

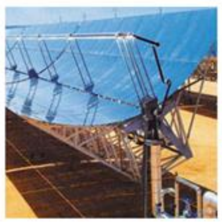

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a group company of MITSUBISHI HEAVY INDUSTRIES, LTD.

Turboden Solutions in the Oil&Gas Industry

LLOYD'S REGISTER • LRQA
ISO 9001

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Update: 31/08/2016

About Us

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Turboden is a leading European company in development and production of ORC (Organic Rankine Cycle) turbogenerators. This state-of-the-art equipment generates heat and power from renewable sources and heat recovery in industrial processes.

The company was founded in 1980 in Milan by Mario Gaia, Associate Professor at *Politecnico di Milano*, teaching Thermodynamics, Renewable Energy and specifically studying ORC systems. At present Prof. Gaia is Honorary Chairman. A number of his former students are key persons in the Company and the whole Company is permeated by innovative and research oriented spirit.

Turboden has always had a single mission: to design ORC turbogenerators for the production of heat and electrical power from renewable sources, while constantly striving to implement ORC technical solutions.

In 2009, Turboden became part of UTC Corp., a worldwide leader in development, production and service for aero engines, aerospace drive systems and power generation gas turbines, to develop ORC solutions from renewable sources and waste heat worldwide.

In 2013 UTC exits the power market forming strategic alliance with Mitsubishi Heavy Industries.

In 2013 Mitsubishi Heavy Industries acquires from UTC Pratt & Whitney Power Systems (now PW Power Systems, Inc.) and the affiliate **Turboden.**
Today Turboden S.r.l. and PW Power Systems, Inc. are MHI group companies to provide a wider range of products and services for thermal power generation systems.

In 2013 Turboden's Quality Management System gets certified to ISO 9001:2008.

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ISO 9001

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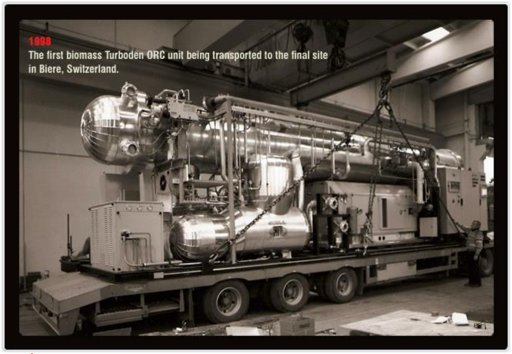
Over 35 Years of Experience

1980 - Founded by Mario Gaia, professor at *Politecnico di Milano*

1990's – First ORC projects in solar, geothermal and heat recovery applications



1998 – First ORC biomass plant in Switzerland (300 kW)

2000's - ORC biomass plants in Europe

2009 - United Technologies Corp. (UTC) acquires the majority of Turboden's quotas. PW Power Systems supports Turboden in new markets beyond Europe. **100 plants sold**

2013 - **MHI** acquires the majority of Turboden. Italian shareholders stay in charge of management

MITSUBISHI
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Today - Over 300 plants in the world, **over 270 in operation**

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Over 35 Years of Experience

1984 – 40 kW_e ORC turbo-generator for a solar plant in Australia

1987 – 3 kW_e ORC turbo-generator for a biomass plant in Italy

1988 – 200 kW_e ORC geothermal plant in Zambia

2008 – 3 MW_e ORC turbo-generator for heat recovery on a waste incinerator in Belgium

2009 – First 100 plants and first installed 100 MW_e

2010 – First plant overseas

2016 – Over 300 ORC plants in the world

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Turboden – a Group Company of MHI

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Energy & Environment
the largest segment of MHI
over $13 billion (in fiscal 2014)

Energy & Environment

Providing optimal solutions in the energy-related fields of thermal power, nuclear energy and renewable energy in different environmental areas and for chemical plants & other industrial infrastructures elements.

Machinery, Equipment & Infrastructure

Providing a wide range of products that form the foundation of industrial development, such as machine tools, material handling, construction machinery, air-conditioning and refrigeration systems.

MITSUBISHI
HEAVY INDUSTRIES, LTD.

Commercial Aviation & Transport Systems

Delivering advanced land, sea and air transportation systems, including civilian aircraft, commercial ships and transit networks.

Integrated Defense & Space Systems

Providing advanced land, sea and air defense systems, including naval ships, defense aircraft, launch vehicles and special vehicles, as well as space-related services.

Mitsubishi Heavy Industries is one of the world's leading heavy machinery manufacturers, with consolidated sales of over $33 billion (in fiscal 2014).

Foundation July 7, 1884

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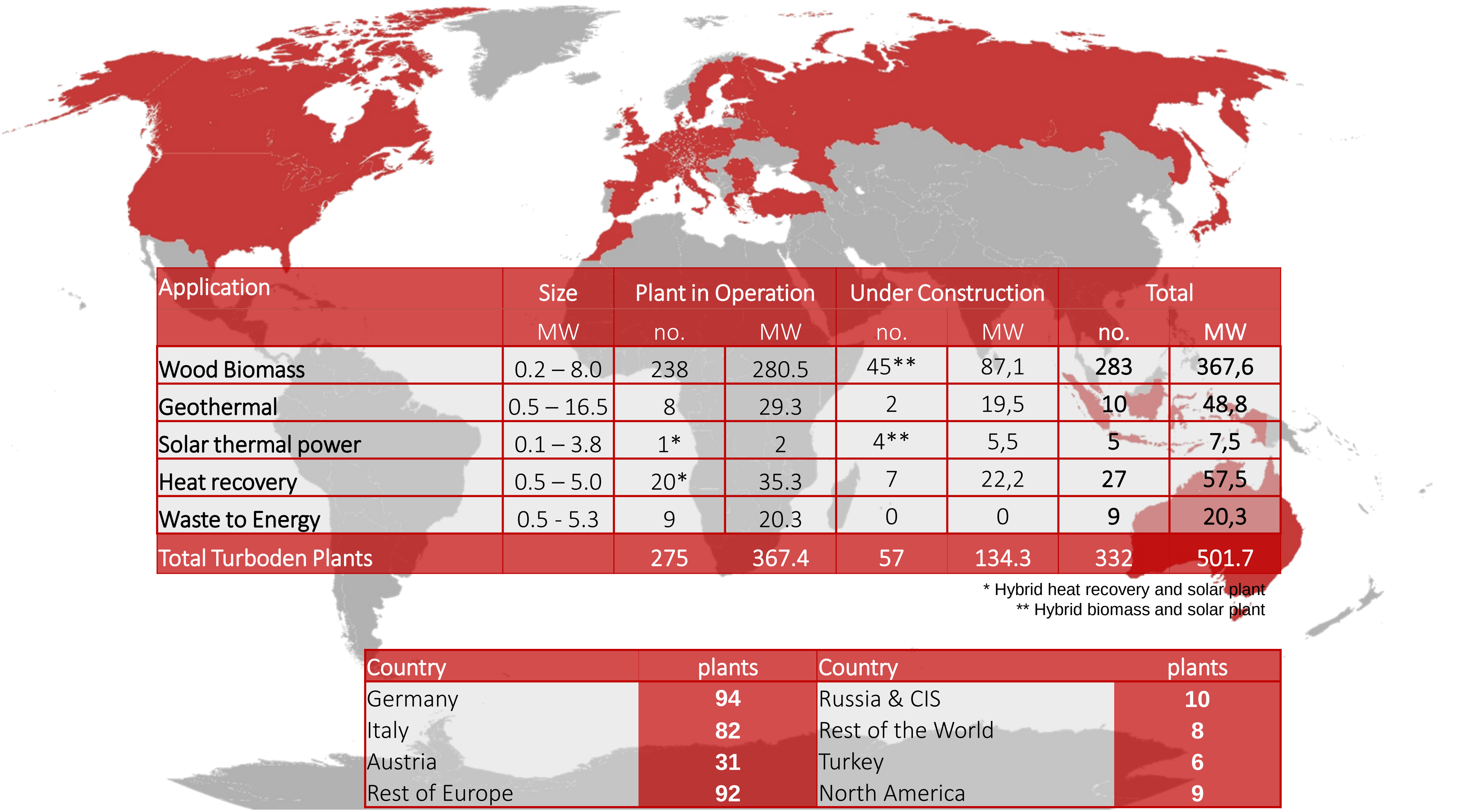
Turboden has currently more than 300 reference plants worldwide



Application	Size	Plant in Operation		Under Construction		Total	
	MW	no.	MW	no.	MW	no.	MW
Wood Biomass	0.2 – 8.0	238	280.5	45**	87,1	283	367,6
Geothermal	0.5 – 16.5	8	29.3	2	19,5	10	48,8
Solar thermal power	0.1 – 3.8	1*	2	4**	5,5	5	7,5
Heat recovery	0.5 – 5.0	20*	35.3	7	22,2	27	57,5
Waste to Energy	0.5 - 5.3	9	20.3	0	0	9	20,3
Total Turboden Plants		275	367.4	57	134.3	332	501.7

* Hybrid heat recovery and solar plant
** Hybrid biomass and solar plant

Country	plants	Country	plants
Germany	94	Russia & CIS	10
Italy	82	Rest of the World	8
Austria	31	Turkey	6
Rest of Europe	92	North America	9

Last Update: August 2016

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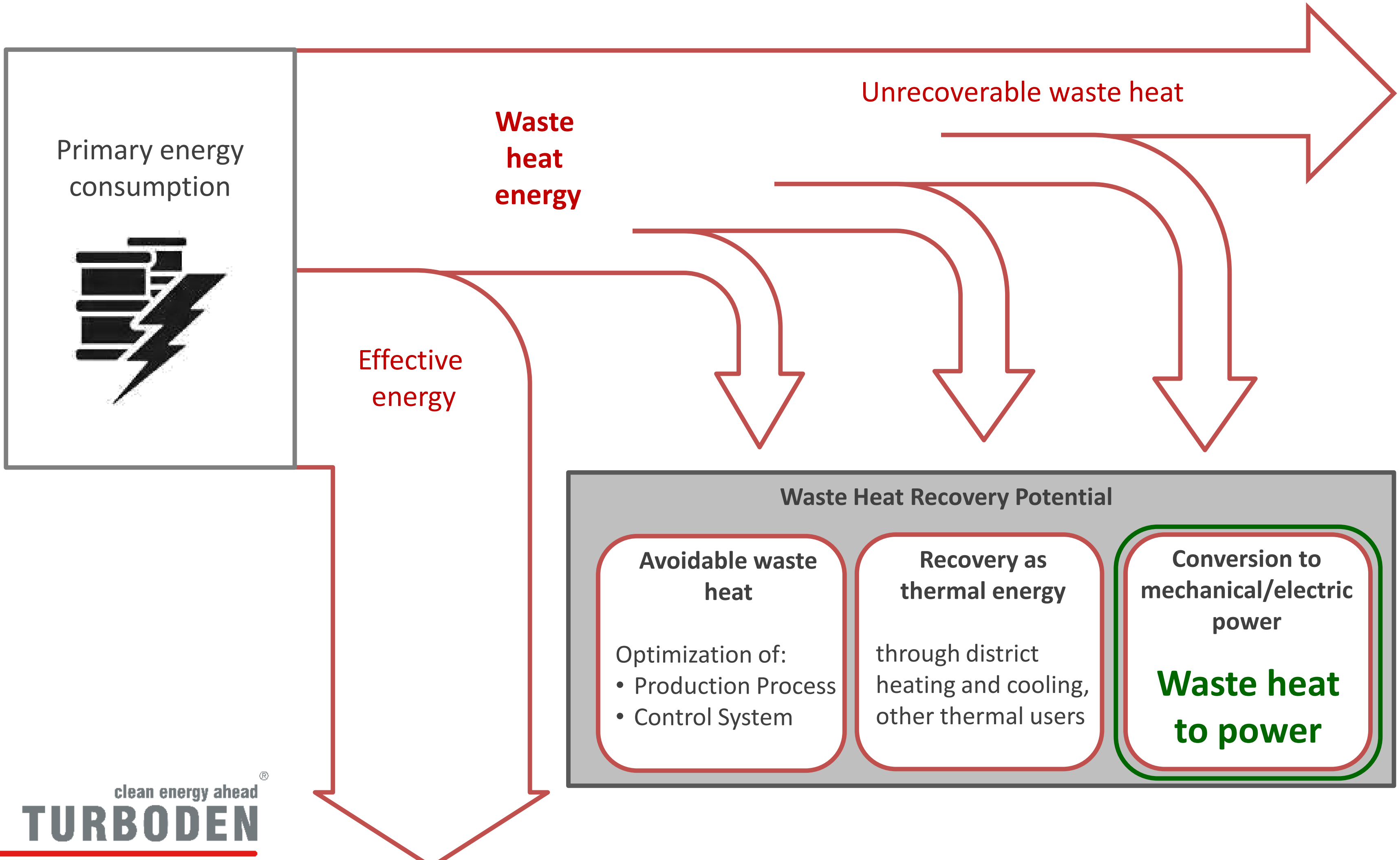
Waste heat from industrial processes can be recovered and converted into power



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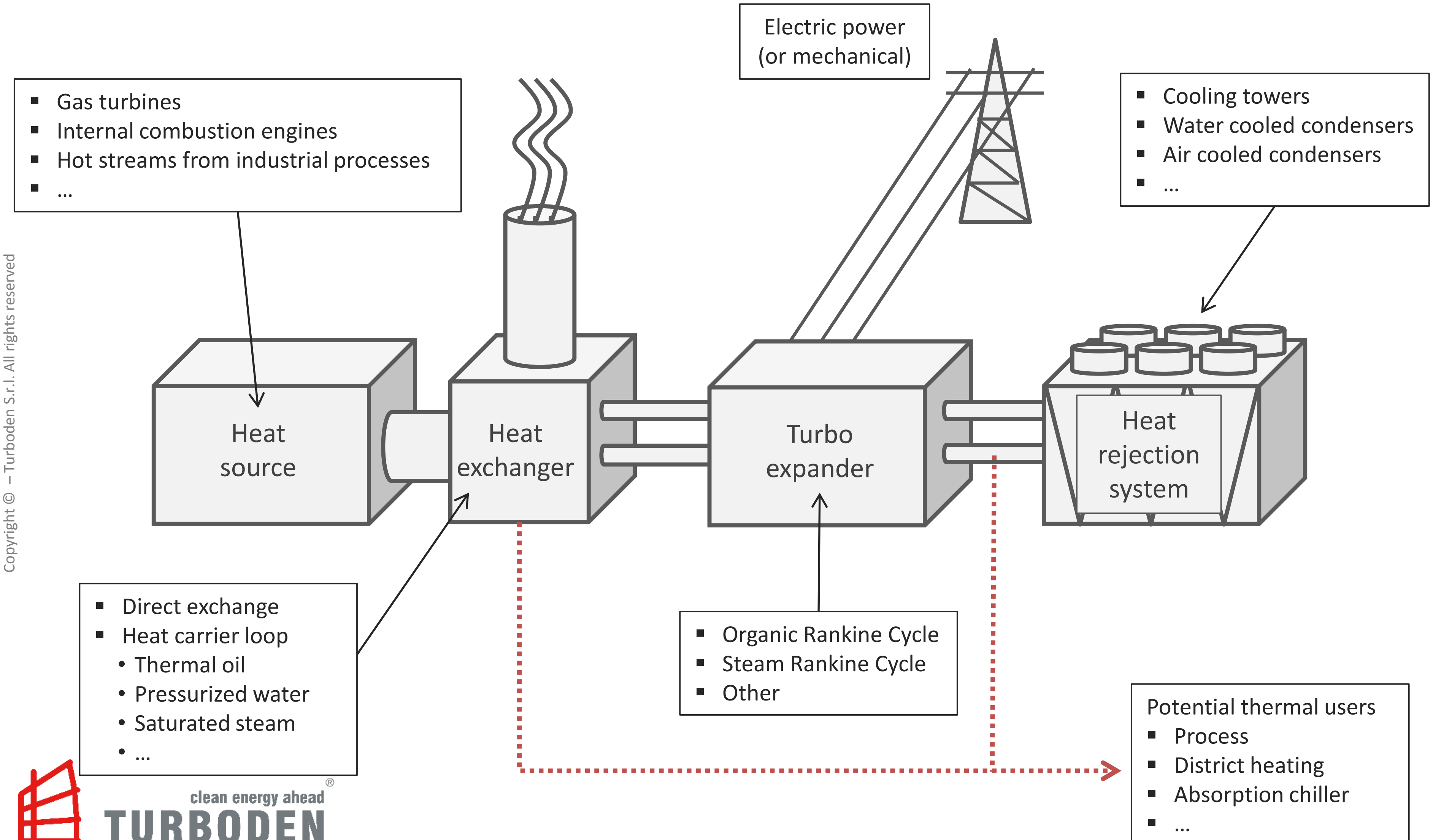
Waste heat to power



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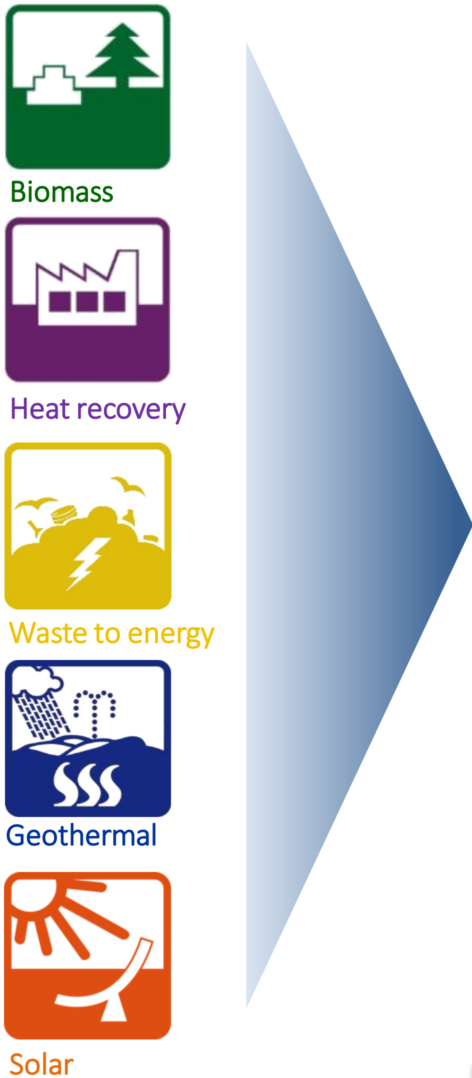
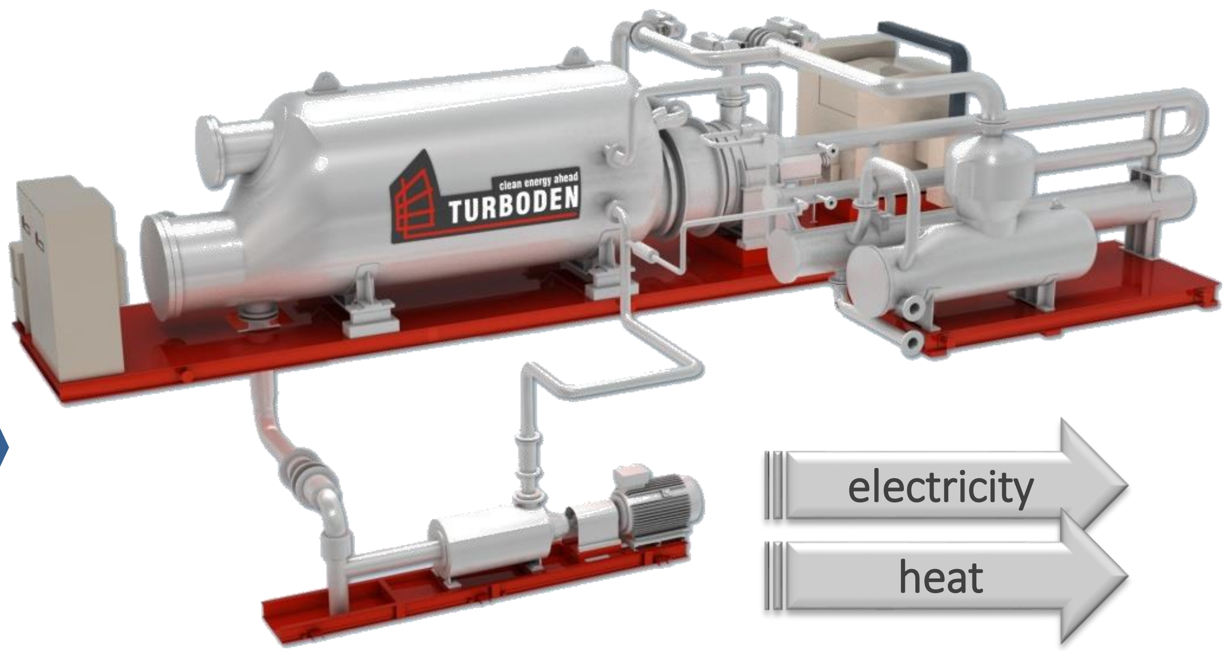
What we do





Turboden designs, develops and maintains turbogenerators based on the Organic Rankine Cycle (ORC), a technology for the combined generation of electric power and heat from various renewable sources, particularly suitable for distributed generation.

➢ **Turboden solutions** from 200 kW to 20 MW electric per single shaft

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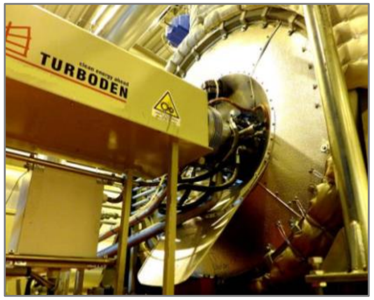
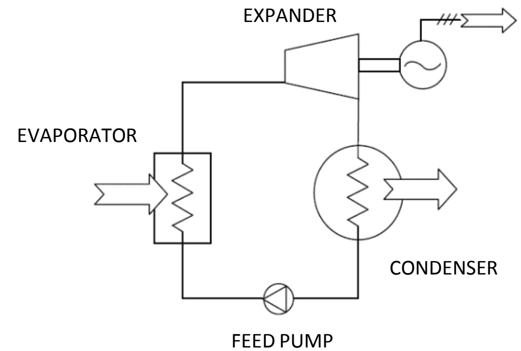
Organic Rankine Cycle: concept

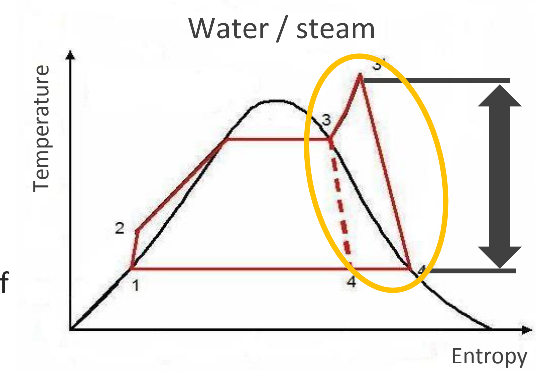


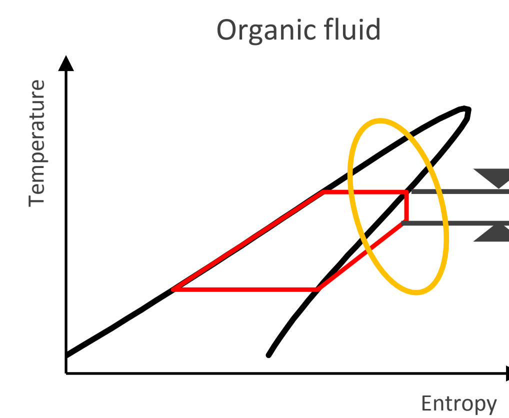
Cycle	it is a thermodynamic cycle
Rankine	it is theoretically given by 2 isobar and 2 adiabatic thermodynamic transformations
Organic	it exploits an organic working fluid



The principle is based on a turbogenerator working as a normal steam turbine to transform thermal energy into mechanical energy and finally into electric energy through an electric generator. **Instead of** the **water** steam, the ORC system **vaporizes an organic fluid**, characterized by a **molecular mass higher than water**, which **leads to** a **slower rotation** of the turbine and **to lower pressure and erosion** of the metallic parts and blades.

Efficiency: 98% of incoming thermal power is transformed into **electric power** (around **20%**) and **heat** (**78%**), with extremely limited thermal leaks, only 2% due to thermal isolation, radiance and losses in the generator. The electric efficiency obtained in **non-cogeneration** cases is much higher (more than **24%** of the thermal input).





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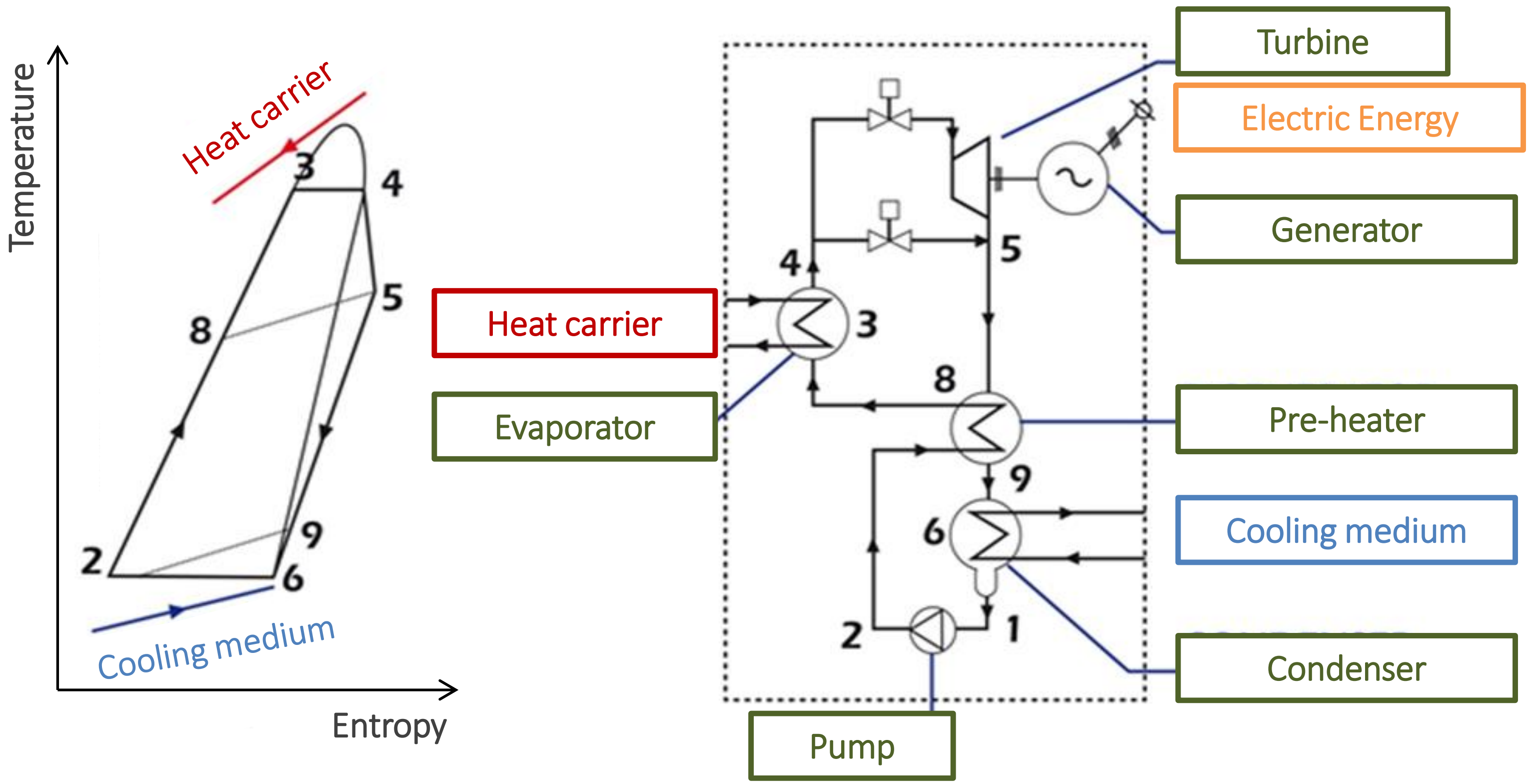
Organic Rankine Cycle: Thermodynamics



The turbogenerator uses the **heat carrier** (e.g. hot temperature thermal oil) to pre-heat and vaporize a suitable organic working fluid in the **evaporator** (8→3→4). The organic fluid vapor powers the **turbine** (4→5), which is directly coupled to the **electric generator** through an elastic coupling. The exhaust vapor flows through the **regenerator** (5→9) where it heats the organic liquid (2→8). The vapor is then condensed in the **condenser** (cooled by the water flow or other) (9→6→1). The organic fluid liquid is finally **pumped** (1→2) to the **regenerator** and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

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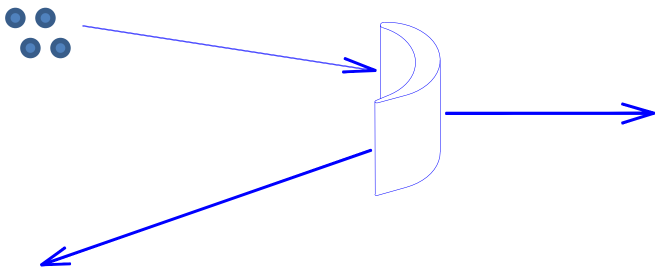
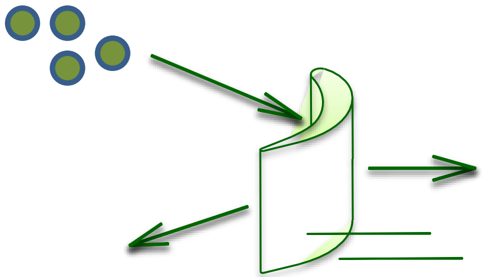
Water vs High Molecular Mass - Working Fluid



Water

- Small, fast moving molecules
- Metal parts and blade erosion
- Multistage turbine and high speed with mechanical stress



High molecular mass fluid

- Large flow rate
- Larger diameter turbine with high efficiency of the turbine (85-90%)
- No wear of blades and metal parts
- Slow rotation speed and few stages (2-6)

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ORC provides significant advantages as compared to steam

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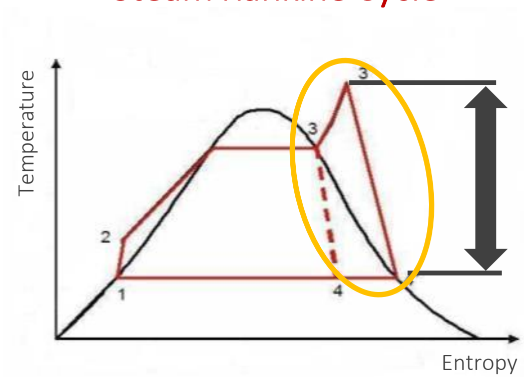
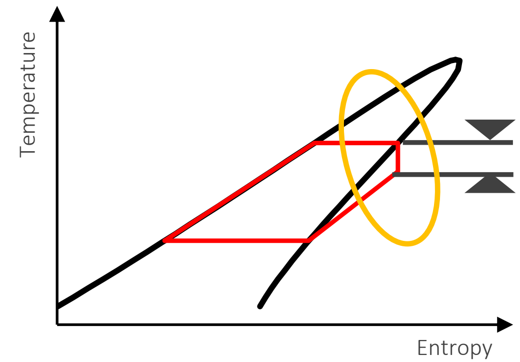
	Steam Rankine Cycle	Organic Rankine Cycle (ORC)
		
Thermodynamic features and consequences	• High enthalpy drop • Superheating needed • Risk of blade erosion	• Small enthalpy drop • No need to superheat • No supercritical pressure • No risk of blade erosion
Operation and maintenance costs	• Water treatment required • Highly skilled personnel needed • High pressures and temperatures in the cycle	• Non-oxidizing working fluid with no corrosion issues • Minimum personnel and O&M (1) • Completely automatic (2) • No blow down
Other features	• Convenient for large plants and high temperatures • Low flexibility with significantly lower performances at partial load	• High flexibility and good performances at partial load • High availability (average >98%) • Possibility to work at low temperatures (90+°C)

(1) Standard maintenance: 2-3 days per year
(2) Fast start-stop procedure (ca. 20 min), partial load operation (down to 10% of nominal load)

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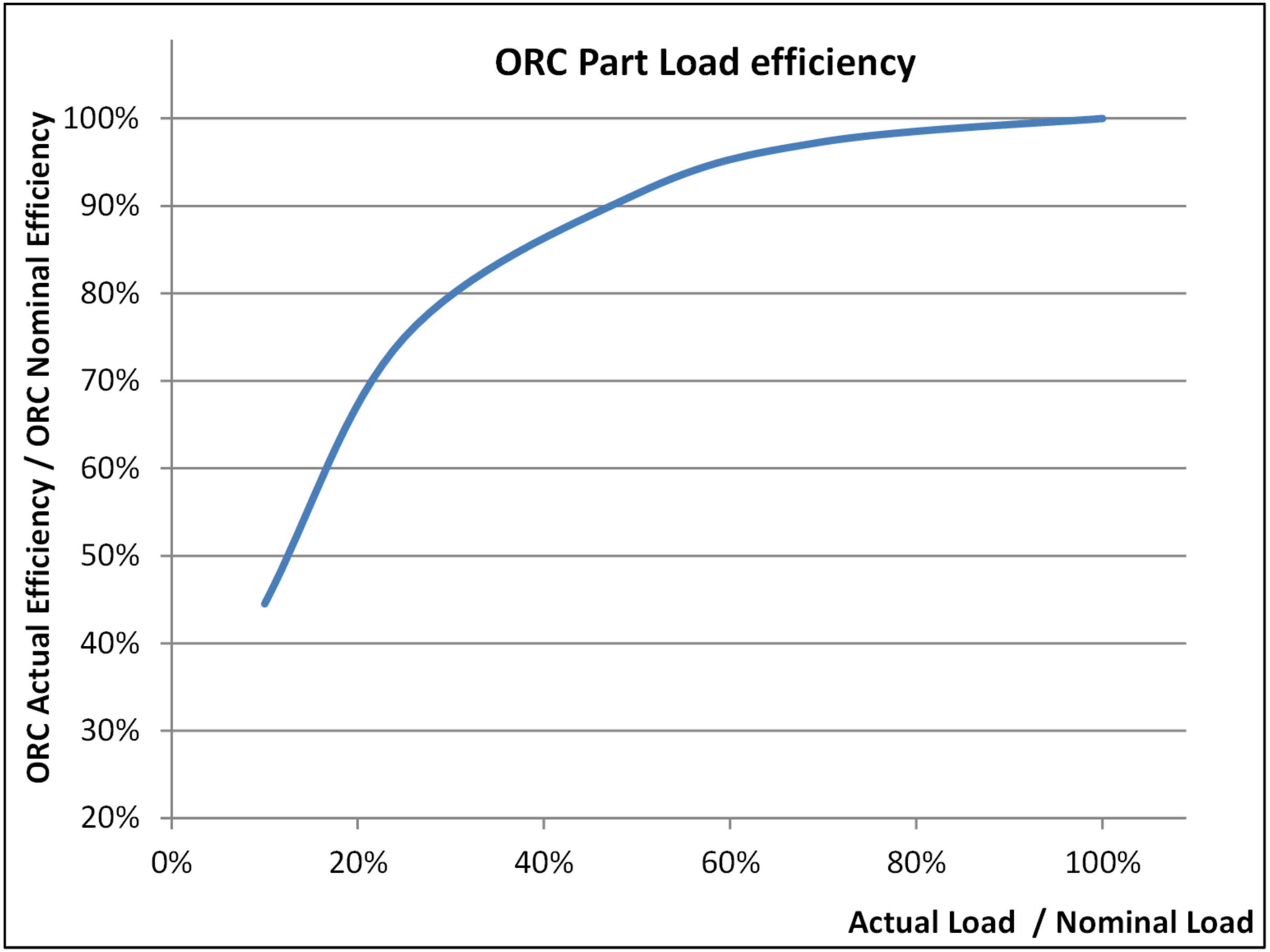
ORC performance at partial load



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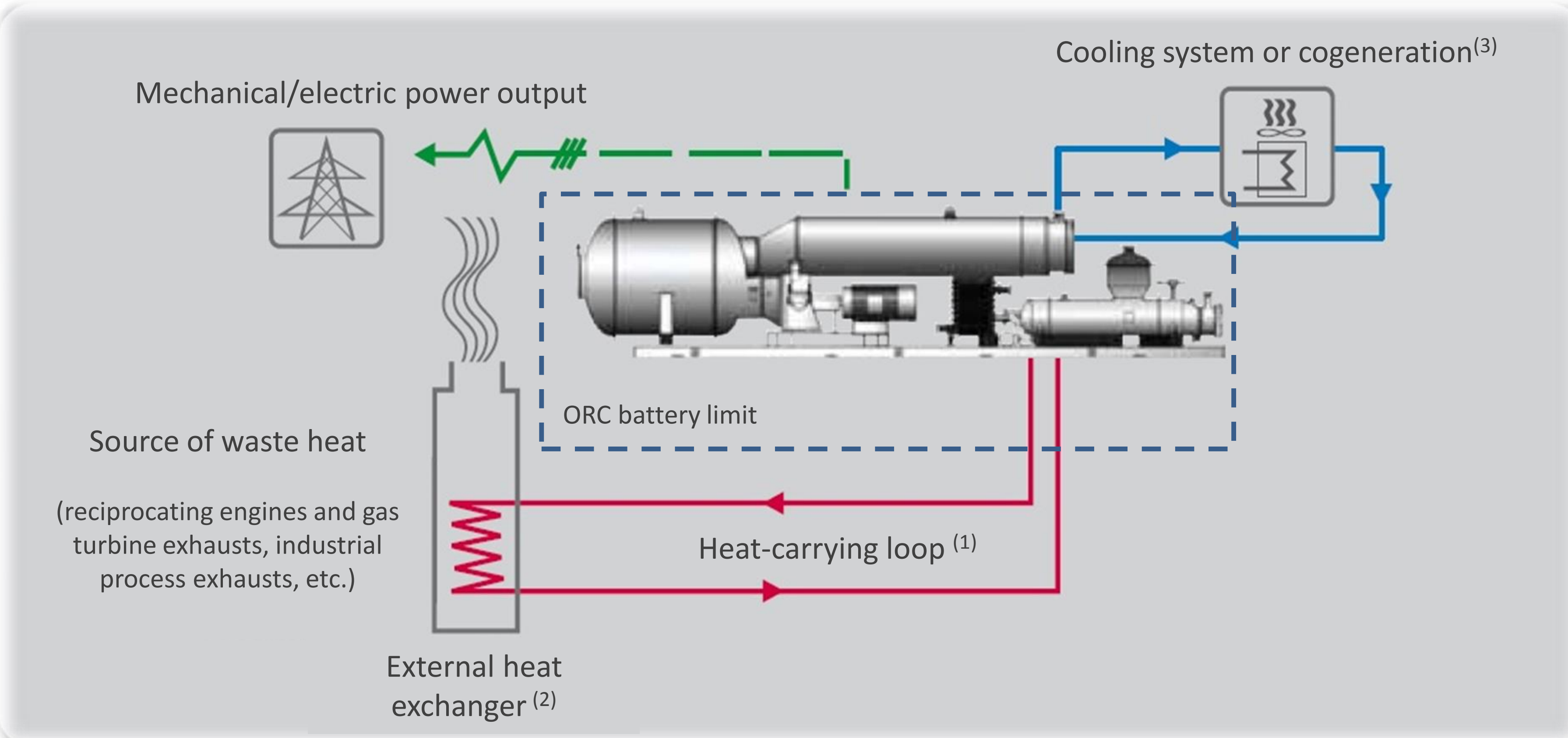
Waste heat to power ORC plant



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Note

1) Heat-carrying loop may be filled with verse media e.g. thermal oil, saturated steam, pressurized water or it can be replaced by a direct exchange between the exhaust and the organic fluid
2) Possibility to exploit multiple thermal sources
3) Cooling tower, water cooled condenser, air cooled condenser, other

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ORC finds many applications in the Oil&Gas sector

A. Gas turbines exhaust gas

Gas compressor stations, natural gas liquefaction, oil pumping stations, etc.

B. Hot water from exhausted/unused oil wells

C. Associated Petroleum Gas (APG)

D. Refinery hot streams

Distillation columns, Oil/Gasoline/Kerosene production, etc.

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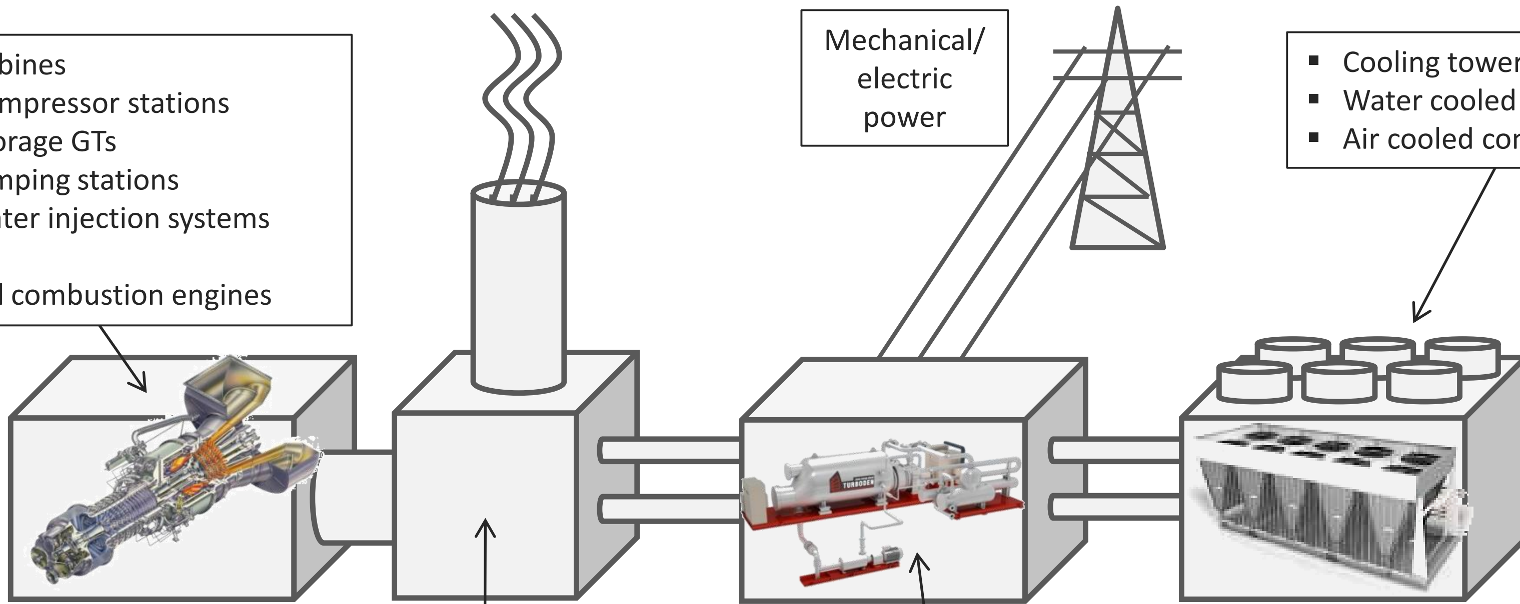
Oil&Gas applications

(A) Gas turbines exhaust gas

- Gas turbines
  - Gas compressor stations
  - Gas storage GTs
  - Oil pumping stations
  - Sea water injection systems
  - …
- Internal combustion engines

Mechanical/ electric power

- Cooling towers
- Water cooled condensers
- Air cooled condensers



Heat exchanger

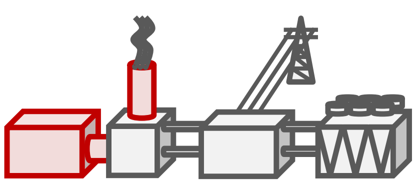
- Direct exchange
- Thermal oil

Organic Rankine Cycle

25 ÷ 35% additional power (1)

Turboden References

- **TransGas – Canada**
  GT power: 3.5 MWe
  ORC power: **1 MWe**
  Thermal oil circuit
  In operation since Q4 2011
- **Polyimpex – Russia**
  GT power: 25 MWe
  ORC power: **3 MWe**
  CHP th. power: 15 MWth
  Direct Exchange
  Status: under construction



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(1) Percent of the prime mover nominal power

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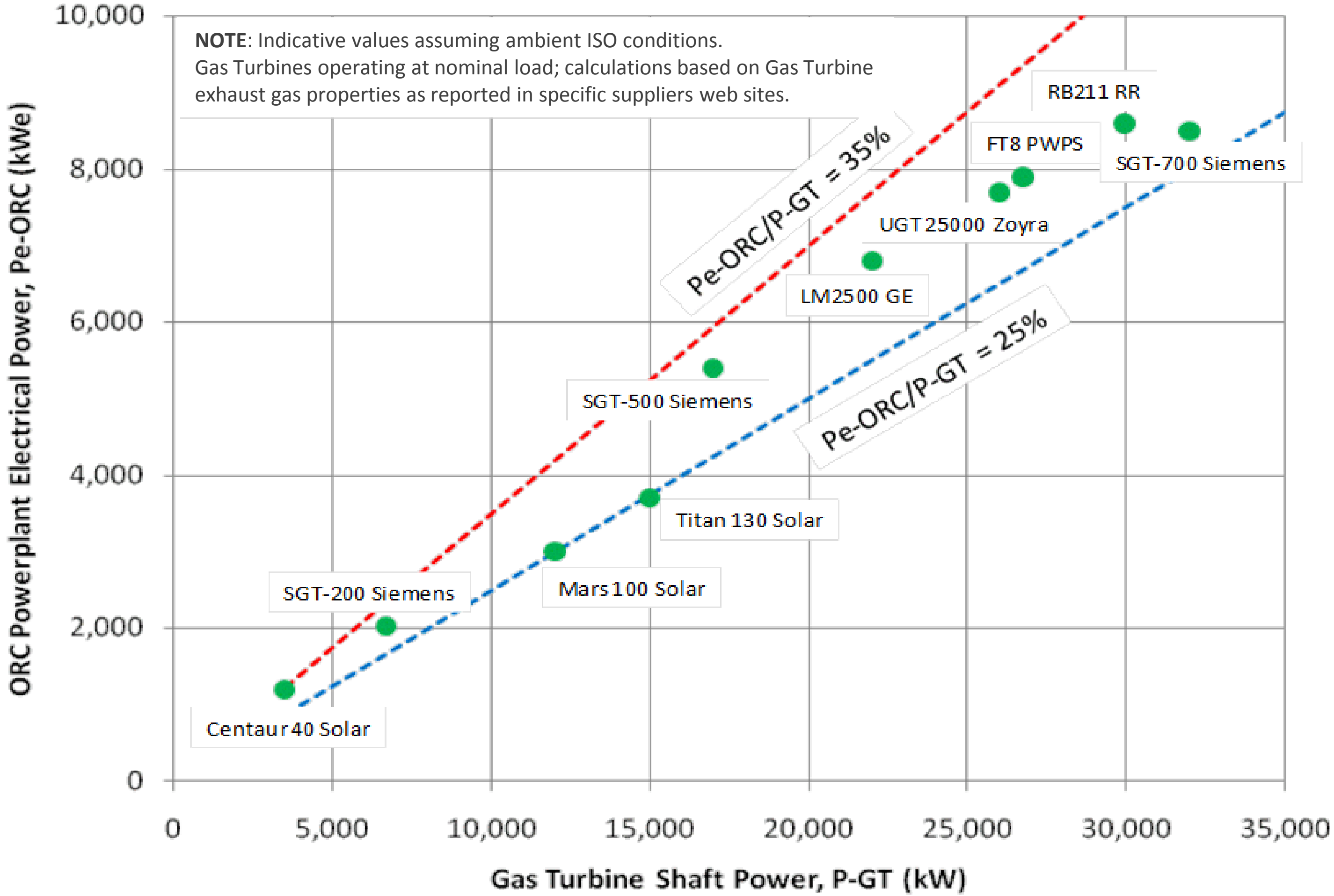
25% - 35% of the prime mover nominal power output is recovered through ORC



Up to 35% additional power

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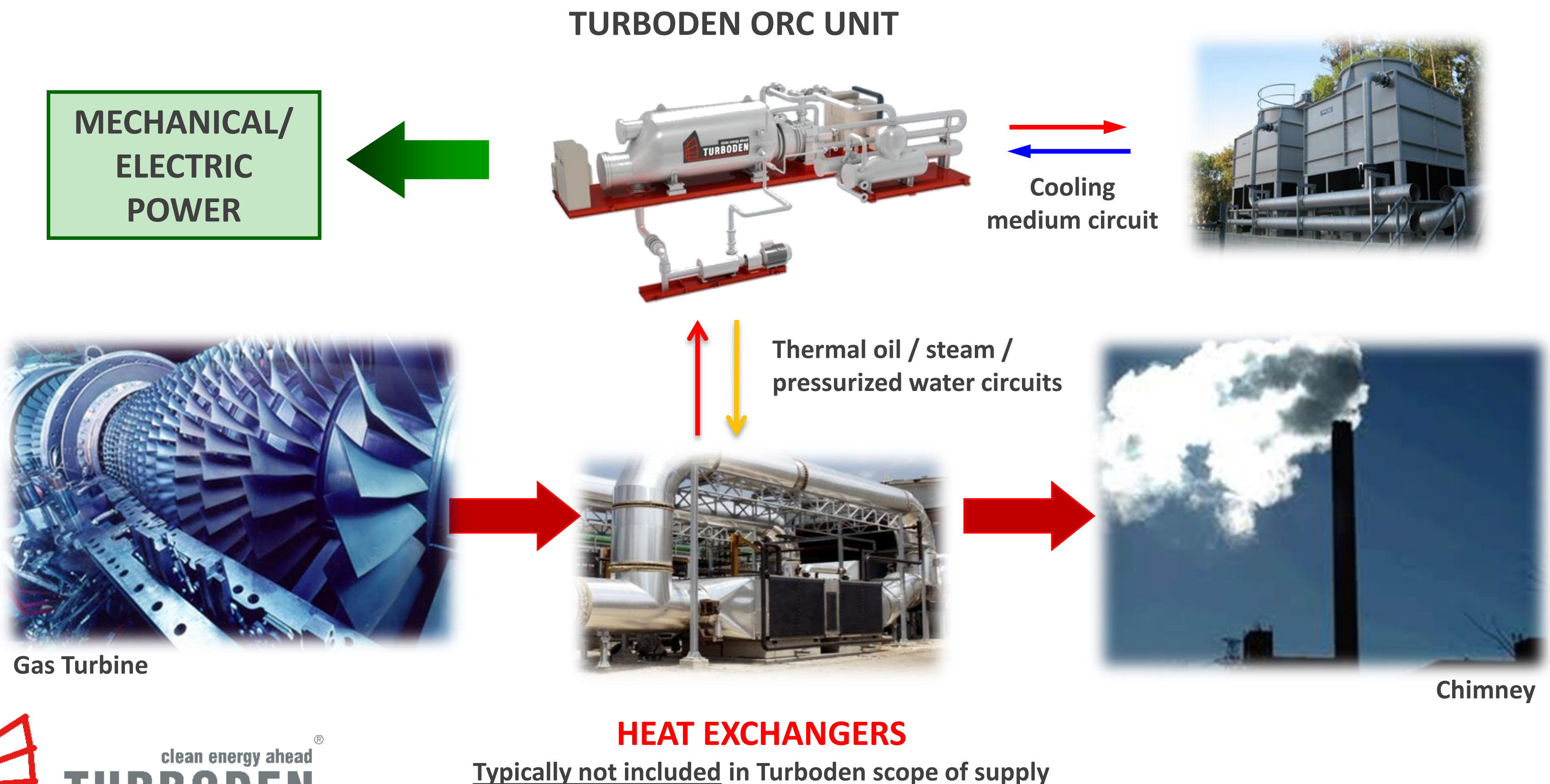
Thermal oil heat carrier loop

ORC-based heat recovery solution:

- Thermal oil / pressurized water / steam heat recovery exchangers with exhaust gas
- Silicon-based fluids, hydrocarbons or refrigerants used as working fluids
- Water cooled or air cooled condensers employable



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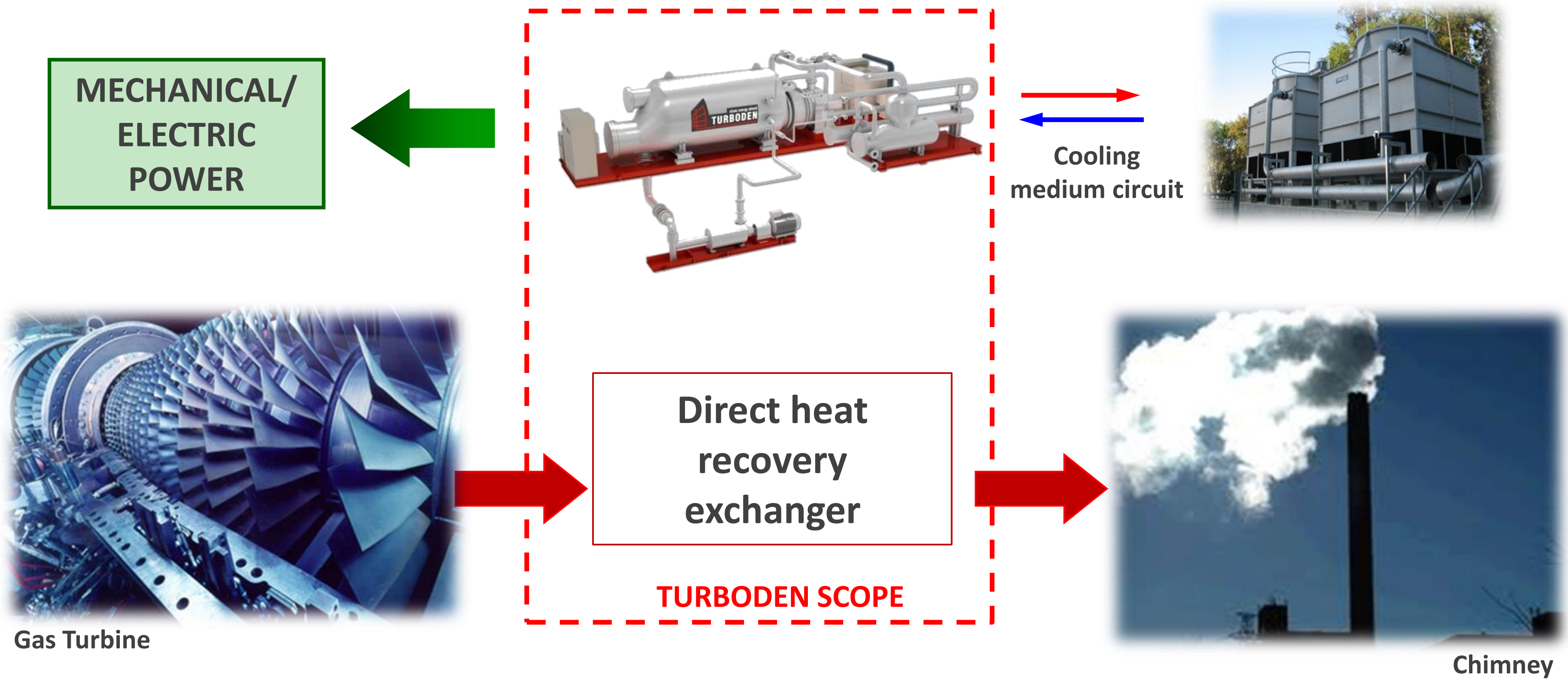
Direct exchange

ORC direct exchange solution:

The thermal energy contained in the exhaust gas is transferred directly, through direct exchange between exhaust gas and the working fluid, to the ORC plant.

For this solution the primary exchanger (exhaust gas / ORC working fluid) is included in the Turboden scope of supply.



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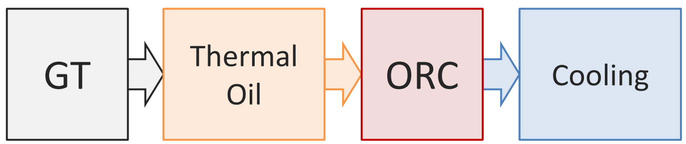
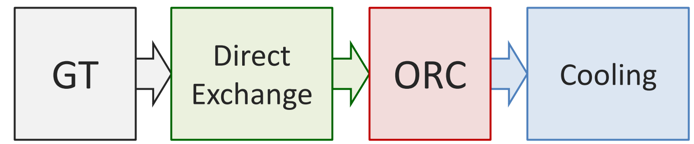
CCGT Schemes

1 turbine, 1 ORC

Thermal Oil

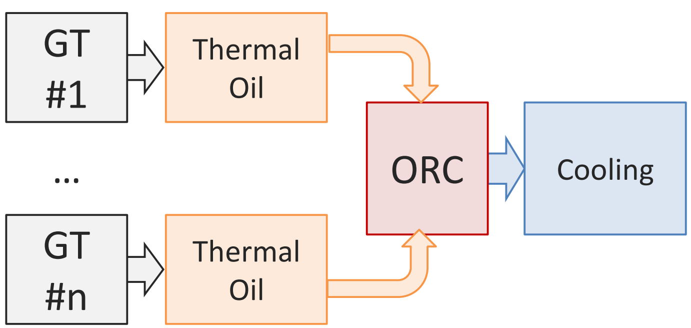


Direct Exchange

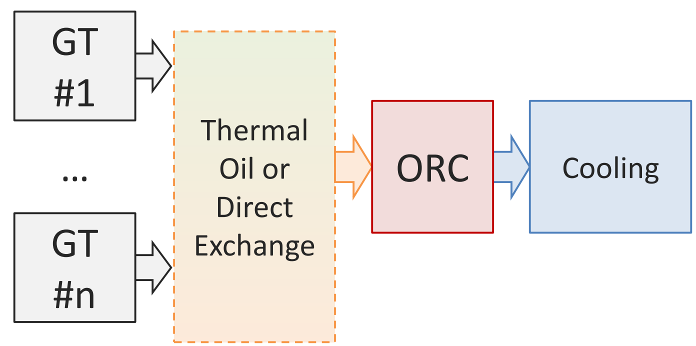


Multiple Heat Sources

Separated thermal oil heat recovery exchangers



Exhaust gas conveyed to a single heat recovery exchanger



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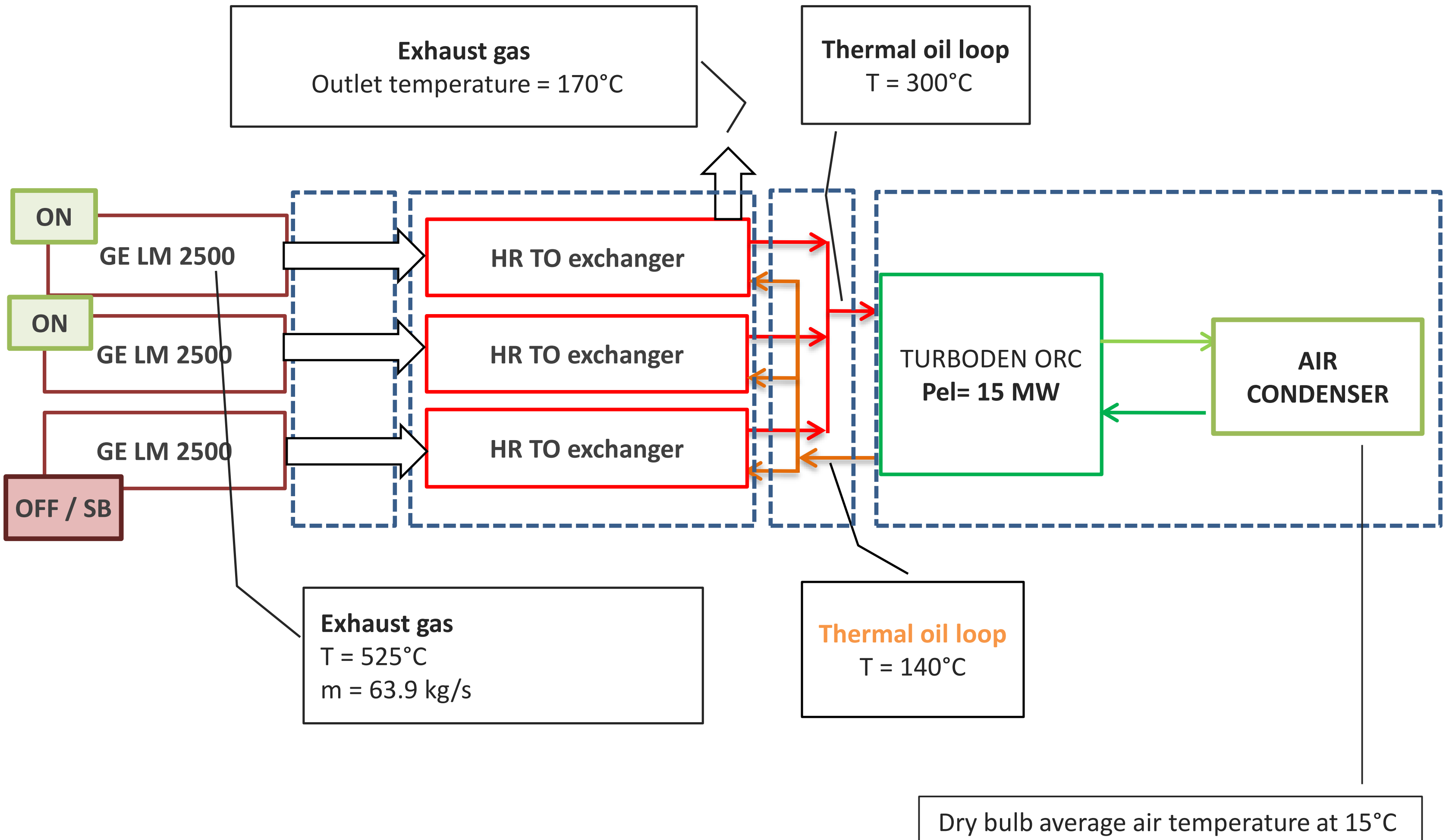
CCGT multiple recovery example



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A huge potential resides in WHR on Oil&Gas infrastructures

<u>Reference case</u>

Germany Gas Transmission System Operator

28 Gas Compressor Stations on **11,550 km** network **(1)**

Capacity factor considered: **45%** **(2)**

Total mechanical drive installed capacity: **990 MW**

Equivalent power considered: **445 MW**

ORC recovery factor: **30%**

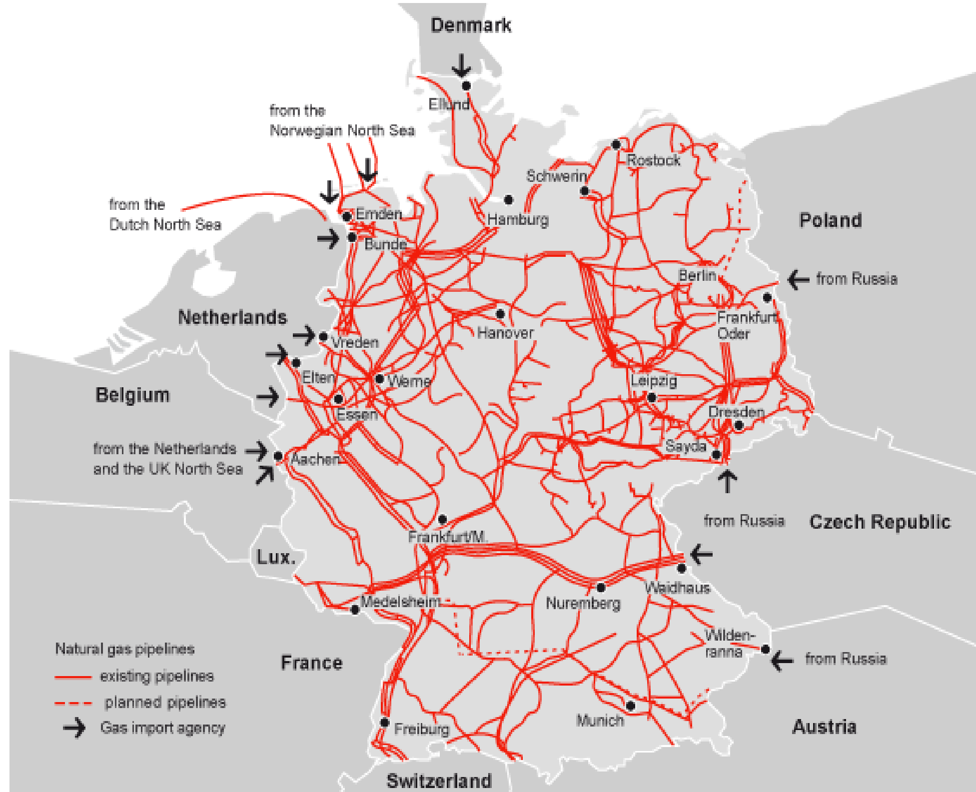
ORC potential: **135 MWe**

Equivalent operating hours: **6,000 h/y**(3)

Energy savings: **800 GWhe → 48 M€/y**(4)

or 208 million cubic meter of natural gas(5)

Emission avoided: **320,000 t CO_2/y**(6)



Example: Germany midstream application

(1) Source ENTSOG Ten Year Network Development Plan 2011-2020
(2) Assuming 3 gas turbine per site. Average power: 1 nominal (100%) + 1 partial load (35%) + 1 backup (0%)
(3) Assuming seasonal fluctuations in GCS operation, ORC availability > 95%
(4) Assuming an electricity value of 60 €/MWhe
(5) Assuming a consumption of 260 mc of natural gas per MWh of power generated
(6) Assuming an average emission factor of EU power generation plants of 400 t CO_2 per GWh (source IEA 2013)

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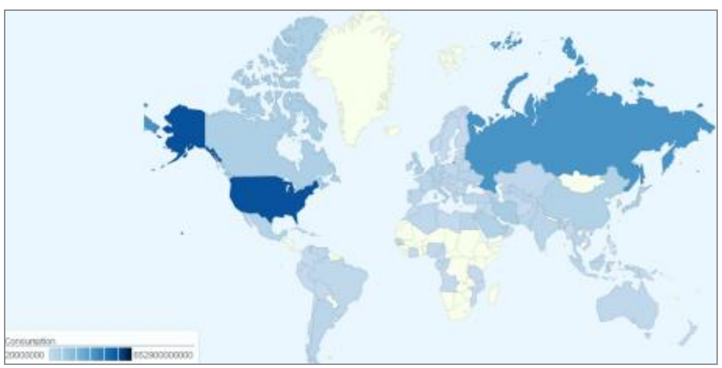
Natural Gas Compressor Stations: a big opportunity for Heat Recovery

- World natural gas yearly consumption: about 3,000 billion m^3
- Compressor stations usually placed at 40 to 100 miles intervals along the pipelines
- Dozens of GW of compression capacity to move natural gas from production sites to users
- Most compressor stations are operating on an open cycle (efficiency about 30-35%)

Dozens of GW of thermal power (in form of hot exhaust gas) are wasted into the atmosphere



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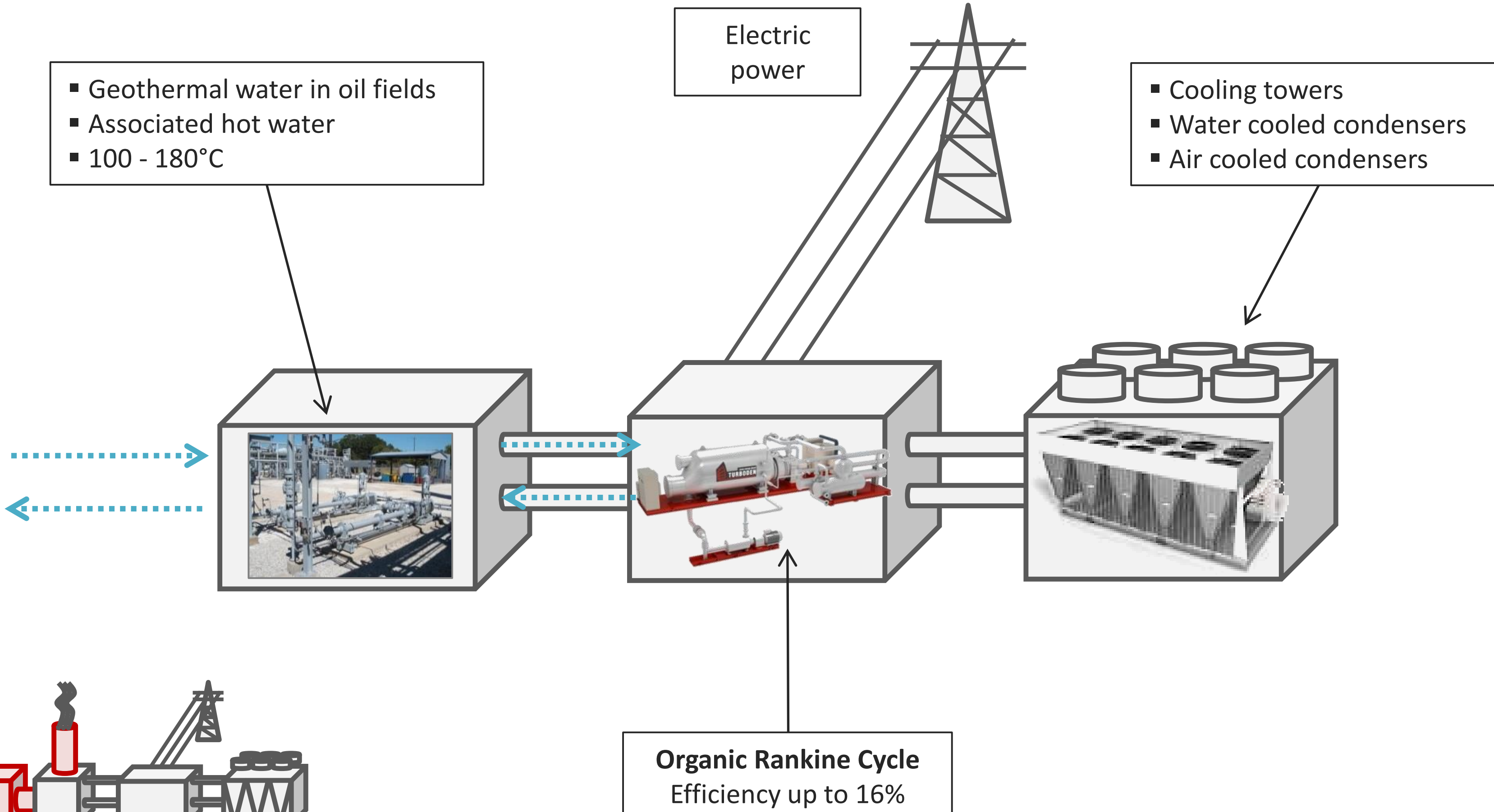
Oil&Gas applications

Ⓑ Hot water from exhausted oil wells



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48.8 MW in 10 geothermal plants

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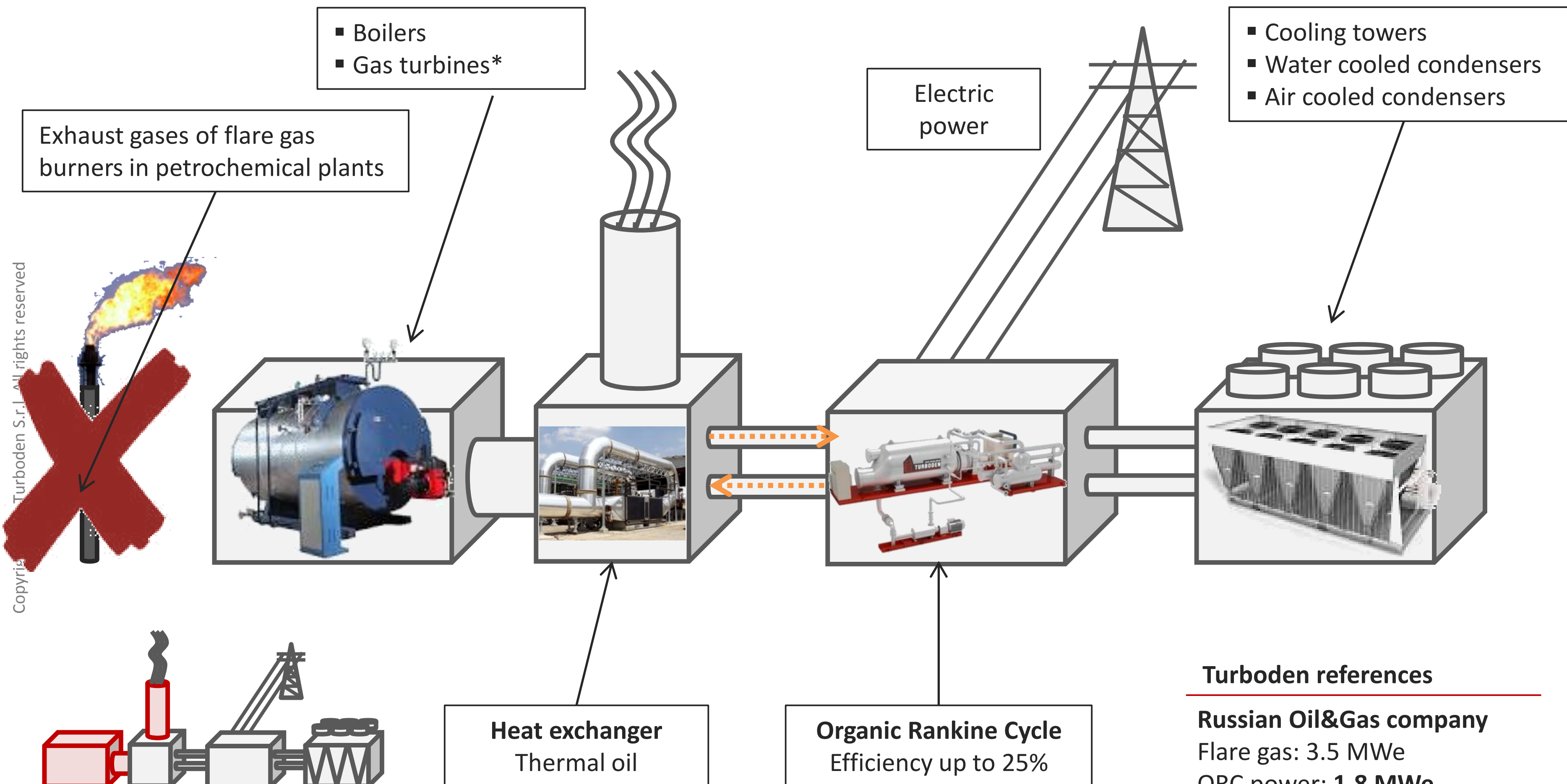
Oil&Gas applications

Ⓒ Associated Petroleum Gas (APG)



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Russian Oil&Gas company
Flare gas: 3.5 MWe
ORC power: **1.8 MWe**
Burner + thermal oil circuit
Start up: Q1 2015

* Low heating value gas turbine

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Turboden reference – APG exploitation

Site: Perm, Russia

Customer/End user: LabNT/LUKoil

Status: in operation since September 2015

Heat source: flare gas burning (boiler designed to burn gas with a minimum lower calorific value of 4,500 kcal/Nm3

Heat source temperature: thermal oil at 300 °C

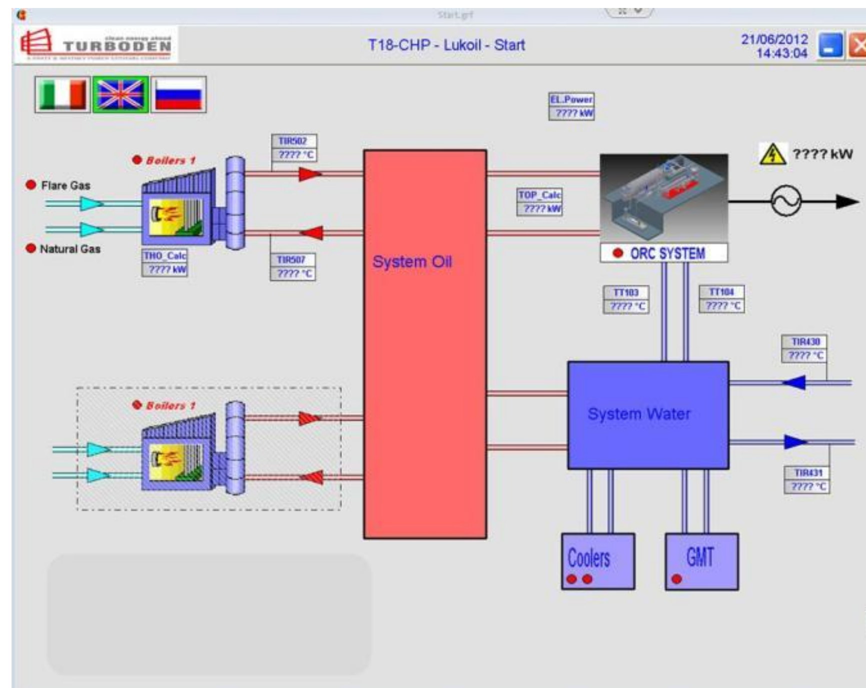
Inlet/Outlet water temperature: 65/95 °C

Electric power: ~1.8 MW

Net electric efficiency: ~18%

Project description

Flare gas from oil extraction wells is burned to heat up thermal oil which is used to feed up an ORC CHP unit. The electricity produced reduces the plant consumptions, whereas the hot water produced is exploited in oil refinery processes including warming up of refined products to be pumped.



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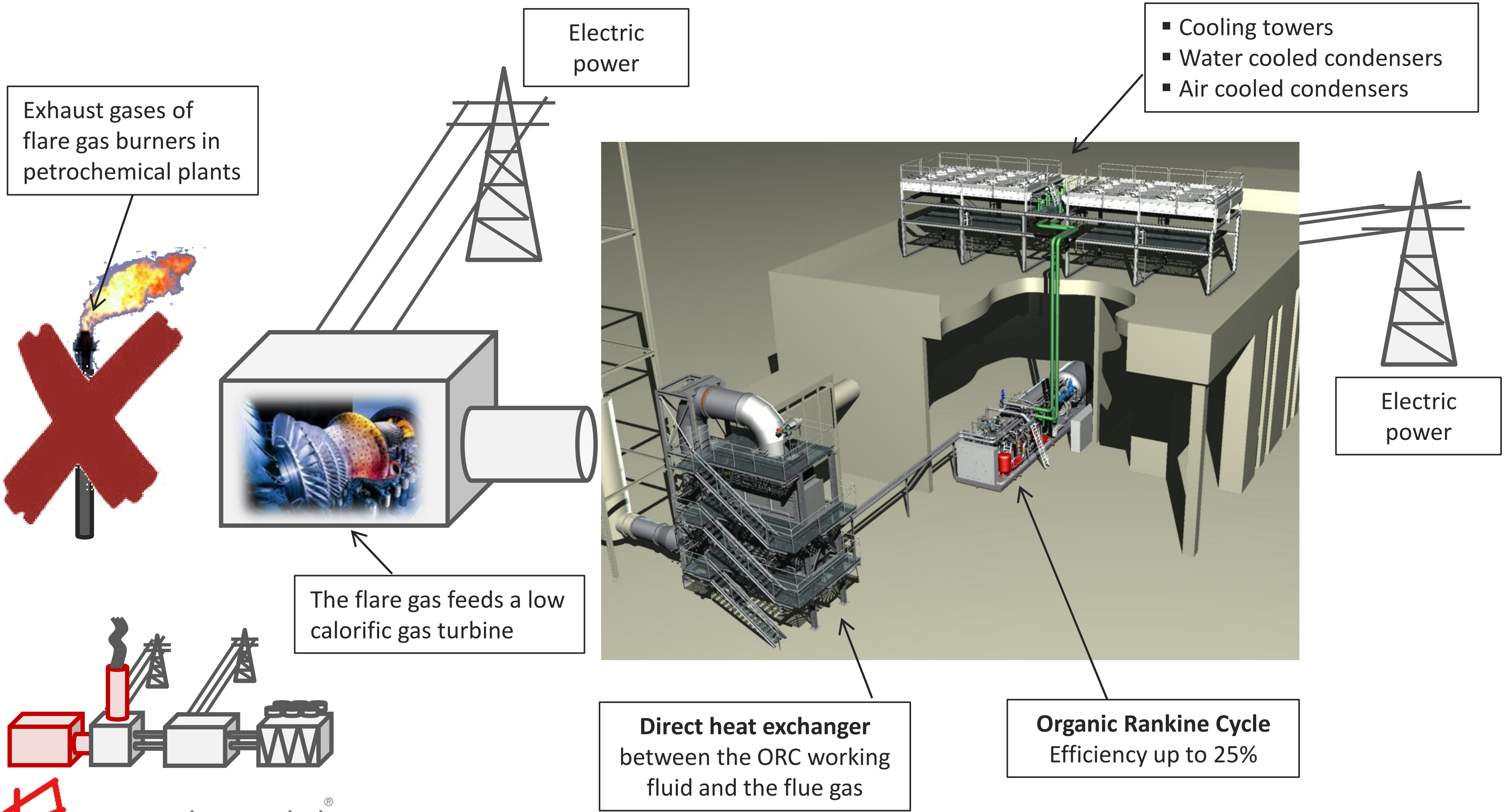
APG exploitation – Further development

As a further development of the solution a low calorific value gas turbine can be employed and the ORC can be configured in direct exchange mode, exploiting the exhaust gases of the gas turbine.



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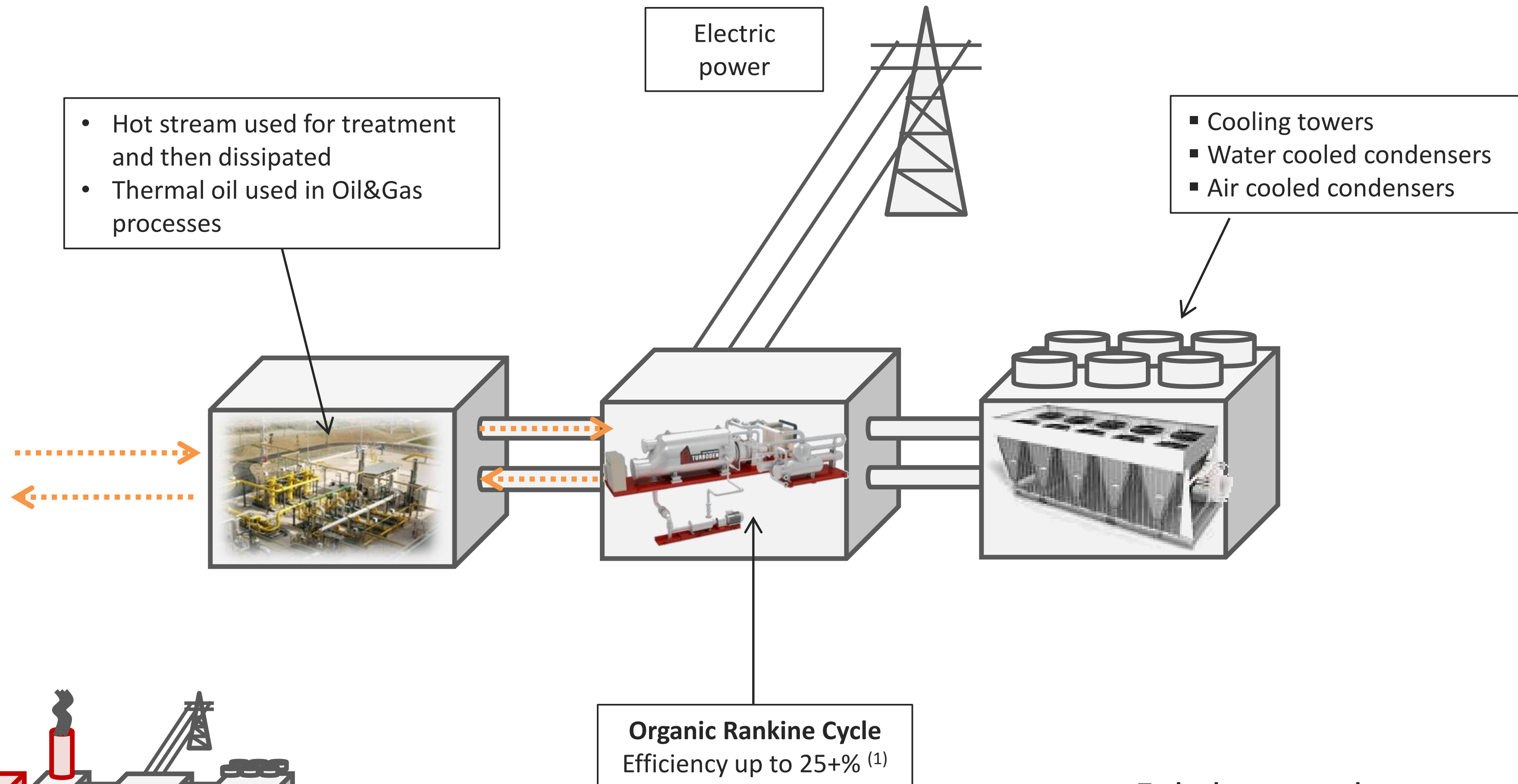
Oil&Gas applications

Ⓓ Refinery hot streams



Turboden case study

Thermal oil power: 53 MW
ORC electric power: 10 MW

(1) Heat carrier temperature above 300°C

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References – Combined Cycle Gas Turbines

Gas Compressor Station – TransGas

Heat recovery from **Solar CENTAUR gas turbine** in a **Gas compressor station** in **Canada**
Gas turbine prime power: **3.5 MWe**
Gas turbine efficiency: 28%
ORC electric power: **1 MW**
General contractor: **IST**
Final client: **TransGas**
Start up: **in operation since November 2011**

Gas Compressor Station

Heat recovery from **Solar TITAN 130 gas turbine** in a **Gas Turbine Power Plant (GTPP)** in **Russia** (Moscow region)
Gas turbine prime power: **15 MWe**
Gas turbine efficiency: 30%
ORC electric power: **3 MW** direct exchange cogenerative solution
ORC thermal power: 15 MW of hot water at 90° C
General Contractor: **Energo development LCC**
Final Client: **undisclosed**
Status: under construction

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References – Internal Combustion Engines

Project	ORC Module	Site	Engines
Pisticci I	18 HR SPLIT (**1.8 MWe**) Start up: Q2 2010	Pisticci (IT)	3 x 8 MWe Wartsila Diesel engines
Termoindustriale	6 HR SPLIT (**0.6 MWe**) Start up: Q4 2008	Pavia (IT)	1 x 8 MWe MAN Diesel engine
Pisticci II	40 HR SPLIT (**4 MWe**) Start up: Q2 2012	Pisticci Scalo (IT)	2 x 17 MWe Wartsila Diesel engines
Cereal Docks	6 HR **DIR. EXCH**. (**0.6 MWe**) Start up: Q1 2012	Portogruaro (IT)	1 x 7 MWe Wartsila Diesel engine
E&S Energy	6 HR SPLIT (**0.6 MWe**) Start up: Q2 2010	Catania (IT)	2 x 1 MWe JGS/GE gas engines + 3 x 0.8 MWe JGS/GE gas engines + 1 x 0.6 MWe JGS/GE gas engine
Ulm	10 HR cogenerative **(1 MWe)** Start up: Q3 2012	Senden (DE)	2 x 2 MWe JGS/GE gas engines (+ additional heat from the process)
Kempen	6 HR cogenerative **(0.6 MWe)** Start up: Q1 2012	Kempen (DE)	Gas engines
Mondopower	10 HR **(1 MWe)** Start up: Q4 2012	Chivasso (IT)	1 x 17 MWe Wartsila Diesel engine
HSY	14 HR **(1.3 MWe)** Start up: Q4 2011	Ämmässuo, Espoo (FIN)	4 x 4 MWe MWM gas engines
Fater	7 HR **DIR. EXCH**. **(0.7 MWe)** Start up: Q2 2013	Pescara (IT)	1 x 8 MWe Wartsila Diesel engine

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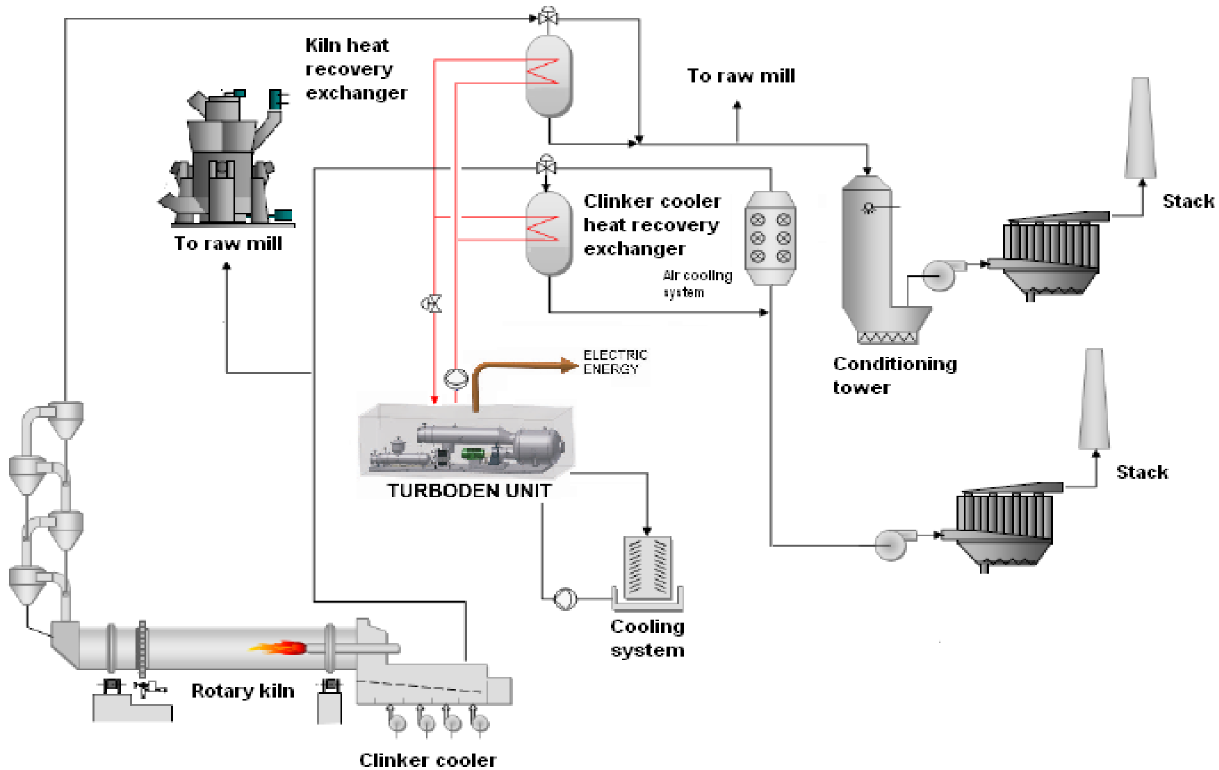
WHTP with ORC in cement industry



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Start up year	References in cement plants	Heat source	ORC gross electric power [MW]
2010	Italcementi - Ciment du Maroc, Marocco	PH + CSP	1.5
2012	Holcim Romania	PH + CC	4
2014	CRH (ex Holcim Group)	PH + CC	5
2015	Heidelberg Cement – Cartpatcement Romania	PH + CC	4
2016	Cementi Rossi	PH + CC	2

(PH): preheating system, (CSP): concentrated solar power, (CC): clinker cooler

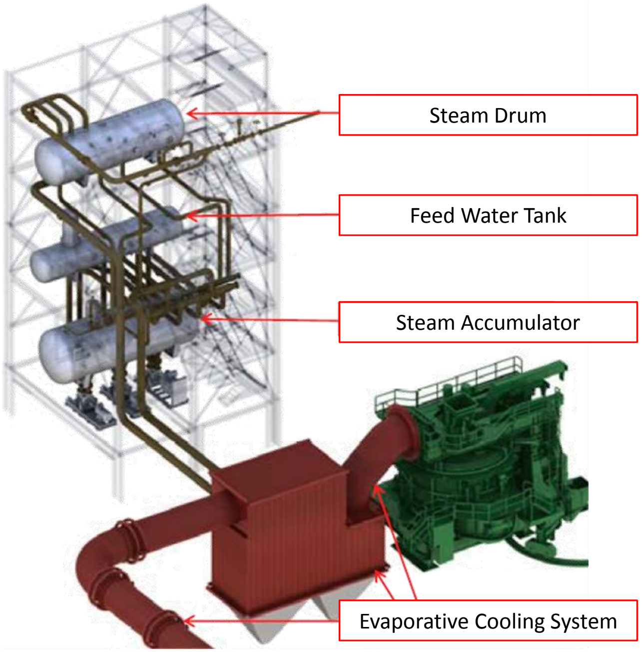
References – Steel industry

1. Electric Arc Furnace Data

Heat source	**EAF process off-gas**
Steel production	1M tons/year
Heats per day (average)	32
EAF hourly production	133 tons/hour
Tapping weight	100 tons
Tapping temperature	1,600°C
Charge weight	113 tons
Average off-gas temperature (core temperature ex EAF)	1,100°C
Average off-gas flow rate	100,000 – 140,000 Nm^3/h

2. Heat recovery system Data

Nominal steam data at steam drum	247°C – 38 bar(a)
Water content cooling system (pipes + tank)	approx. 37 m^3
Capacity of steam accumulation of cooling system	1,442 kg
Inlet thermal power to the ORC	13,517 kW
Steam temperature into ORC	228÷245°C
Condensate temperature out from ORC	100°C
Thermal power to the cooling water	10,640 kW
Cooling water temperatures (in/out ORC)	26°C / 44°C
Gross electric power output	2,680 kW
Net electric power output	**2,560 kW**



In operation since December 2013

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References – Direct Exchange

Project	Customer	Site	Heat Source	ORC power	Start up
food industry	Cereal Docks	Italy	7 MW diesel engine	700 kW	Q1 2012
personal care industry	Alma CIS/Fater	Italy	18V32 diesel engine	700 kW	Q2 2013
steel industry	Natsteel/TATA group	Singapore	hot rolling mill reheating furnace	700 kW	Q1 2013
cogenerative	Polyimpex	Russia	Solar TITAN 130 gas turbine	3,000 kW	Under construction
cement industry	Cementi Rossi	Italy	clinker cooler	2,000 kW	Under construction

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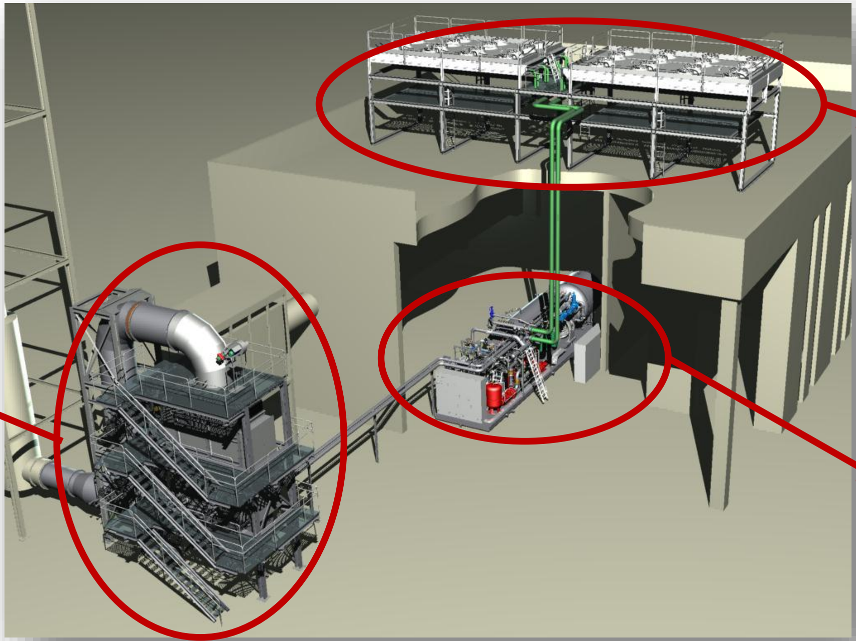

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References – Biomass

236 references in operation, 277 MW installed

Example of large size ORC (thermal oil input): West Fraser Mills Ltd

West Fraser

Site 1: Chetwynd, British Columbia - Canada - 2 x Turboden ORC Units; in operation since March 2015

Site 2: Fraser Lake, British Columbia - Canada - 2 x Turboden ORC Units; in operation since November 2014

- ❑ **Fuel**: sawmill scraps, woodchips
- ❑ **ORC heat carries**: thermal oil
- ❑ **ORC electric power**: 4 x 6.5 MW

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References – Geothermal

8 references in operation, 29 MW installed

Sauerlach

Customer: SWM - StadtWerke München (Munich multi-utility)

Site: Sauerlach, Germany

ORC size: 5.6 MWe + 4 MWth to district heating

Start up: January 2013

Scope of supply: Complete ORC supply, air condenser includes

Dürrnhaar

Customer: Hochtief Energy Management GmbH

Site: Dürrnhaar (München), Germany

ORC size: 5.6 MWe

Start up: December 2012

Scope of supply: full EPC for ORC, air condenser and BOP

Kirchstockach

Customer: Hochtief Energy Management GmbH

Site: Kirchstockach (München), Germany

ORC size: 5 MWe

Start up: January 2013

Scope of supply: full EPC for ORC, air condenser and BOP

Key factors:

- **Close to the Munich urban area (<10 km)**
- Coupled with urban **district heating network**
- Possibility to work **on island mode** (Sauerlach)
- **Medium enthalpy: 140°C**
- **Non-flammable** working fluid
- **Small area covered** due to houses in the nearby
- **Turboden supply all the components** except geothermal pump an circuit

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References – Low temperature water

Waste to energy – Mirom, Belgium

MIROM
MILIEUZORG ROESELARE EN MENEN

Heat recovery from **pressurized water** boiler in **waste incinerator**

Customer: MIROM

Location: Roeselare, Belgium

Source: hot water at 180° C (back at 140° C)

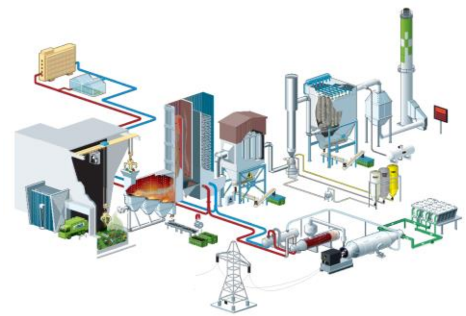
Cooling source: air coolers

ORC electric power: 3 MW

Electrical efficiency: 16.5%

Availability: >98%

Start up: Q2 2008



Waste to energy – Séché, Francia

Heat recovery from **pressurized water** boiler in **waste incinerator**

Customer: Séché Environnement Usine - Alcea

Location: Nantes, France

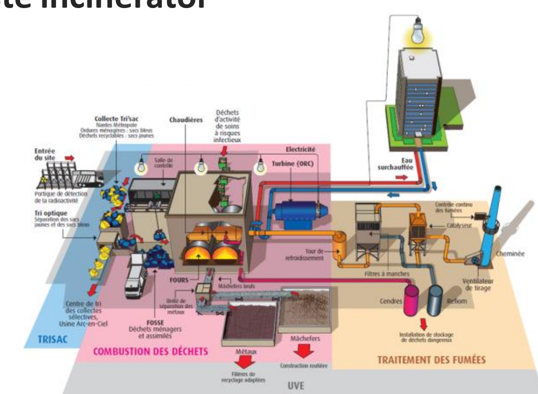
Source: hot water at 200° C (back at 130° C)

Cooling source: air coolers

ORC electric power: 2.4 MW

Electrical efficiency: 16.5%

Start up: Q3 2014



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Case study – Heat recovery from GTs (1/2)

Reference case

3 gas turbine (Siemens SGT 600) at full load (100%)

Site: **Middle East**

Cooling temperature (ambient air): **26°C**

Cooling system: **Air cooled condenser**

ORC Size: **15 MWe**

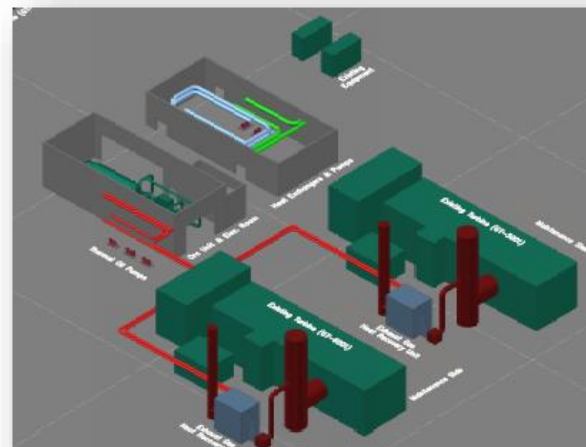
Net Power: **13.2 MWe**

Equivalent operating hours: **8,000 h/y** (1)

Energy savings: **106 GWhe → 6.3 M€/y** (2)

or 22 mcm of natural gas (3)

Emission avoided: **68,900 t CO_2/y** (4)



(1) Middle East Gas infrastructures work continuously, ORC availability > 95%
(2) Assuming an electricity value of 80 €/MWhe as barrels of oil savings
(3) Assuming a consumption of 260 mc of natural gas per MWh of power generated
(4) Assuming an average emission factor of EU power generation plants of 650 t CO_2 per GWh (source IEA 2013)

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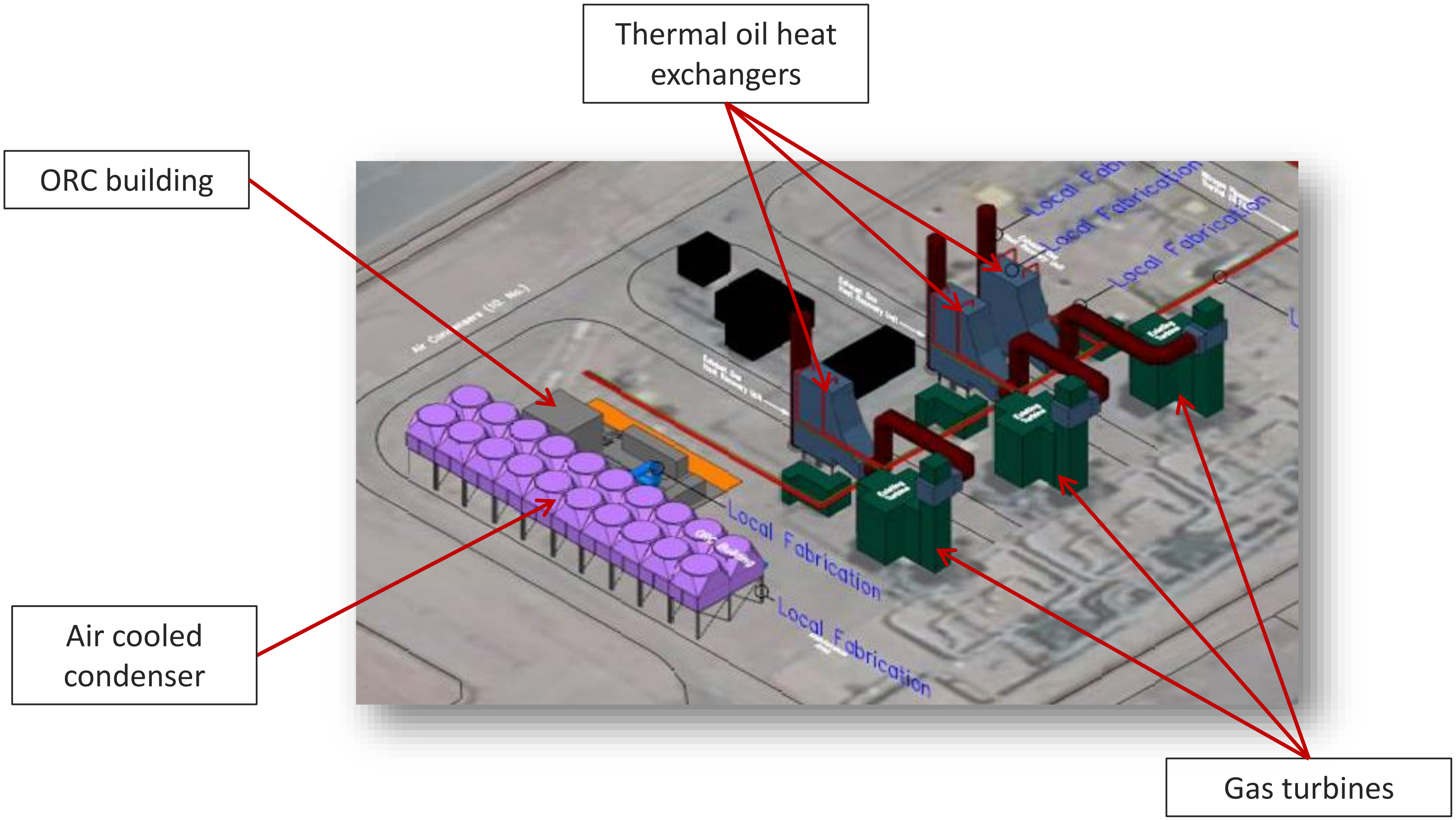
Case study – Heat recovery from GTs (2/2)



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Conclusion

- ORC technology is a proven way to reduce equivalent fuel consumption and CO_2 emission in Oil&Gas infrastructure equipment

- Turboden ORC technology for waste heat recovery makes Oil&Gas greener

- Turboden has experience in Oil&Gas technical codes and standards

- Provide us with your waste heat data to allow us studying an optimum heat recovery solution

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Turboden at a Glance

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Turboden strong points

R&D	Sales/marketing	Design	Operations & manufacturing	Aftermarket service

▪ Participation in national & EU research programs
▪ Cooperation with EU Universities and Research Centres
▪ Thermodynamic cycle optimization
▪ Working fluid selection & testing
▪ Thermo-fluid-dynamic design and validation
▪ Implementation & testing of control/supervision software
▪ Many patents obtained
	▪ Pre-feasibility studies: evaluation of technical & economical feasibility of ORC power plants
	▪ Customized proposals to maximize economic & environmental targets
		▪ Complete in-house mechanical design
		▪ Proprietary design and own manufacturing of ORC optimized turbine
		▪ Tools
		  ◦ Thermo-fluid-dynamic programs
		  ◦ FEA
		  ◦ 3D CAD-CAM
		  ◦ Vibration analysis
			▪ Outsourced components from highly qualified suppliers
			▪ Quality assurance & project management
			▪ In-house skid mounting to minimize site activities
				▪ Start-up and commissioning
				▪ Maintenance, technical assistance to operation and spare parts service
				▪ Remote monitoring & optimization of plant operation

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