TOMORROW’S ENERGY

The time for developing clean and sustainable energy sources for the future is now. As a leading turboexpander innovator for more than 50 years, Atlas Copco Gas and Process calls upon its experience to offer a full line of Organic Rankine Cycle products delivering superior efficiency and reliability. We help companies around the world to fully utilize geothermal, waste heat and cold energy to power resources.
Future-oriented technologies, such as geothermal power, together with waste heat and cold energy recovery applications, are delivering green, renewable energy. In the case of geothermal power, this provides important baseload capacity around the clock.

Experience Meets Innovation

Efficiency is paramount for effective Organic Rankine Cycle (ORC) operations – and Atlas Copco Gas and Process delivers on this promise. Our radial in-flow turbines, or turboexpanders, form the basis for our entire range of ORC solutions.

Employing integral gear technology, the industry’s most efficient and compact drive design, as well as Variable Inlet Guide Vanes (IGVs), our turboexpanders deliver continuous, reliable power production.

Turboexpander expertise is just the beginning. From core turboexpander units, with up to 40 MW per train, all the way to customized ORC power plants, we provide a single point of contact for a complete range of solutions that generate power from geothermal, waste-heat or cold energy resources.

Through our extensive network, active in more than 180 countries, we provide customer-specific, clean energy solutions around the globe. We also offer a matching aftermarket team to assist with plant add-ons such as remote monitoring, or island mode, which allows for continued operation should a plant disconnect from the power grid.

Industry-leading ORC Projects

We have enabled numerous customers throughout the world to realize their energy production goals. These solutions extend from remote, unmanned generation facilities to large-scale power plants. Atlas Copco has delivered solutions through more than 20 completed or active projects.

A cutting-edge plant in Pamukören, Turkey, (pictured above) and an innovative dual-use geothermal power/district heating facility in Bavaria, Germany (right) are two of several projects around the world that use Atlas Copco turboexpanders and ORC solutions to generate electricity from the Earth’s heat.
Customer Benefits

• Custom-engineered solutions to match specific applications

• Radial in-flow turbines are equipped with Integral Gear Technology, the industry’s most efficient drive design

• Variable Inlet Guide Vanes and Advanced Impeller Design for optimal power generation

• Wide operational range to accommodate temperature and process variations

• Working fluid selection to best match process requirements

• Thousands of turboexpander references worldwide across a wide range of industries

• Reliable and stable power production for a secure return on investment

One of our flagship projects is a geothermal power plant in Pamukören, Turkey, which (as of 2014) has a net electrical capacity of 45 MW. Once expansion of this plant (adding an extra 45 MW) and other projects in the country are completed, the combined geothermal power capacity in Turkey made possible by Atlas Copco will top 150 MW, easily meeting the energy needs of at least 130 000 people.

A Future Full of Potential

Currently, the total installed capacity of all geothermal power plants throughout the world is roughly 13 000 MW. Conservative estimates see this capacity rising by an impressive 1200% to 160 000 MW before 2050.’

The potential for waste heat to power is equally staggering. In the US, less than 1% of the 7–10 GW that could be generated through industrial waste heat is utilized.** In the EU, waste heat ORC technology could produce about 2.5 GW, representing 4.8% of the total electricity consumed by the European industry sector.***

Through current, proven technologies Atlas Copco enables companies around the globe to take advantage of this potential. As evidenced by our ongoing, extensive Research & Development commitment to further develop ORC, this is an important technical area where we do more for our customers.

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* Figures as of 2010. Source: International Geothermal Association and paper: B.A. Goldstein et al., Great Expectations for Geothermal Energy to 2100


A cutting-edge plant in Pamukören, Turkey, is one of our flagship projects in the energy recovery sector. Atlas Copco led a consortium with Exergy and SPIG to deliver a 45 MW plant. As of 2014, construction is underway to expand this plant by another 45 MW.

FULL GEOTHERMAL POTENTIAL

As a leading company in the field of geothermal energy, Atlas Copco Gas and Process develops Organic Rankine Cycle (ORC) power plants capable of unlocking the full potential of geothermal resources.
Ideal for Medium-to-low Temperature Heat Sources

Atlas Copco geothermal solutions utilize heat sources with an enthalpy of up to 1000 kJ/kg (430 Btu/lb), equating to reservoir temperatures up to 230 °C (450 °F). Our proprietary radial inflow turboexpanders, combined with a careful selection of the best-suited working fluids, ensure maximum power generation from medium-to-low temperature geothermal resources.

For higher-enthalpy heat sources, we can offer a customized ORC plant that can be combined with an existing flash plant.

We provide solutions in a wide range of sizes, up to 40 MW capacity per train. For larger plants, power trains can be combined together, allowing maximum utilization of each reservoir.

Slim, Efficient Design

Thanks to their low profile and slim design, our compact ORC plants blend into the local landscape.

Moreover, Atlas Copco ORC power plants require minimal on-site operations personnel, which can be further reduced through a number of remote monitoring options, making them ideally suited for generating power in remote locations.

Peak Performance from the Organic Rankine Cycle

Our geothermal power plants use the Organic Rankine Cycle (ORC) along with Atlas Copco radial inflow turbines to maximize power production.

ORC is an efficient, proven technology that works much as a steam engine does. Heat is transferred from a resource to a working fluid in a closed loop system and the working fluid goes through a phase change – from a liquid to a vapor and back.

An expander plays a central role in this process. It extracts energy from the working fluid vapor and turns this energy into mechanical power.

The expander must accommodate the differential pressure between the vaporizer, where the working fluid is turned into a vapor, and the condenser, where it is cooled back into a liquid.

Atlas Copco turboexpanders with variable Inlet Guide Vanes are able to maintain high efficiency levels over a wider range of differential pressure ratios than expanders that aren’t equipped with variable IGVs.

In practical terms, this means more consistent, efficient energy production, even as ambient temperatures or resource fluid levels fluctuate.


POWER FROM WASTE HEAT

Many industrial processes produce heat as a by-product. Our waste heat recovery solutions utilize this heat, which would otherwise be released into the atmosphere, and convert it into useful electrical power.

An Abundant Source of Clean Energy

Energy generation from waste heat employs an ORC process similar to that found in geothermal power plants. It produces valuable energy from heat that would otherwise remain unused.

Waste heat can be recovered from flue, stack, vent and combustion gases across a range of temperatures in numerous industrial processes. Examples where it can be employed include natural gas compressor stations, chemical plants, petroleum refineries, pulp and paper mills, and cement factories.

Standard and Transcritical

Due to the high temperatures at work, power generation from waste heat is also suitable for so-called transcritical ORC processes. Here, high pressures are employed to push a working fluid above its critical point, where distinct gas and liquid phases do not exist. By incorporating supercritical principles, thermal efficiency can be increased even further. Transcritical technology can also be applied to geothermal applications, especially those with high-temperature heat resources.

Atlas Copco provides waste heat recovery solutions that are perfectly suited to a wide range of heat sources with temperatures up to 650 °C / 1200 °F.

Our solutions are able to collect heat from one or more sources, which may be liquid, gaseous or a combination of the two.

Customized Industrial Solutions

The basic principles of waste heat recovery solutions are similar to those of geothermal applications.

However, design parameters for waste heat applications need to take high temperatures into account. This influences the selection of the optimal working fluid for the process. In some cases, input temperatures

Customer Benefits

- Both standard and transcritical solutions to ensure optimal power generation
- Able to collect heat from liquid, gaseous and multiple sources
- Little or no impact on main industrial processes
- Reduced emissions through lower power consumption
- Flexible plant design to fit available space on site
- Potential eligibility for emission-certificate credits (depending on country or region)
might be reduced in the ORC system so that low-cost working fluids can be used. For higher temperatures, Atlas Copco experts can also determine whether a transcritical process is the best option.

As a rule of thumb: Waste heat power generation is an excellent investment at industrial sites with a capacity factor above 60% (more than 5250 operating hours/year).

### Potential Electrical Power from Waste Heat Recovery*

Amount of utilized waste heat above 140 °C, relative to overall energy usage in major industrial segments.

<table>
<thead>
<tr>
<th>Industrial sectors</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement production</td>
<td>up to 40 %</td>
</tr>
<tr>
<td>Metal production</td>
<td>up to 30 %</td>
</tr>
<tr>
<td>Chemical / Petrochemical</td>
<td>up to 8 %</td>
</tr>
<tr>
<td>Across all industry segments</td>
<td>up to 18 %</td>
</tr>
</tbody>
</table>

* Source: Fraunhofer Institute, analyzing German industrial segments.

Atlas Copco delivered the turboexpander for this hyper-efficient natural gas compressor station in the Canadian Rockies, where a transcritical process is employed.
COLD ENERGY RECOVERY

A new field for ORC technology employs the “cold energy” of incoming liquid natural gas (LNG) to generate electricity. Cold energy recovery promises power generation possibilities for LNG terminals.

Power from the Cold

Cold energy recovery employs a working fluid with a low boiling point and capitalizes on the temperature difference between incoming LNG and a heat source.

Incoming LNG from a tanker is heated by a gaseous working fluid in a condenser/vaporizer. This condenses the working fluid vapor into a liquid and also turns LNG into a gas.

After the working fluid has been condensed, its pressure is increased by a circulation pump. It is then heated in an evaporator which uses sea water to turn the working fluid into a gas.

After the working fluid’s phase change in the evaporator, it enters the turbine for expansion, thus driving the generator.

Customer Benefits

• Secure investment with short payback period
• No effect on standard LNG receiving terminal operations
• Underutilized power source generates power for direct on-site electricity usage
• 10 MW cold energy potential at typical LNG import terminal with 5 MTPA (million tons per annum)*
• Ideal for remote and centrally-located terminals
• Remote monitoring for 24-hour unmanned supervision


Whether large or small, in an isolated location or near a major port, cold energy recovery can deliver valuable energy at LNG terminals throughout the world.
A LIFETIME OF PERFORMANCE

Our ORC power plants are designed for many years of reliable, efficient performance. We are here to guide customers through every step of the ORC plant lifecycle.

Tailor-Made Solutions

From initial site studies, product design, and set-up, through commissioning, process optimization, service and personnel training, our specialists are ready to provide assistance. Backed by decades of expertise and vital contributions to milestone ORC projects around the world, our experts will draft solutions to create the best returns.

Seamless Operations for Decades

Our Aftermarket team offers servicing agreements that deliver the tailored coverage that customers require. Regularly scheduled service visits and optional storage of spare parts on location ensure the fastest possible turnaround.

Regardless of the service plan, transparency is always key: Service agreements describe in advance the exact coverage and activities, ensuring first-rate operations for a lifetime of productivity.

Years of Sustainable Productivity

Our service offering is far from finished when a plant is commissioned. We are here to ensure a smooth transition into full-fledged plant operations. For plant owners who choose remote monitoring options, Atlas Copco Gas and Process will set up plant status and data protocols, giving access to either Atlas Copco staff or plant operators.

With an eye on the future, our dedicated team of Aftermarket services specialists can evaluate the optimization potential in a running project.

Whenever customer or process requirements change, we are ready to assist – for example, in cases where geothermal well conditions fluctuate or a new process is employed at an industrial waste heat facility.

Initial plant designs can even be tailored in advance to accommodate later structural additions – such as a new heat exchanger – with minimal overhead.
THE TECHNICAL EDGE

The Atlas Copco Gas and Process Division is a market leader and pioneer in radial inflow turbine and turboexpander technologies. Thousands of our turboexpanders are in operation throughout the world, across many different industries, delivering outstanding efficiency, reliability and performance.

Variable Inlet Guide Vanes

Atlas Copco turboexpanders are equipped with Variable Inlet Guide Vanes (IGVs), one of our division’s key competence areas. Variable IGVs ensure the optimum angle of attack at the leading edge of the turbine’s rotor blade, even when flow levels change.

For ORC applications, this flexible design translates into maximum power from a given resource. Even if application conditions vary from original specifications, efficiency and performance remain at peak levels.

Variable-IGV technology is ideal for climate zones with considerable fluctuations in seasonal or daily ambient temperatures.

Impellers

Our engineers use computation-fluid dynamics (CFD) and finite element analysis (FEA) to design turboexpander impellers, which function as the secondary expansion device in ORC processes. Impeller design takes into account project-specific variables such as gas flow, enthalpy drop, and shaft rotating speeds.

Integral Gear Technology

Utilizing integral gear technology – the industry’s most efficient and compact mechanical drive design – Atlas Copco is able to mount more than one turbine stage onto a single gearbox. This offers increased flexibility in plant design and added performance. It presents a cost-efficient solution in ORC-based power plant applications where a single turbine cannot fully utilize all available power. Our integral gear technology is also key for processes where power is delivered at multiple pressure levels.
Wide Range of Working Fluids

ORC applications rely on one of a number of organic (or even non-organic) working fluids to power the turbine at the heart of the cycle. These fluids can be hydrocarbons or refrigerants. Our specialists select working fluids that are best-matched to the specific heat source and ambient conditions at each site.

Atlas Copco Gas and Process engineers incorporate a wide range of working fluids into our solutions, taking into account not only their thermal properties, but also environmental and safety considerations. Because our solutions are compatible with all readily available working fluids, customers are ensured the most efficient designs possible.

Cool Under Pressure

ORC solutions from Atlas Copco Gas and Process can employ all common cooling systems, including: air-cooled condensers and water-cooled condensers with either a cooling tower or natural cooling (such as from a river or local reservoir).

Island Mode

This option allows plants to switch to an emergency status, isolating their generators from the power grid but continuing to produce power for the plant’s own consumption. This option saves time and money in areas with more unstable power networks.

Remote Control (eConnect)

Atlas Copco’s optional eConnect technology provides full remote monitoring. With dashboards to monitor all frequently used values and processes, eConnect allows users to create extensive reports. Alerts and notifications can be sent to the plant operator or directly to Atlas Copco Aftermarket service staff, per a service agreement.
**PROJECT REFERENCES**

**Geothermal Power Plant in Pamukören, Turkey**
A complete geothermal ORC plant that is currently equipped with two 22.5 MW EEGI power trains (2014). Expansion is already underway that will add 67.5 MW.

- **Type:** EEGI 8.0/8.0 (x 2)
- **Plant Inlet Resource Temperature:** 161 °C (322 °F)
- **Plant Resource Mass Flow:** 1 400 000 kg/h (3 086 472 lb/h)
- **Resource Composition:** 92.3% water, 5.5% steam, 1.6% gas
- **Power:** 45 MW
- **Working Fluid:** n-Butane

**Geothermal Power Plant in Bavaria, Germany**
A complete geothermal plant in Grünwald, Germany, which is connected to a district heating system for cogeneration of electricity and heating.

- **Type:** ETG 560 MS
- **Inlet Resource Temperature:** 127 °C (260 °F)
- **Resource Mass Flow:** 360 000 kg/h (793 664 lb/h)
- **Resource Composition:** 100% water
- **Power:** 3.5 MW
- **Working Fluid:** Isobutane

**WH2P Transcritical ORC Plant, Canada**
At this waste-heat-to-power plant in Canada, exhaust heat from two gas turbines is recovered via a thermal oil cycle. Plant uses on-site remote monitoring unit (eConnect).

- **Type:** EGI-5
- **Inlet Resource Temperature:** 485 °C (905 °F)
- **Resource Mass Flow:** 88 040 kg/h (150 003 lb/h)
- **Resource Composition:** 100% gas turbine exhaust gas
- **Power:** 2 MW
- **Working Fluid:** R134a

**Turboexpander, Transcritical WH2P Plant, Canada**
This waste heat to power plant at a gasline pressure station in the Canadian Rockies employs a transcritical cycle to generate electricity from turbine exhaust heat.

- **Type:** Two-stage EGI-6/ EGI-4
- **Turbine Inlet Temperature:** 250 °C (482 °F)
- **Turbine Inlet Mass Flow:** 185 000 kg/hr (407 850 lb/hr)
- **Turbine Inlet Pressure:** 45 bar(a) (653 psia)
- **Power:** 7.4 MW
- **Working Fluid:** n-Butane
# ORC PRODUCT MATRIX

## Plant Variations
<table>
<thead>
<tr>
<th></th>
<th>Geothermal</th>
<th>Waste Heat to Power</th>
<th>Cold Energy</th>
<th>ORC Expander Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand Alone</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
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<tr>
<td>Bottoming Cycle</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Cogeneration (Heat &amp; Power)</td>
<td>*</td>
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</tbody>
</table>

## Power Utilization
<table>
<thead>
<tr>
<th></th>
<th>Electrical Power</th>
<th>Shaft Power</th>
<th>Cold Energy</th>
<th>ORC Expander Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

## Heat Source Specifications

<table>
<thead>
<tr>
<th><strong>Temperature Range</strong></th>
<th>Geothermal</th>
<th>Waste Heat to Power</th>
<th>Cold Energy</th>
<th>ORC Expander Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid</td>
<td>500–1 000 kJ/kg / 215–430 Btu/lb</td>
<td>300–700 kJ/kg / 130–300 Btu/lb</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Enthalpy

- **Gaseous**: 500–1 000 kJ/kg / 215–430 Btu/lb
- **Liquid**: 300–700 kJ/kg / 130–300 Btu/lb
- **Application-specific**: Not Applicable

### Fluid Types

- **Gaseous**: Steam / Brine
- **Liquid**: Various via Thermal Oil
- **Application-specific**: Ambient source (H₂O, Air)

## Binary Working Fluid

<table>
<thead>
<tr>
<th><strong>Most Common</strong></th>
<th>Geothermal</th>
<th>Waste Heat to Power</th>
<th>Cold Energy</th>
<th>ORC Expander Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane (n-, iso-), R245fa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R134a, Cyclopentane</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Methane, Air, Propane</td>
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</tr>
</tbody>
</table>

### Non-Flammable Options

- **Geothermal**: Butane (n-, iso-), R245fa
- **Waste Heat to Power**: R134a, Cyclopentane
- **Cold Energy**: Methane, Air, Propane

### Non-Corrosable Options

- **Geothermal**: Butane (n-, iso-), R245fa
- **Waste Heat to Power**: R134a, Cyclopentane
- **Cold Energy**: Methane, Air, Propane

## Process Cycles

<table>
<thead>
<tr>
<th></th>
<th>Geothermal</th>
<th>Waste Heat to Power</th>
<th>Cold Energy</th>
<th>ORC Expander Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcritical</td>
<td>*</td>
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<td>*</td>
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<tr>
<td>Transcritical</td>
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</tr>
</tbody>
</table>

### Max. Gross Power

- **Geothermal**: 40 MW / train

### Max. Isentropic Efficiency

- **Geothermal**: 89% (at design point)

### Guide Vane Flow Range

- **Geothermal**: 40–150%

### Standards & Norms

- Local electrical, piping, vessel, fire protection, and civil works codes & standards

* Heat Source, ** Sink (LNG)
We stand by our responsibilities towards our customers, towards the environment and the people around us. We make performance stand the test of time. This is what we call — Sustainable Productivity.

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