot streams in refineries
- Exhaust gases of distillation columns
- Condensing steam in gas treatment process
- Exhausted or not used wells
- Others......

DIESEL PRODUCTION PROCESS

ENERGY EFFICIENCY IMPROVEMENT:
- Plant power consumption reduction
- CO₂ emission reduction
- Fuel-free additional electricity

From stripper

Air fin cooler

Air fin cooler

Water cooling

To coalescer

DM water heaters
FLARE GAS

- Flare gas exploitation up to 50 MW: streams up to 7,500 Sm³/h
- Heat value from 15 MJ/Sm³ and variable chemical composition
- Multiple burning solution in case of high flare flows or high fluctuation (20÷100%)
- ORC output from 1 to 20 MW per single turbine
GAS EXPANDER

Turboden gas expander is a solution to enhance the energy efficiency of a natural gas network infrastructure, producing electricity by taking advantage of the reduction of gas pressure from the delivery level to the one required by the network. The decarbonised electricity is available to the infrastructure, reducing the associated costs.

KEY POINTS

- Design based on 40 years of experience, leveraging Mitsubishi Heavy Industries support
- Long experience in the energy efficiency sector
- Profit generation while reducing the gas pressure
- Solution for natural gas network decarbonisation
- Unmanned installations, thanks to specific technology features
- Turn-key equipment capabilities
- Over 60 Turboden turbine models within the 390 power plants fleet
THE CONFIGURATION

Oil & Gas
### TURBODEN GAS EXPANDER RATING

#### EXPANDERS SIZES

<table>
<thead>
<tr>
<th>Feature</th>
<th>EXP 400</th>
<th>EXP 600</th>
<th>EXP 900</th>
<th>EXP &gt; 1 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine stages/admission</td>
<td>Single stage radial turbine</td>
<td>Multi stages axial turbine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rate</td>
<td>&gt;5000 Sm3/h</td>
<td>5,000 - 100,000 Sm3/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In - out gas pressure range</td>
<td></td>
<td></td>
<td>70 - 1 bar(g)</td>
<td></td>
</tr>
<tr>
<td>Bearings</td>
<td>Magnetic or rolling bearing</td>
<td>Rolling bearing oil lubricated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seals</td>
<td>Single tight casing for impeller and generator</td>
<td>Mechanical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>Permanent Magnet generator</td>
<td>A/Synchronous LV - Eff. 97%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Containerization</td>
<td></td>
<td></td>
<td>Sandwich panel REI 120 if 10m gate distance possible; or concrete if 2m gate distance possible. Necessary to segregate electrical panel and hot water boiler.</td>
<td></td>
</tr>
<tr>
<td>Gas pre-heating</td>
<td>Hot water boiler fed by natural gas and shell&amp;tube heat exchangers + possible combination with electrical heaters and heat pumps – custom based on project specific.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OTHER TURBODEN SOLUTIONS

Among Turboden portfolio of products, two additional solutions are available to produce thermal power serving the facility process:

**HIGH-TEMPERATURE COGENERATION SOLUTIONS**

ORC produces both electricity and a valuable high temperature heat carrier, such as steam (5 - 30 bar), directly exploitable in Oil & Gas processes.

**LARGE-SCALE HEAT PUMPS**

LHP allow to transfer large quantities of heat from a colder source to a higher temperature heat user, like refinery process.
CUSTOMER: TransGas
COUNTRY: Canada
DESCRIPTION: power generation from waste heat from Solar Centaur 40 gas turbine in a gas compressor station
ORC ELECTRIC POWER: 1 MW (more than 28% of gas turbine shaft power)
STATUS: in operation since 2011
AVAILABILITY RECORDED: 95%
GAS TURBINE PRIME POWER: 3.5 MWm
Customer: Uztransgaz
Country: Uzbekistan

Description: Power generation from waste heat from 3 GE LM 1600 gas turbines in Hodzhaabad gas compressor station operated by Uztransgaz.

ORC Electric Power: 1 MW - island mode operation. The ORC unit covers the compressor station captive consumption.

Status: Under finalization of commissioning.

Features:
- Solution with air-cooled condenser, no water needed
- By-pass mode, with no impact on the gas turbines operation.
UZTRANSGAZ: FEATURES

- Fully containerized unit, suitable for climatic and seismic conditions of Uzbekistan
- Minimization of on-site activities with consequent reduction of EPC costs
- Optimization of operation & maintenance activities – possibility to use existing personnel of customer
- Installation on existing compressor plant with complicated layout, without affecting operation of gas pumping units
CUSTOMER: Shurtanneftegaz

COUNTRY: Uzbekistan

DESCRIPTION: power generation from waste heat from 1 MW GE LM 2500 gas turbine in Shurtan gas compressor station operated by Shurtanneftegaz, part of National Holding Company Uzbekneftegaz.

ORC ELECTRIC POWER: 1 MW - island mode operation. The ORC unit covers the compressor station captive consumption

STATUS: contract signed, engineering completed, waiting for project execution starting

FEATURES:
- modularized solution limited activities on site required
- by-pass mode, with no impact on the gas turbines operation
- non-flammable working fluid directly evaporated in the heat recovery exchanger
- solution with air-cooled condenser, no water needed
CUSTOMER: LUKoil
COUNTRY: Russia
DESCRIPTION: power generation from heat released by flare gas combustion (boiler designed to burn gas with a minimum lower calorific value of 4,500 kcal/Nm3)
ORC ELECTRIC POWER: 1.8 MW
STATUS: in operation since 2015
INLET/OUTLET WATER TEMPERATURE (CHP MODE): 65/95 °C – hot water exploited for oil pumping
## REFERENCES FROM INTERNAL COMBUSTION ENGINES

<table>
<thead>
<tr>
<th>PLANT</th>
<th>COUNTRY</th>
<th>START UP</th>
<th>ORC SIZE (MWe)</th>
<th>ENGINES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PISTICCI I</td>
<td>Italy</td>
<td>2010</td>
<td>1.8</td>
<td>3 x 8 MWe Wärtsilä diesel engines</td>
</tr>
<tr>
<td>TERMOINDUSTRIALE</td>
<td>Italy</td>
<td>2008</td>
<td>0.5</td>
<td>1 x 8 MWe MAN diesel engine</td>
</tr>
<tr>
<td>PISTICCI II</td>
<td>Italy</td>
<td>2012</td>
<td>4</td>
<td>2 x 17 MWe Wärtsilä diesel engines</td>
</tr>
<tr>
<td>CEREAL DOCKS</td>
<td>Italy</td>
<td>2012</td>
<td>0.5 (direct exchange)</td>
<td>1 x 7 MWe Wärtsilä diesel engine</td>
</tr>
<tr>
<td>E&amp;S ENERGY</td>
<td>Italy</td>
<td>2010</td>
<td>0.6</td>
<td>2 x 1 MWe Jenbacher gas engines + 3 x 0.8 MWe Jenbacher gas engines + 1 x 0.6 MWe Jenbacher gas engine – landfill gas</td>
</tr>
<tr>
<td>ULM</td>
<td>Germany</td>
<td>2012</td>
<td>0.7</td>
<td>2 x 2 MW Jenbacher gas engines (+ additional heat from process)</td>
</tr>
<tr>
<td>KEMPEN</td>
<td>Germany</td>
<td>2012</td>
<td>0.6</td>
<td>Gas engines</td>
</tr>
<tr>
<td>MONDO POWER</td>
<td>Italy</td>
<td>2012</td>
<td>1</td>
<td>1 x 17 MWe Wärtsilä diesel engine</td>
</tr>
<tr>
<td>HSY</td>
<td>Finland</td>
<td>2011</td>
<td>1.3</td>
<td>4 x 4 MWe MWM gas engines – landfill gas</td>
</tr>
<tr>
<td>FATER</td>
<td>Italy</td>
<td>2013</td>
<td>0.7 (direct exchange)</td>
<td>1 x 8 MWe Wärtsilä diesel engine</td>
</tr>
<tr>
<td>ORTADOGU I</td>
<td>Turkey</td>
<td>under construction</td>
<td>2 x 2.3</td>
<td>28 x 1.4 MWe Jenbacher engines + 4 x 1.2 MWe MWM engines – landfill gas</td>
</tr>
<tr>
<td>ORTADOGU II</td>
<td>Turkey</td>
<td>under construction</td>
<td>2.3</td>
<td>12 x 1.4 MWe Jenbacher engines – landfill gas</td>
</tr>
<tr>
<td>BIOGASTECH</td>
<td>Belgium</td>
<td>2019</td>
<td>0.7</td>
<td>4 x 3.3 MWe Jenbacher gas engines</td>
</tr>
</tbody>
</table>
OUR EXPERIENCE. YOUR POWER.