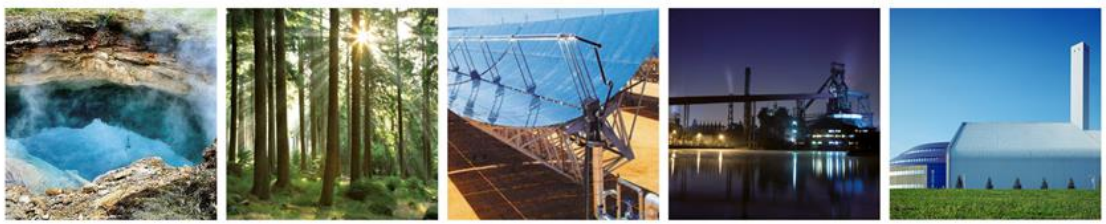

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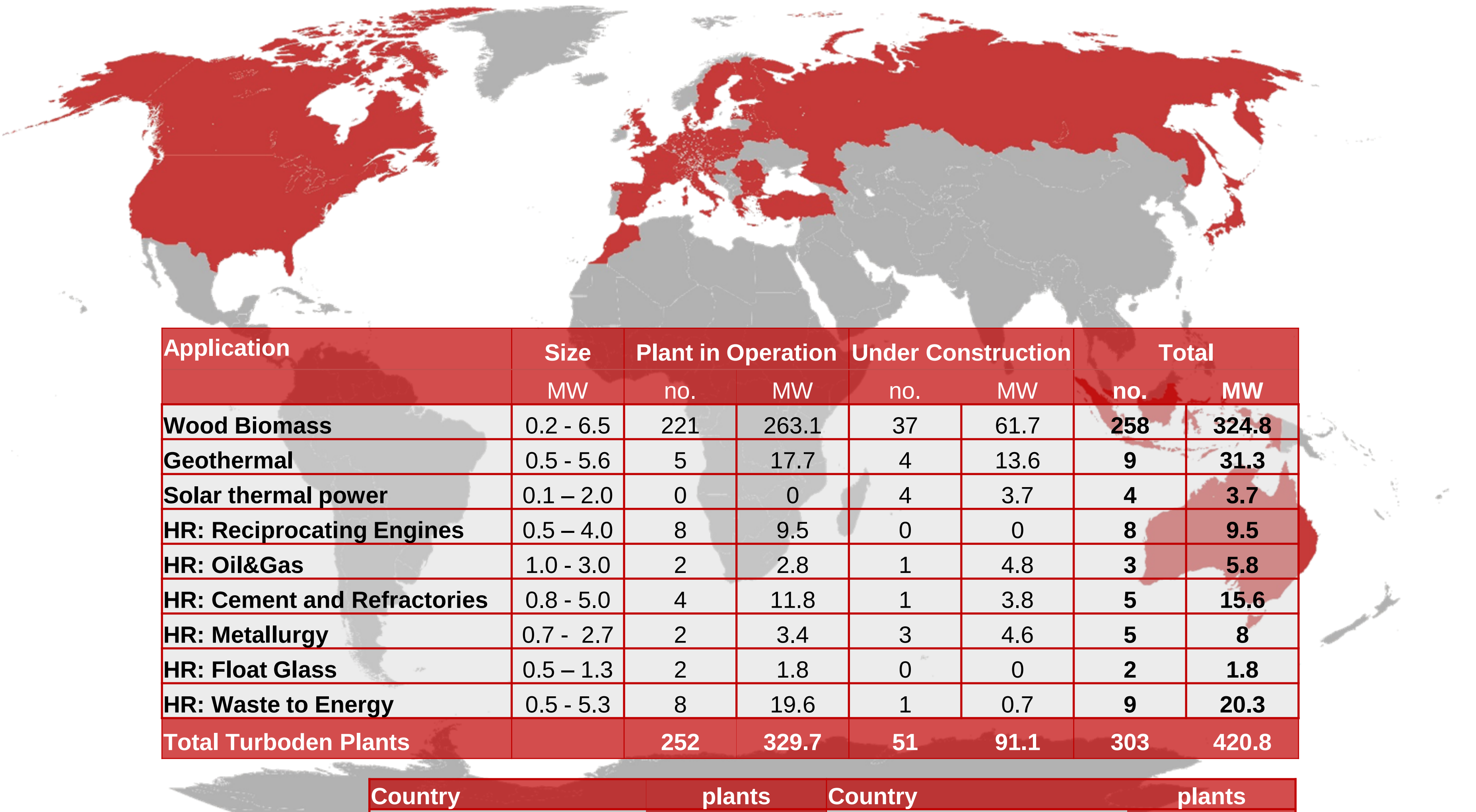
Turboden Solutions in the Oil&Gas Industry

ISO 9001

Doc.: 15-COM.P-14-rev.1

Update: 08/07/2015

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 - 6.5	221	263.1	37	61.7	**258**	**324.8**
Geothermal	0.5 - 5.6	5	17.7	4	13.6	**9**	**31.3**
Solar thermal power	0.1 – 2.0	0	0	4	3.7	**4**	**3.7**
HR: Reciprocating Engines	0.5 – 4.0	8	9.5	0	0	**8**	**9.5**
HR: Oil&Gas	1.0 - 3.0	2	2.8	1	4.8	**3**	**5.8**
HR: Cement and Refractories	0.8 - 5.0	4	11.8	1	3.8	**5**	**15.6**
HR: Metallurgy	0.7 - 2.7	2	3.4	3	4.6	**5**	**8**
HR: Float Glass	0.5 – 1.3	2	1.8	0	0	**2**	**1.8**
HR: Waste to Energy	0.5 - 5.3	8	19.6	1	0.7	**9**	**20.3**
Total Turboden Plants		**252**	**329.7**	**51**	**91.1**	**303**	**420.8**

Country	plants	Country	plants
Germany	**82**	Russia	**6**
Italy	**84**	Rest of the World	**6**
Austria	**31**	Turkey	**5**
Rest of Europe	**81**	North America	**8**

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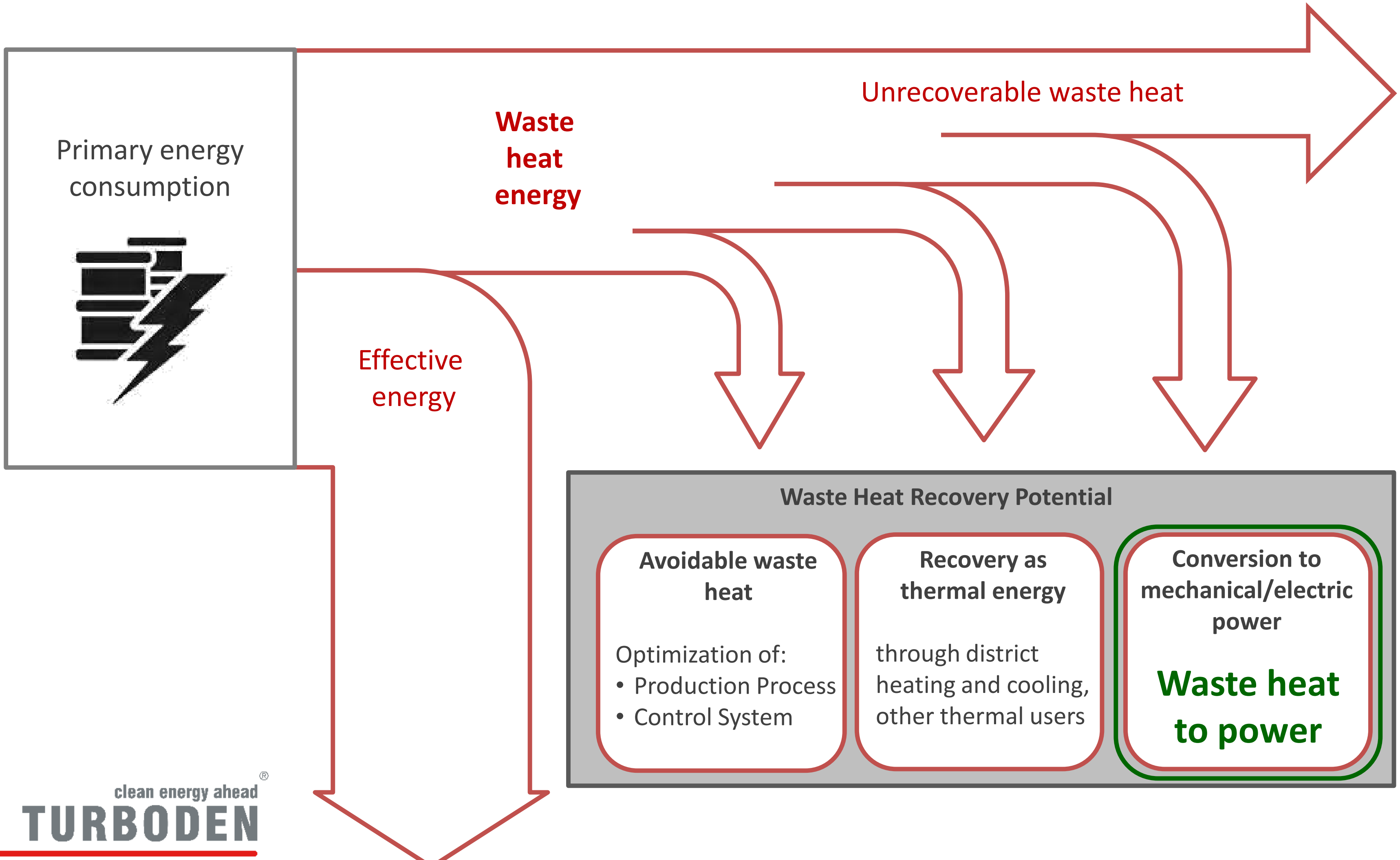
Last Update: May 2015

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



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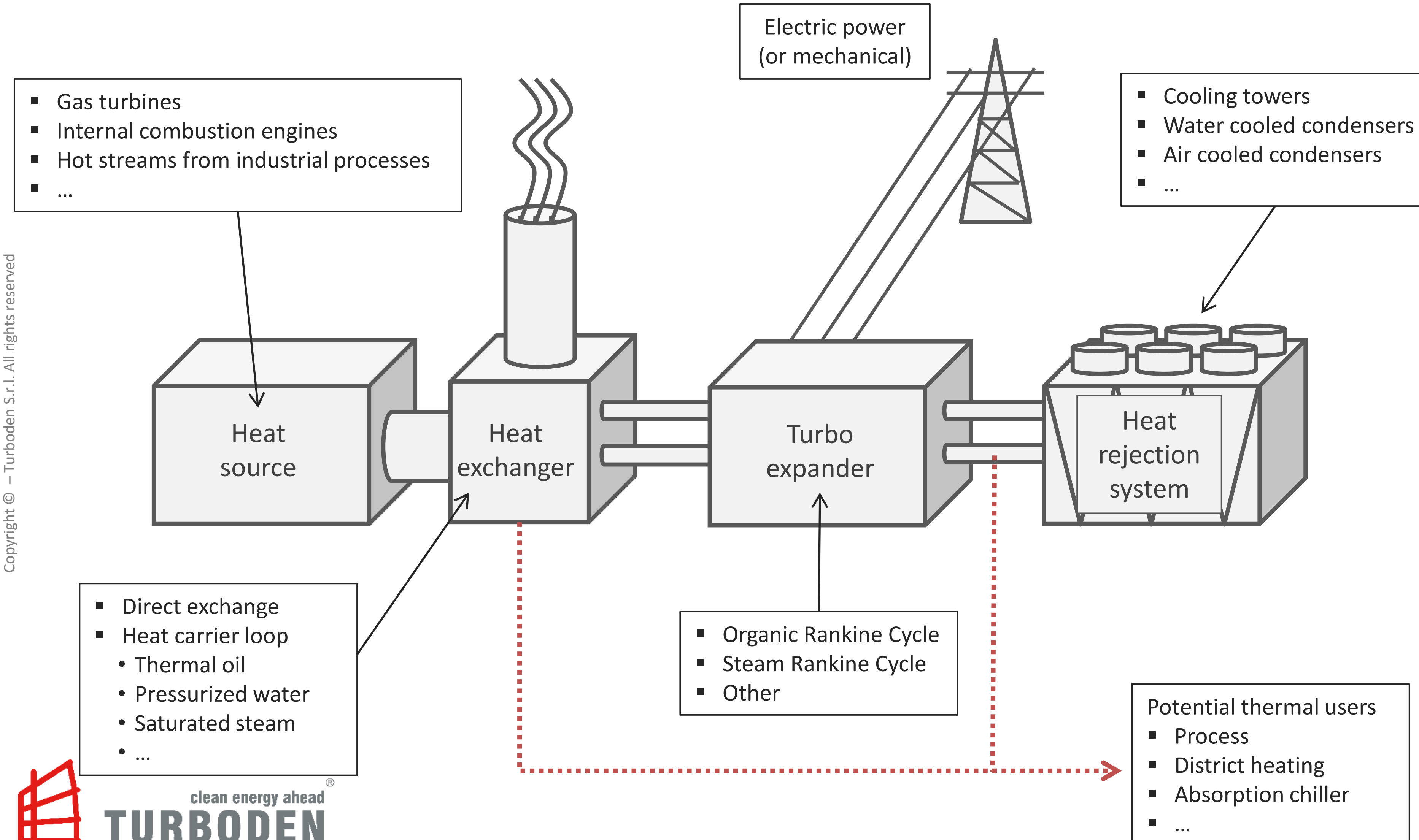
Waste heat to power



What we do

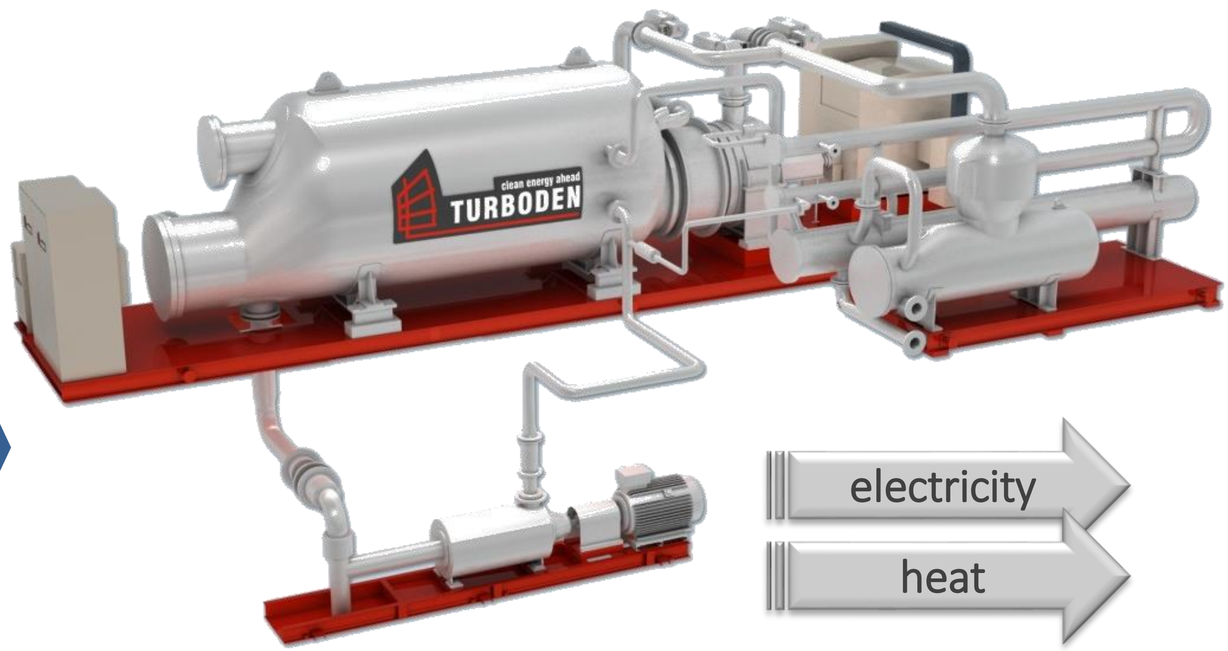

Biomass


Heat recovery


Waste to energy


Geothermal


Solar



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 15 MW electric per single unit

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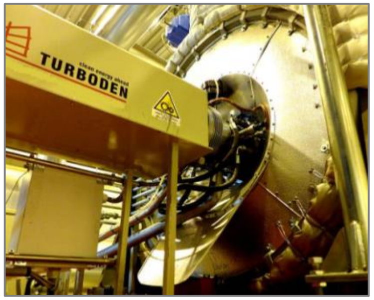
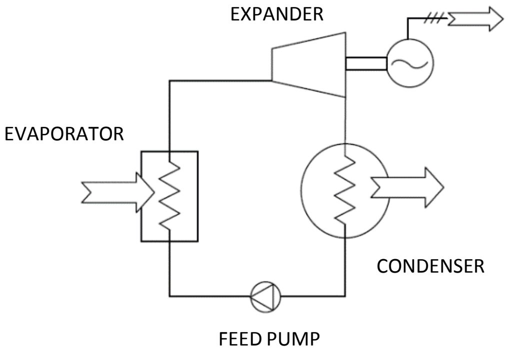
Organic Rankine Cycle: concept

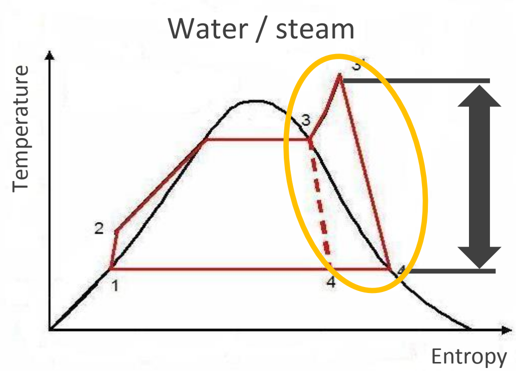


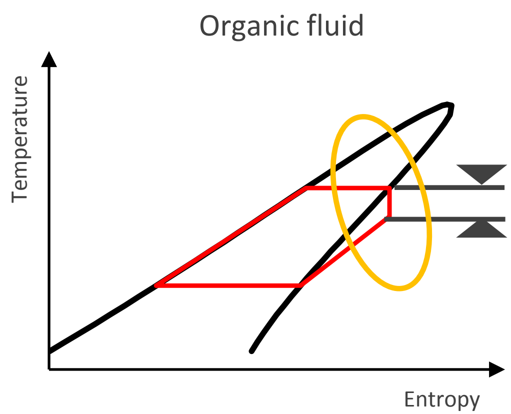
Cycle	it is a thermodynamic cycle
Rankine	it is theoretically given by 2 isobar and 2 adiabatic thermodynamic transformations
Organic	it exploits an organic working fluid

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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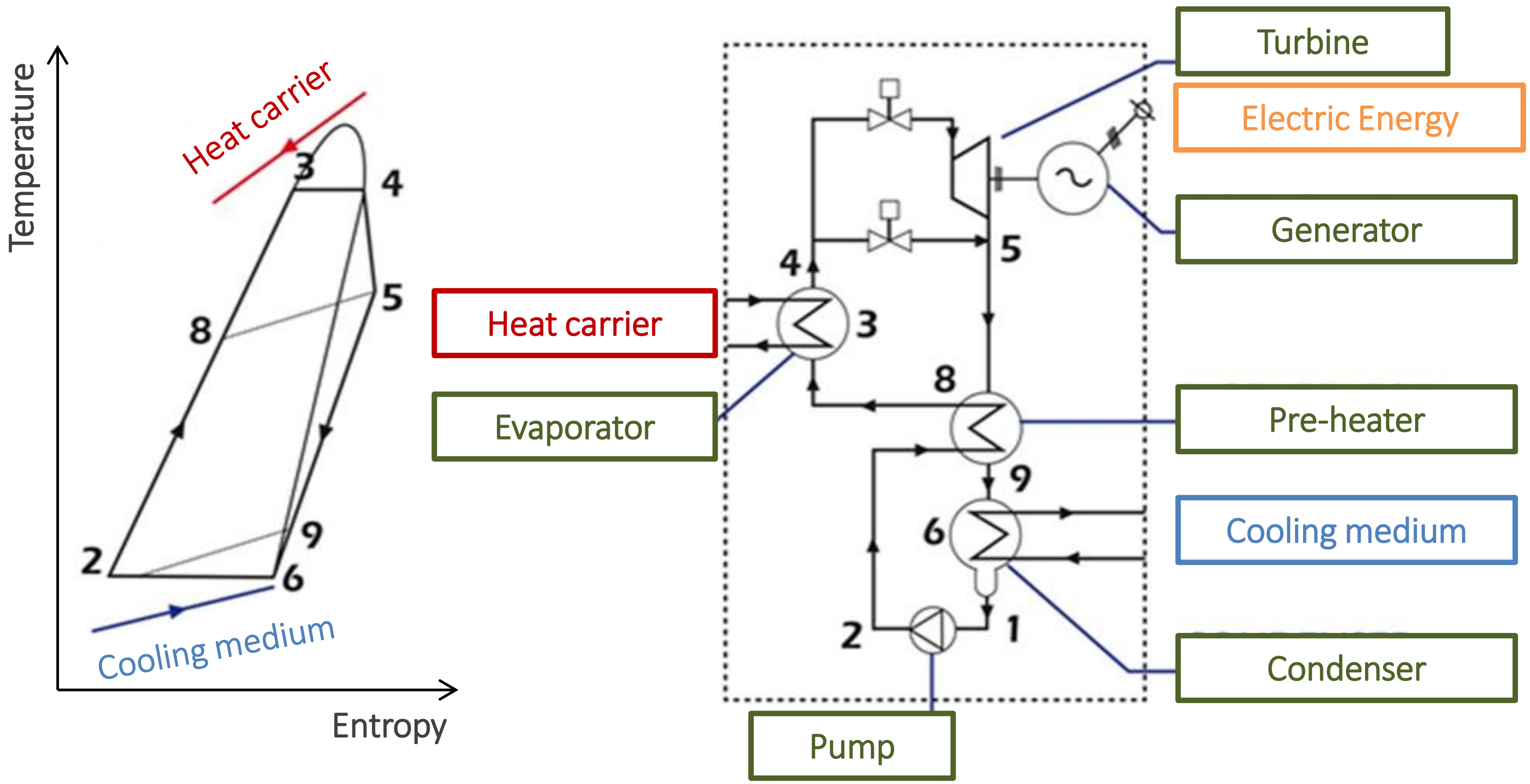
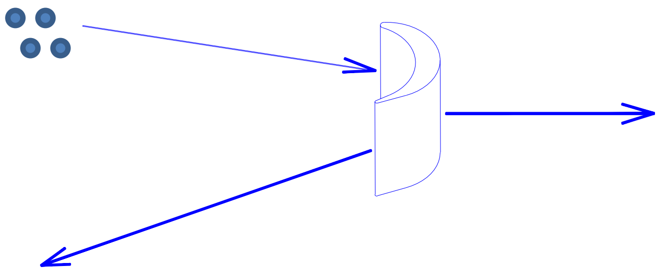
Organic Rankine Cycle: Thermodynamics



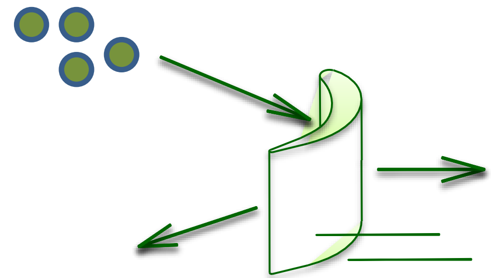
The turbogenerator uses the **heat carrier** (e.g. hot temperature thermal oil) to pre-heat and vaporize a suitable organic working fluid in the **evaporator** (8→3→4). The organic fluid vapor powers the **turbine** (4→5), which is directly coupled to the **electric generator** through an elastic coupling. 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.

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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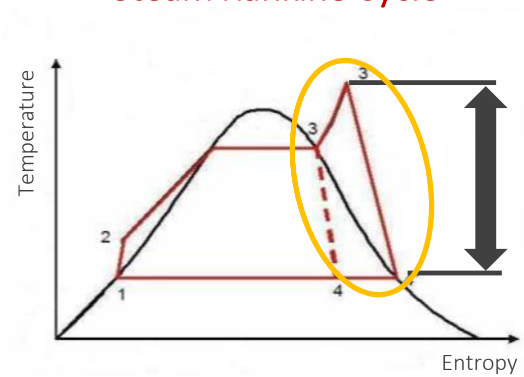
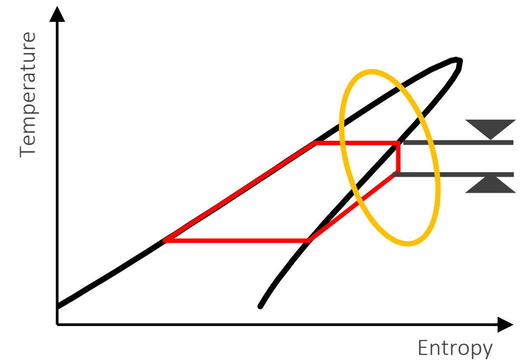
ORC provides significant advantages as compared to steam

	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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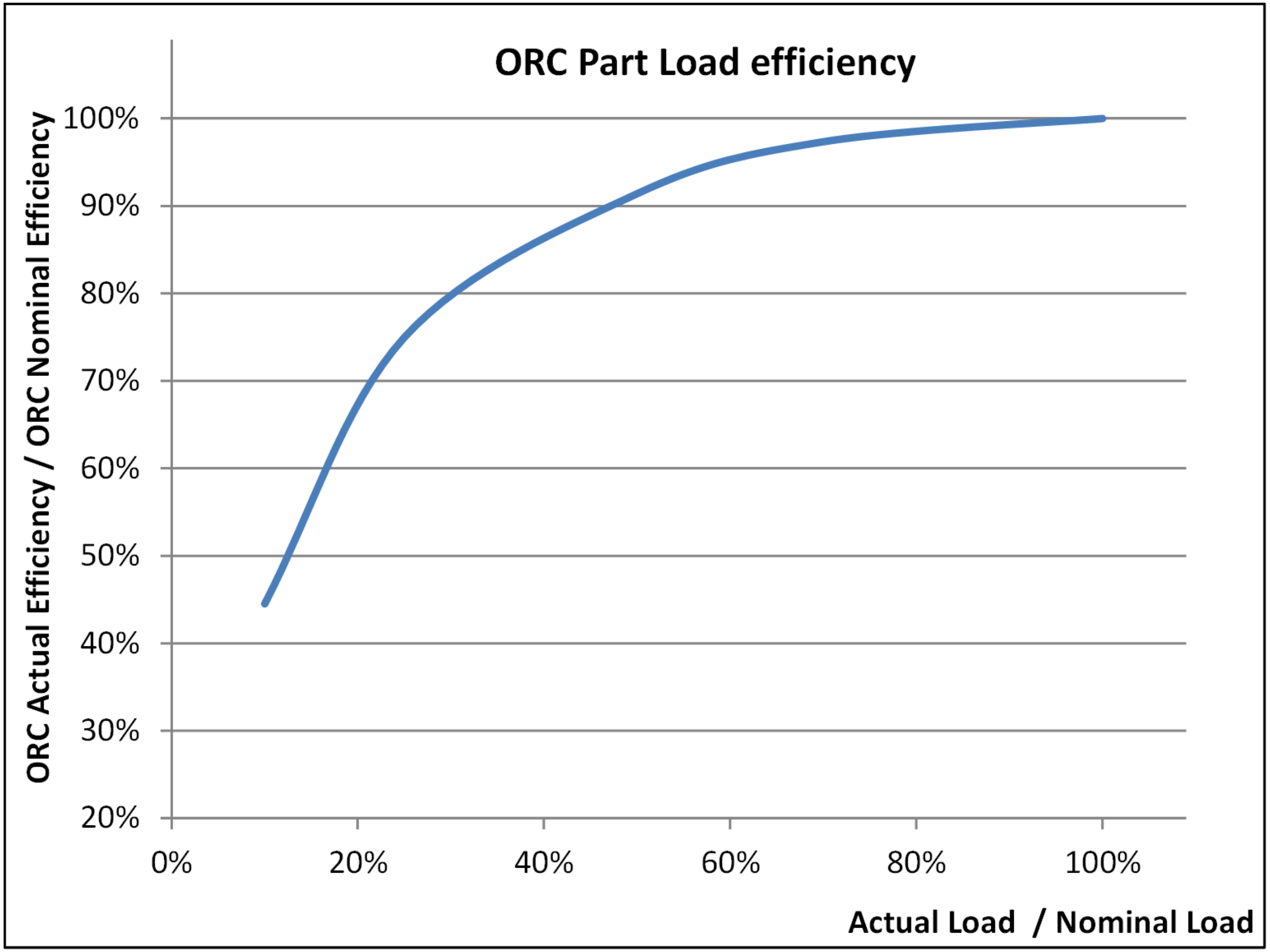
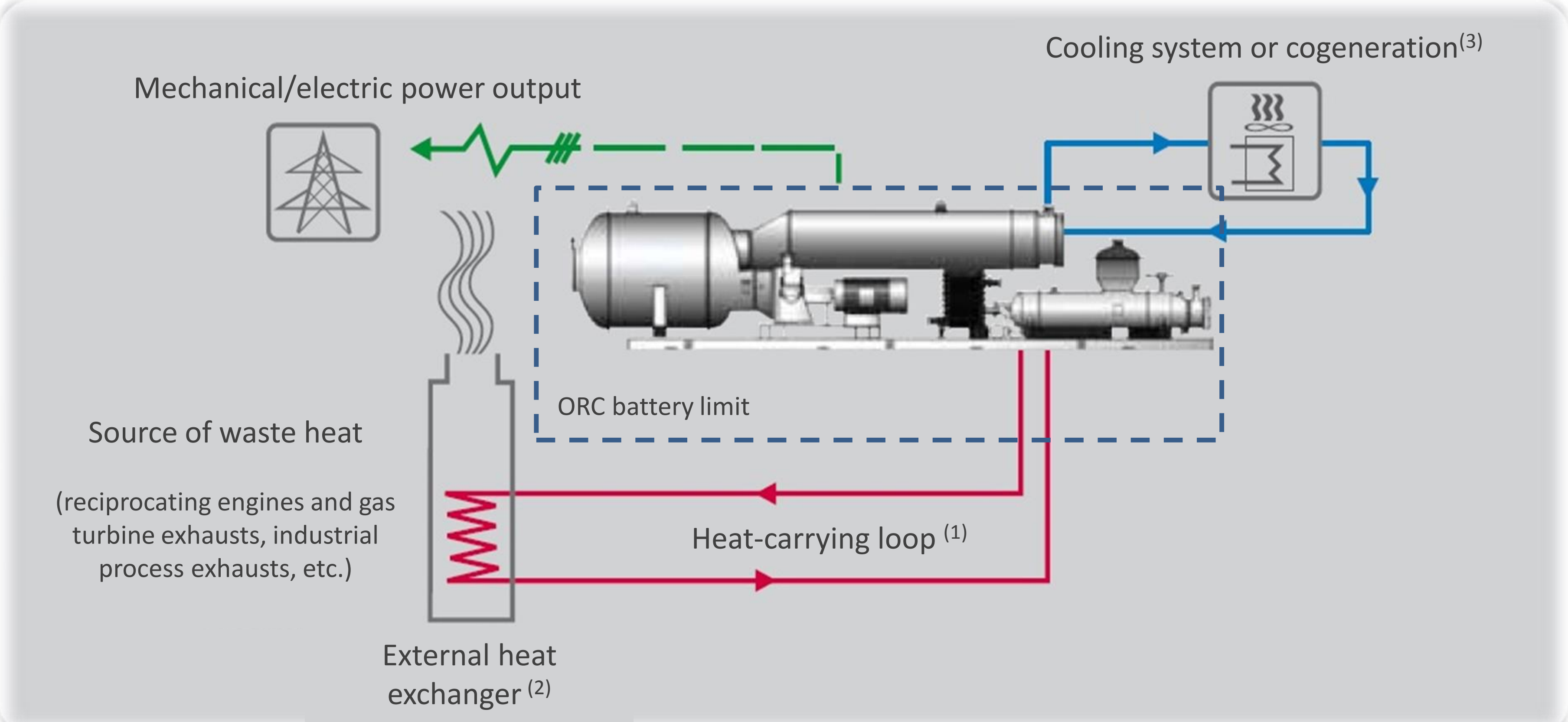
ORC performance at partial load



Waste heat to power ORC plant



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

ORC finds many applications in the Oil&Gas sector

A. Gas turbines exhaust gas

Gas compressor stations, natural gas liquefaction, gas storage, etc.

B. Hot water from exhausted oil wells

C. Associated Petroleum Gas (APG)

D. Refinery hot streams

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

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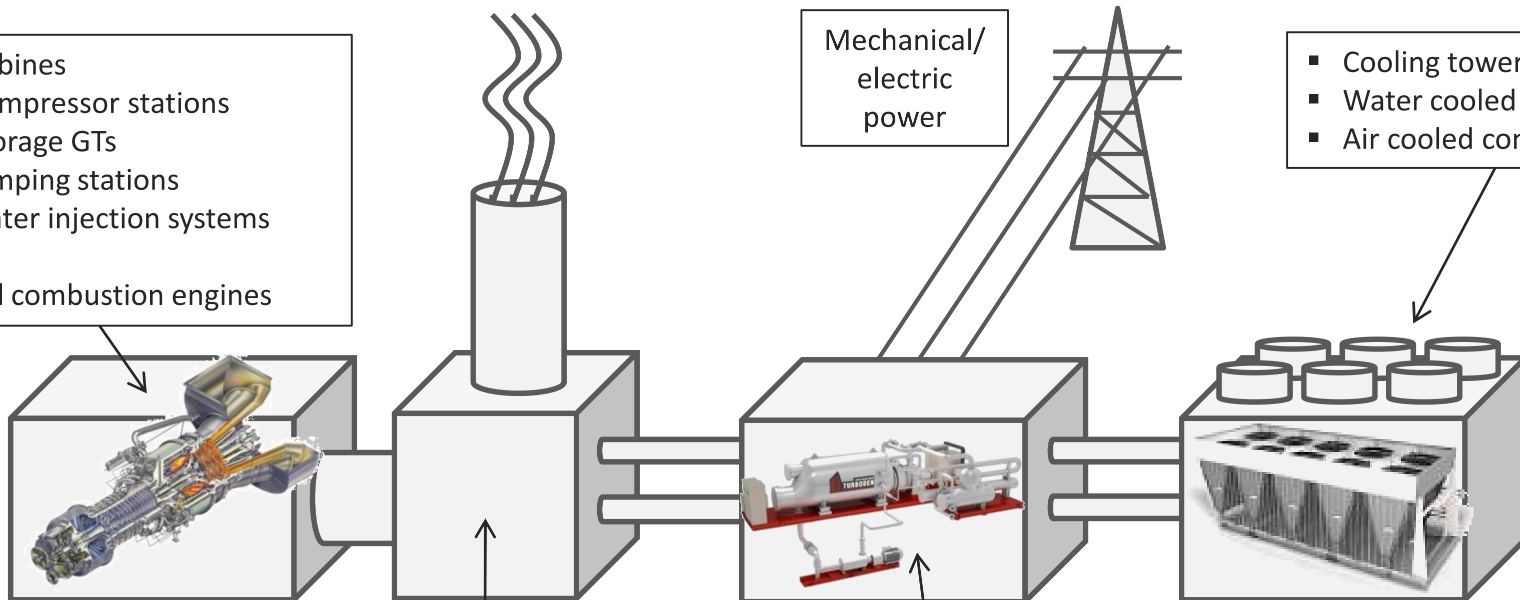
Oil&Gas applications

Ⓐ 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

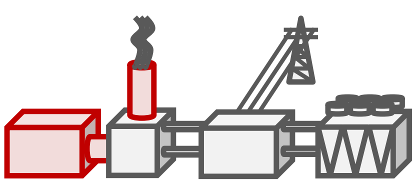


Heat exchanger
- Direct exchange
- Thermal oil

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
- **Polympex – Russia**
  GT power: 25 MWe
  ORC power: **3 MWe**
  CHP th. power: 15 MWth
  Direct Exchange
  Expected start up: 2015



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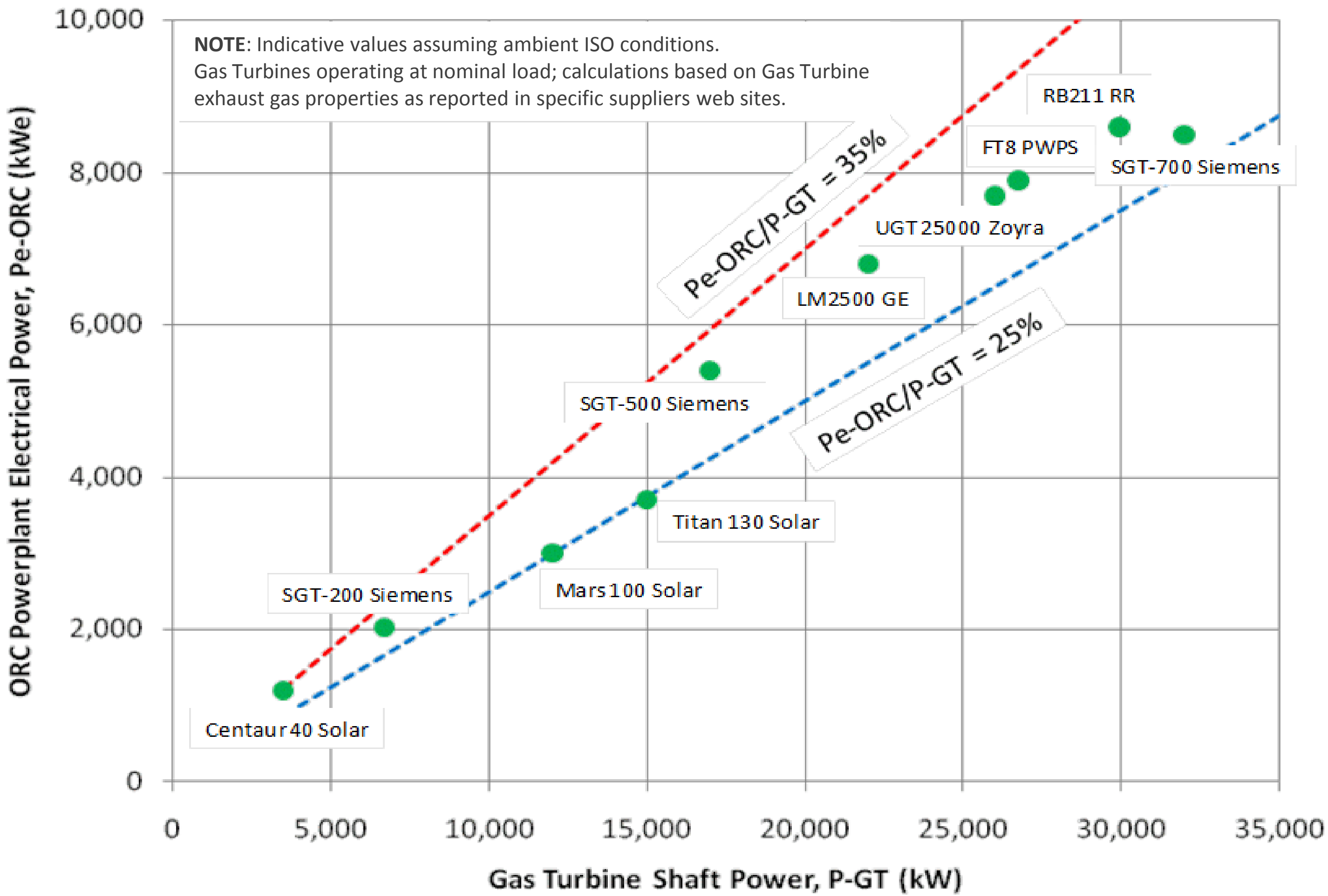
(1) Percent of the prime mover nominal power

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

TURBODEN ORC UNIT

MECHANICAL/ ELECTRIC POWER

Cooling medium circuit

Thermal oil / steam / pressurized water circuits

Gas Turbine

Chimney

HEAT EXCHANGERS

<u>Typically not included</u> in Turboden scope of supply

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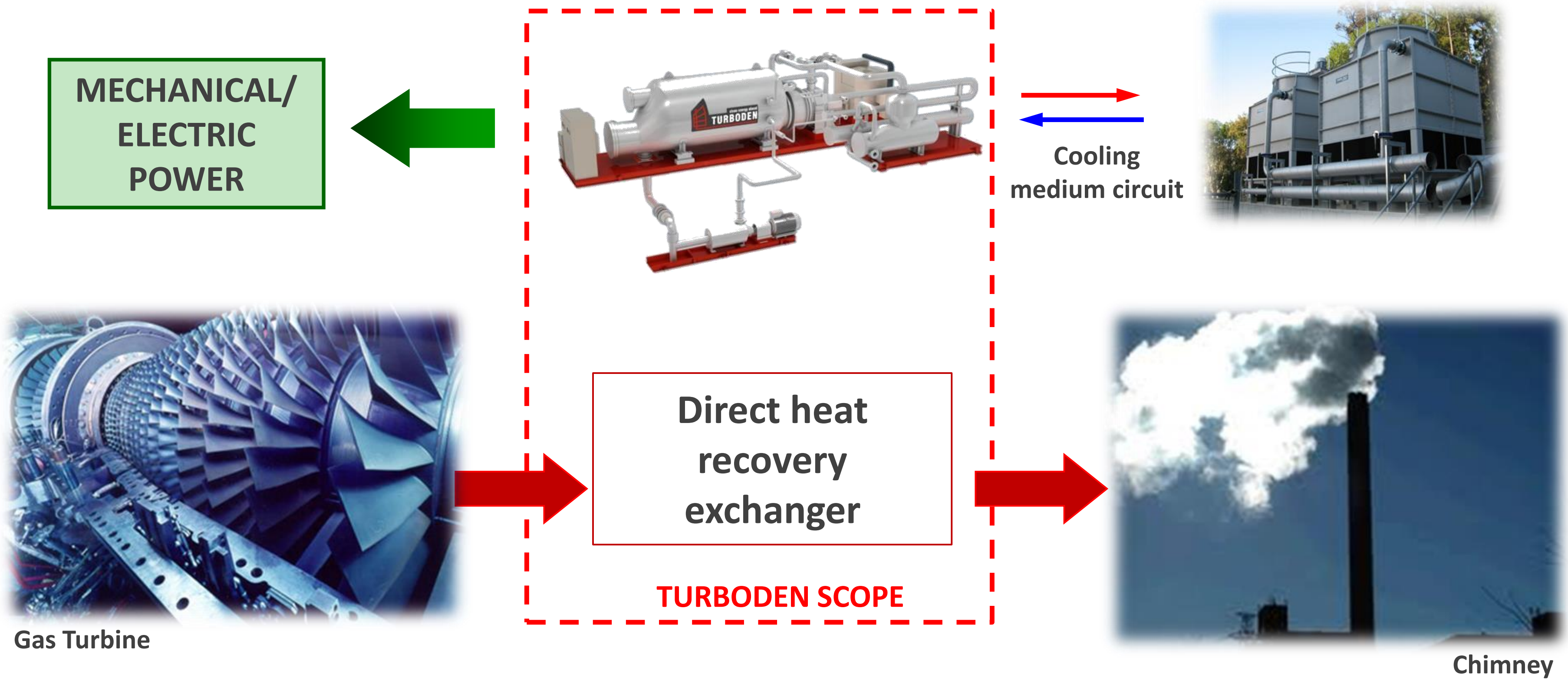
Direct exchange

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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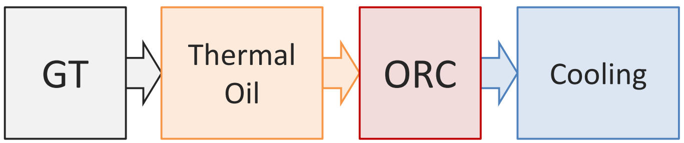
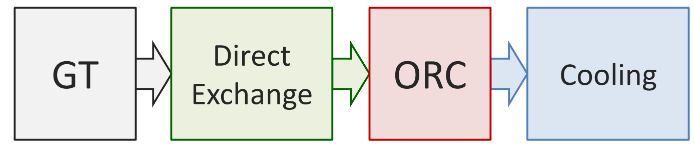
CCGT Schemes

1 turbine, 1 ORC

Thermal Oil

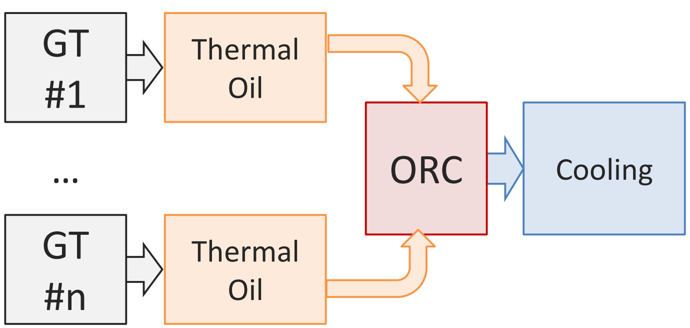


Direct Exchange

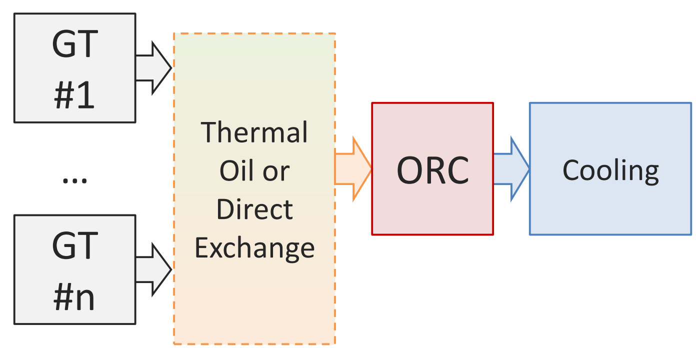


Multiple Heat Sources

Separated thermal oil heat recovery exchangers



Exhaust gas conveyed to a single heat recovery exchanger



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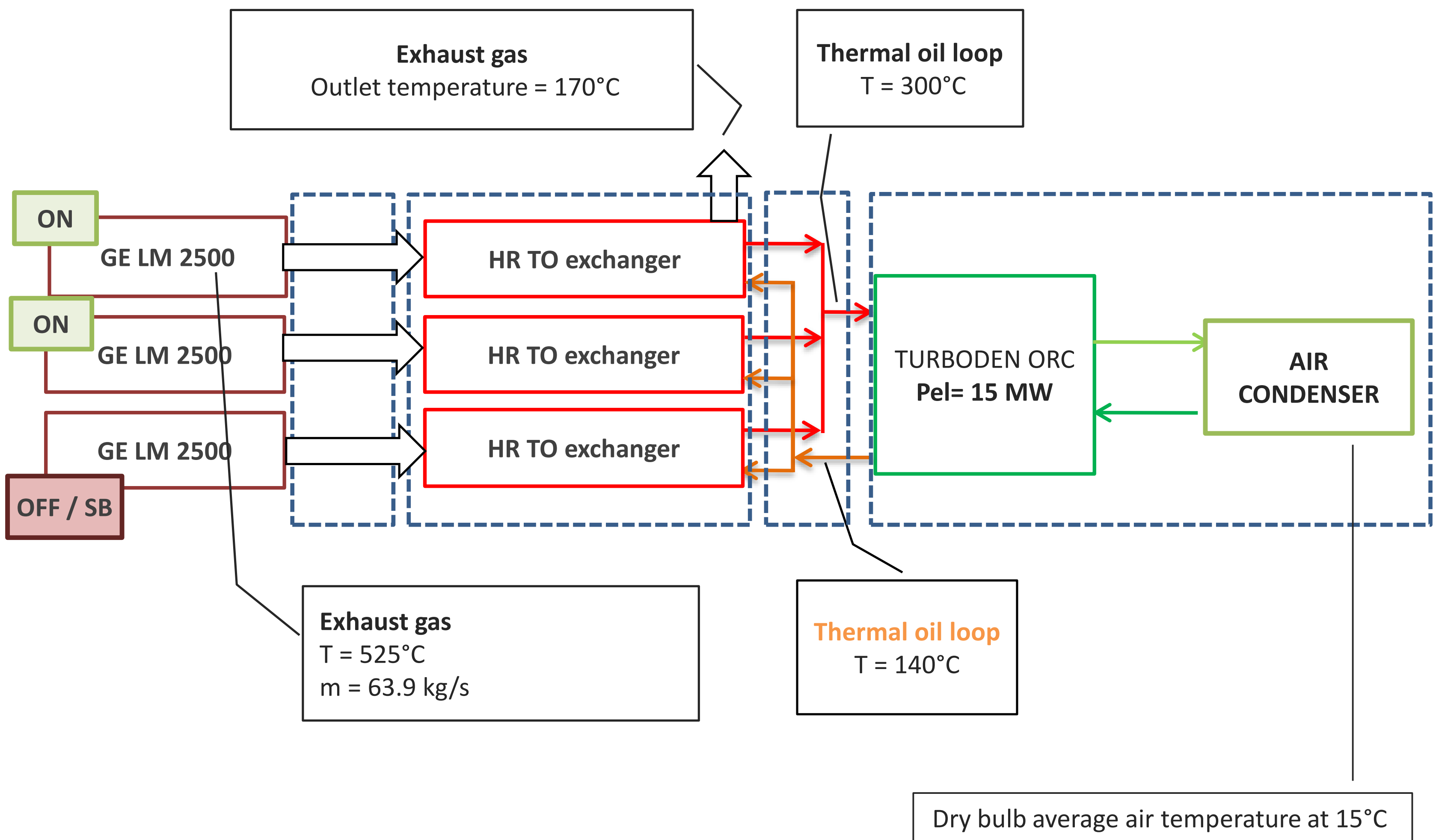
CCGT multiple recovery example



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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**

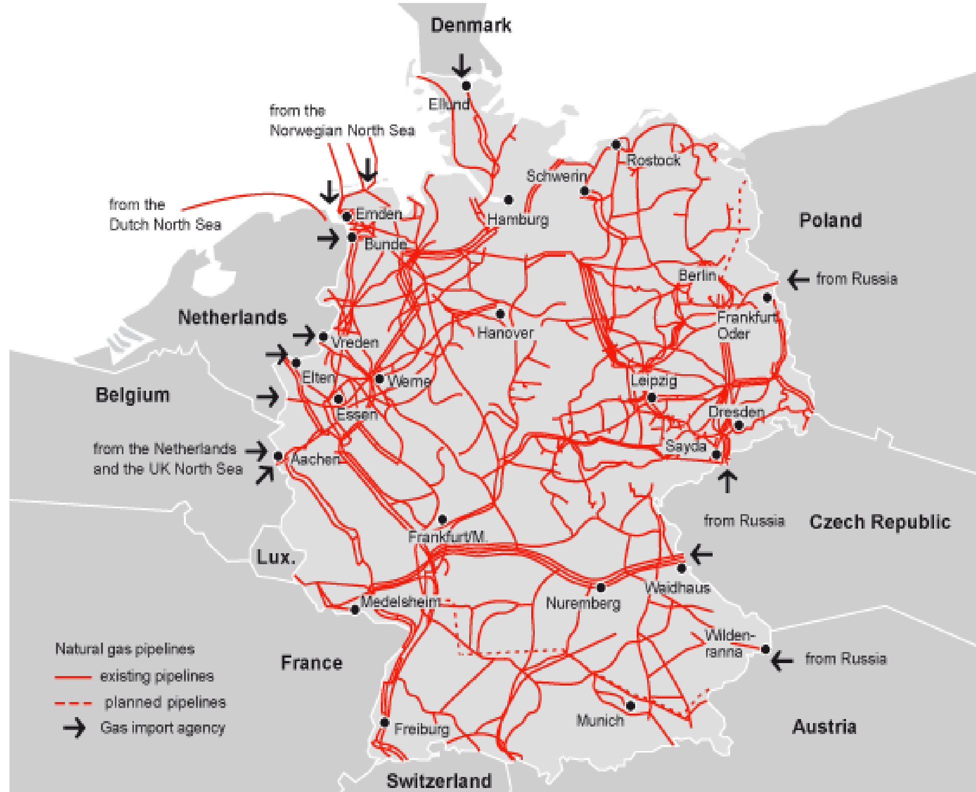
⇩

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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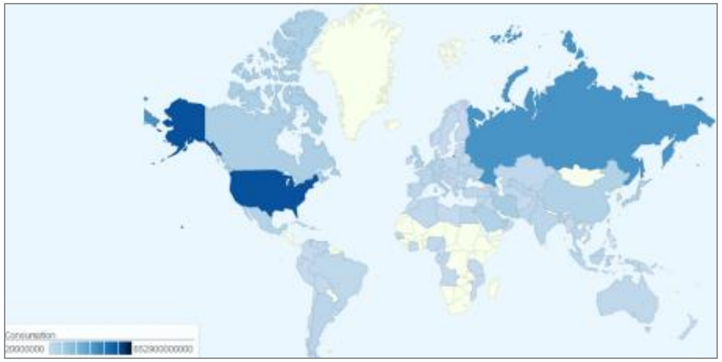
Natural Gas Compressor Stations: a big opportunity for Heat Recovery

- 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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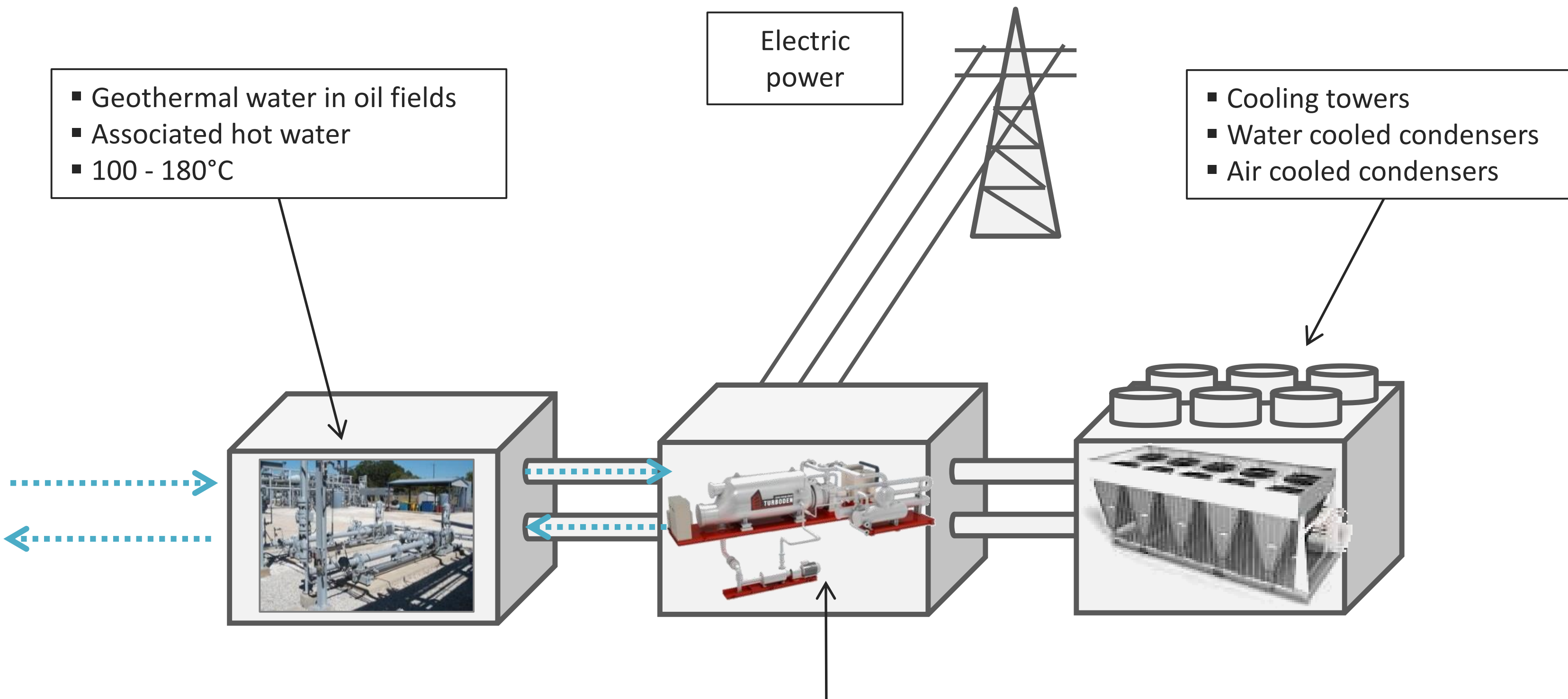
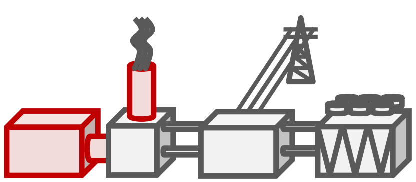
Oil&Gas applications

Ⓑ Hot water from exhausted oil wells





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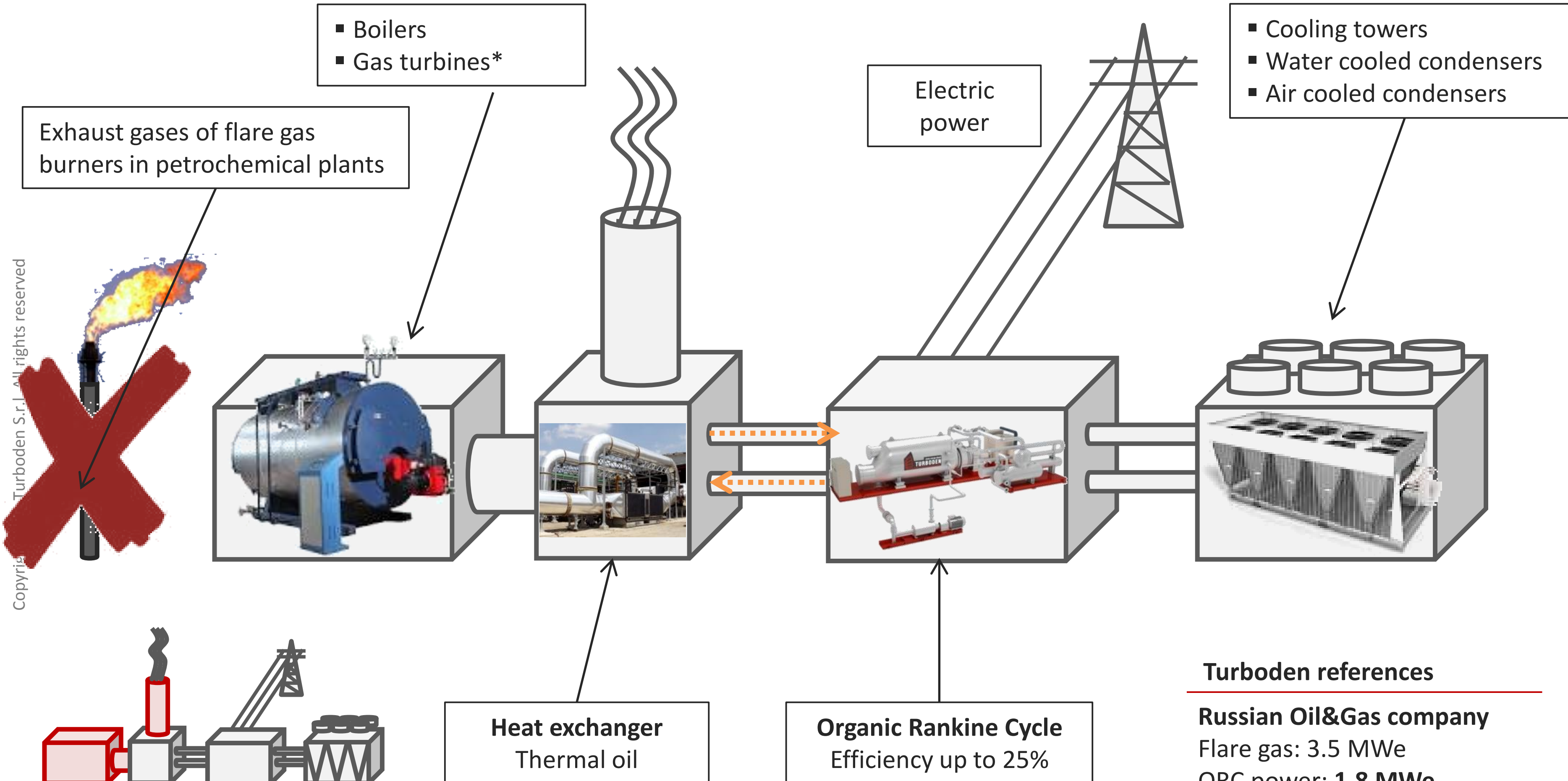
Turboden references

31 MW in 9 geothermal plants

Oil&Gas applications

Ⓒ Associated Petroleum Gas (APG)



Turboden references

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

Turboden reference – APG exploitation

Site: Perm, Russia

Customer/End user: LabNT/LUKoil

Status: started up in January 2015

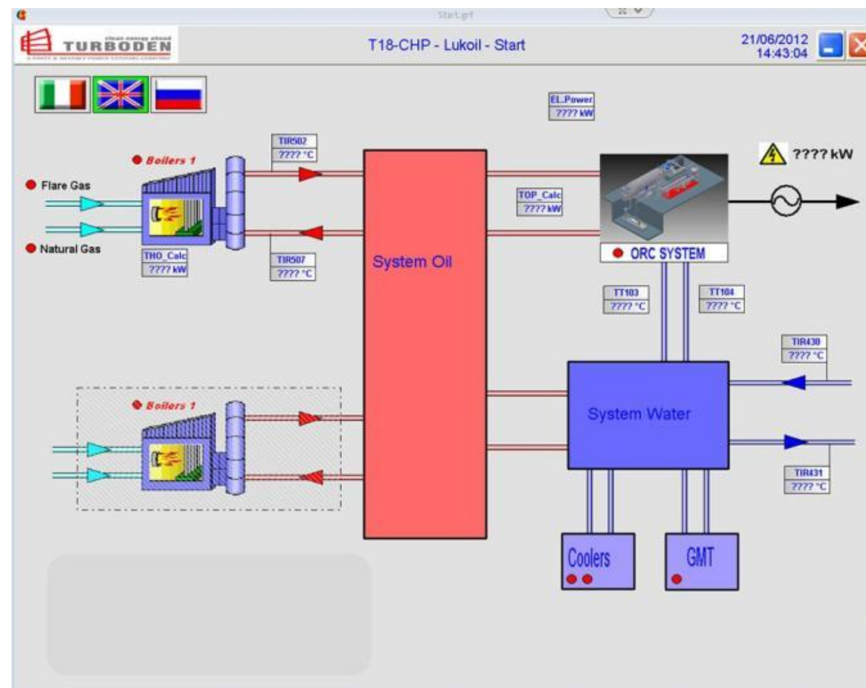
Heat source: flare gas burning (boiler designed to burn gas with a minimum lower calorific value of 4,500 kcal/Nm3

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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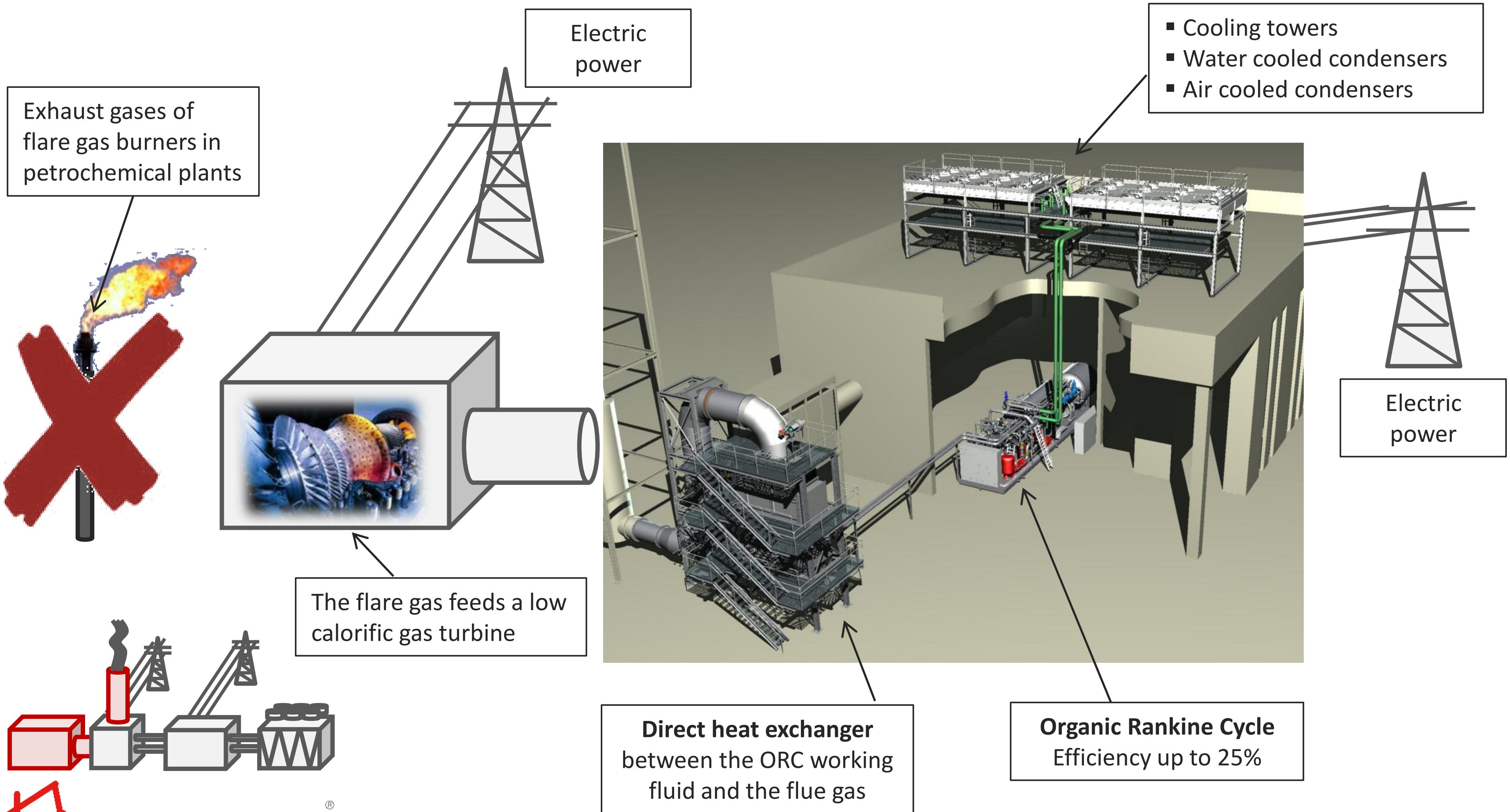
APG exploitation – Further development

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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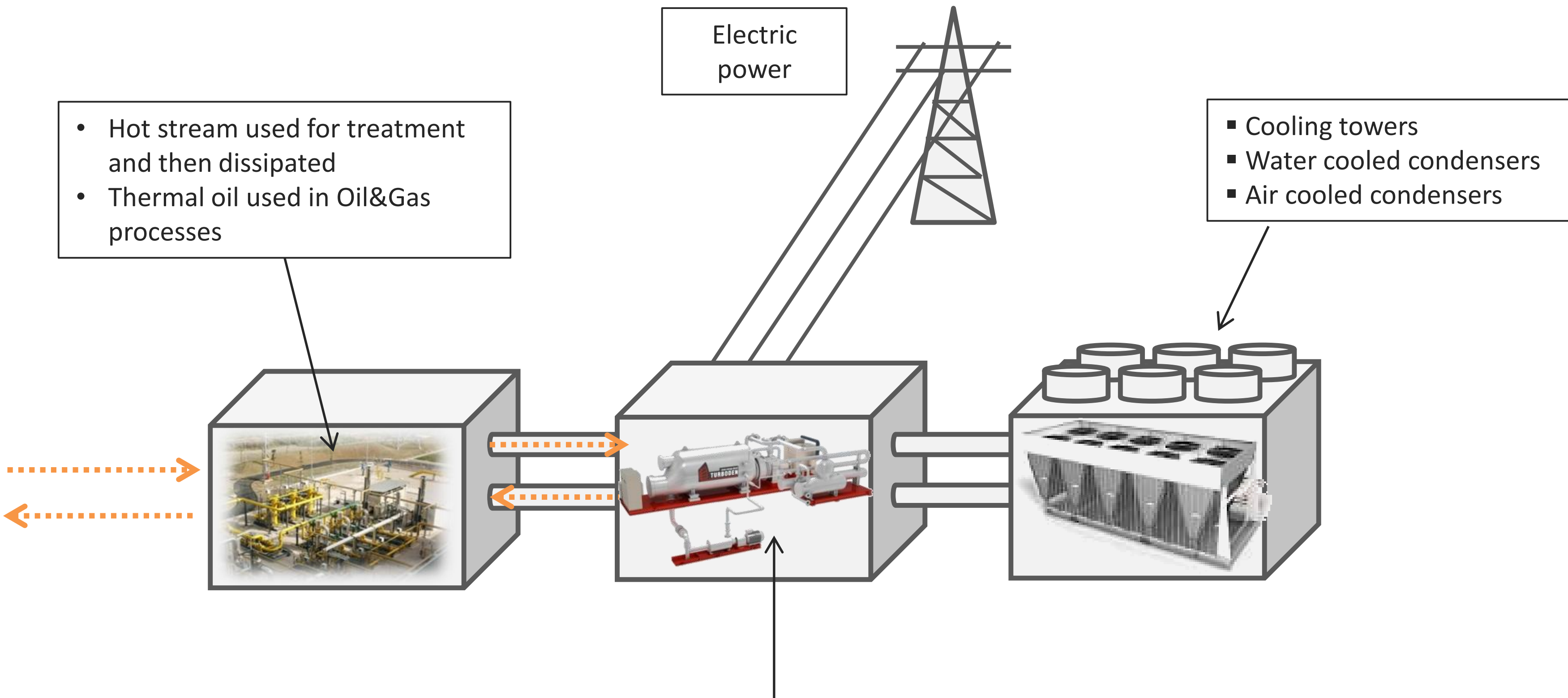
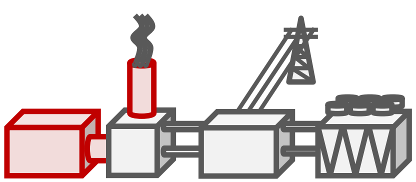
Oil&Gas applications

(D) Refinery hot streams



Turboden case study

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



(1) Heat carrier temperature above 300°C

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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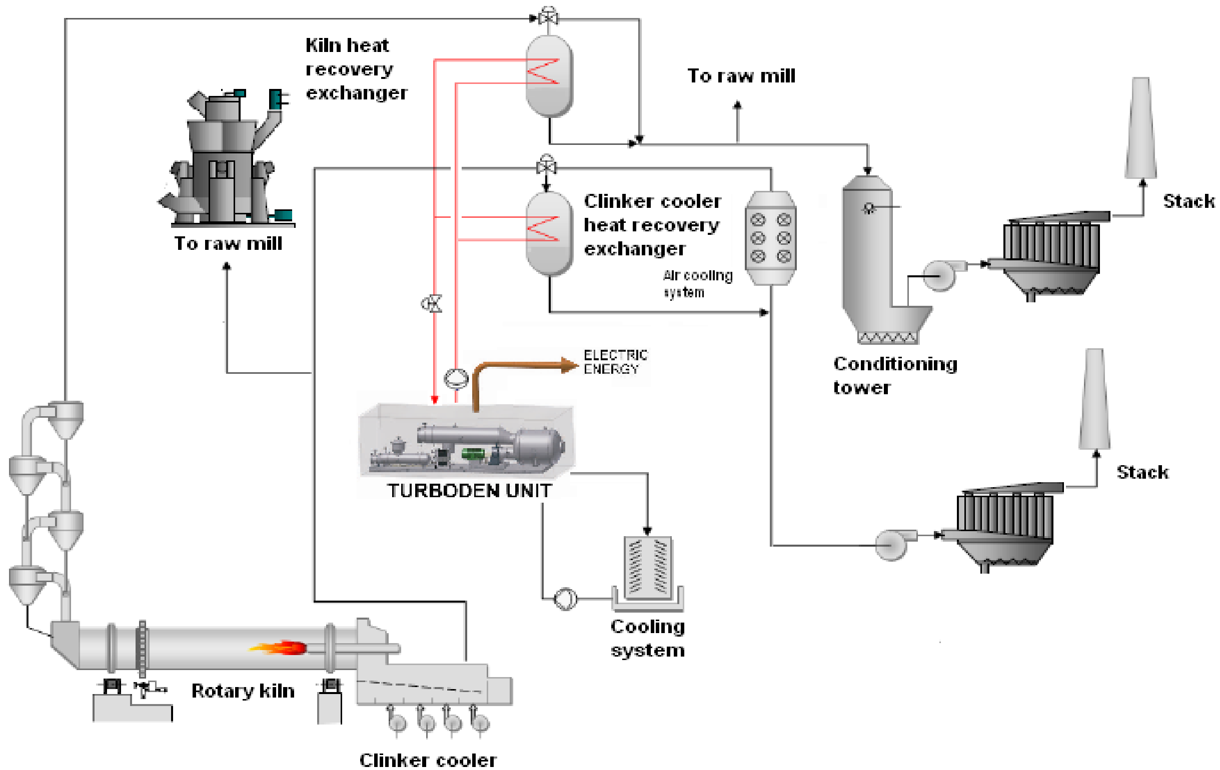
References – Internal Combustion Engines

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 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: Q3 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

WHTP with ORC in cement industry



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	Holcim Slovakia	PH + CC	5
Under construction	Heidelberg Cement – Cartpatcement Romania	PH + CC	4

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

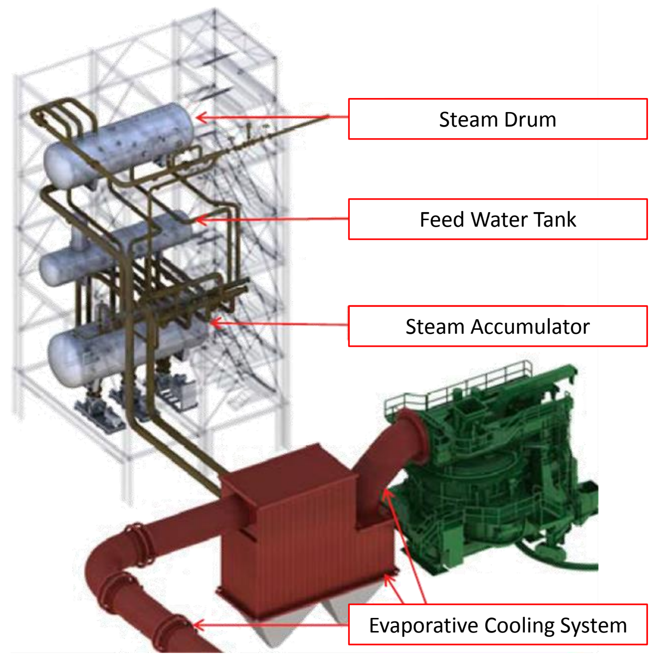
References – Steel industry

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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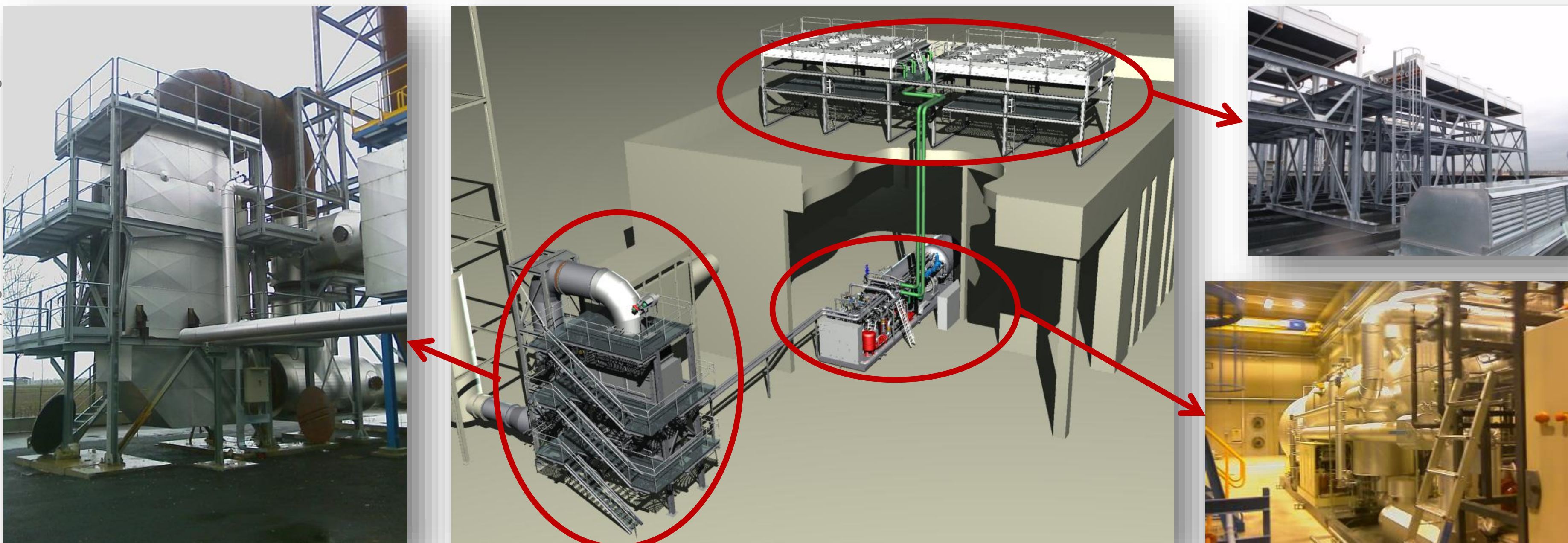
References – Direct Exchange

Project	Customer	Site	Heat Source	ORC power	Start up
Cereal Docks	food industry	Italy	7 MW diesel engine	700 kW	Q1 2012
Alma CIS/Fater	personal care industry	Italy	18V32 diesel engine	700 kW	Q2 2013
Natsteel/TATA group	steel industry	Singapore	hot rolling mill reheating furnace	700 kW	Q1 2013
Polympex	cogenerative	Russia	Solar TITAN 130 gas turbine	3,000 kW	Q4 2014



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References – Biomass

218 references in operation, 248 MW installed

West Fraser

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

Site 1: Chetwynd, British Columbia - Canada - 2 x Turboden ORC Units; expected start up Q2 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

6 references in operation, 19 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)

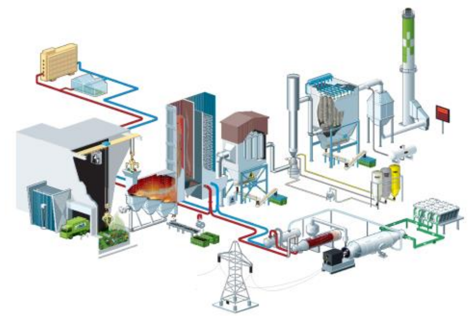
Cooling source: air coolers

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

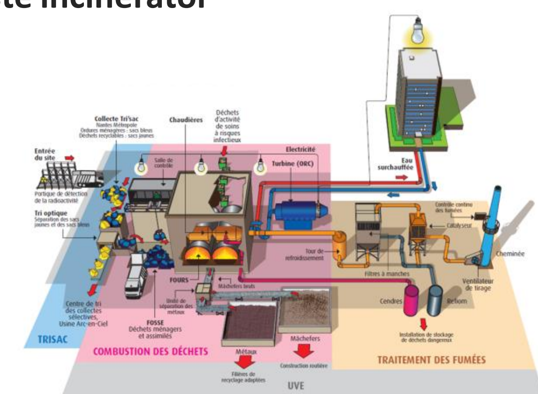
Source: hot water at 200° C (back at 130° C)

Cooling source: air coolers

ORC electric power: 2.4 MW

Electrical efficiency: 16.5%

Start up: Q3 2014



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**

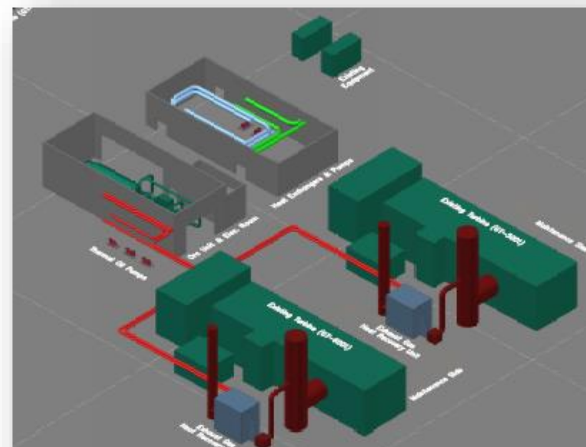
Net Power: **13.2 MWe**

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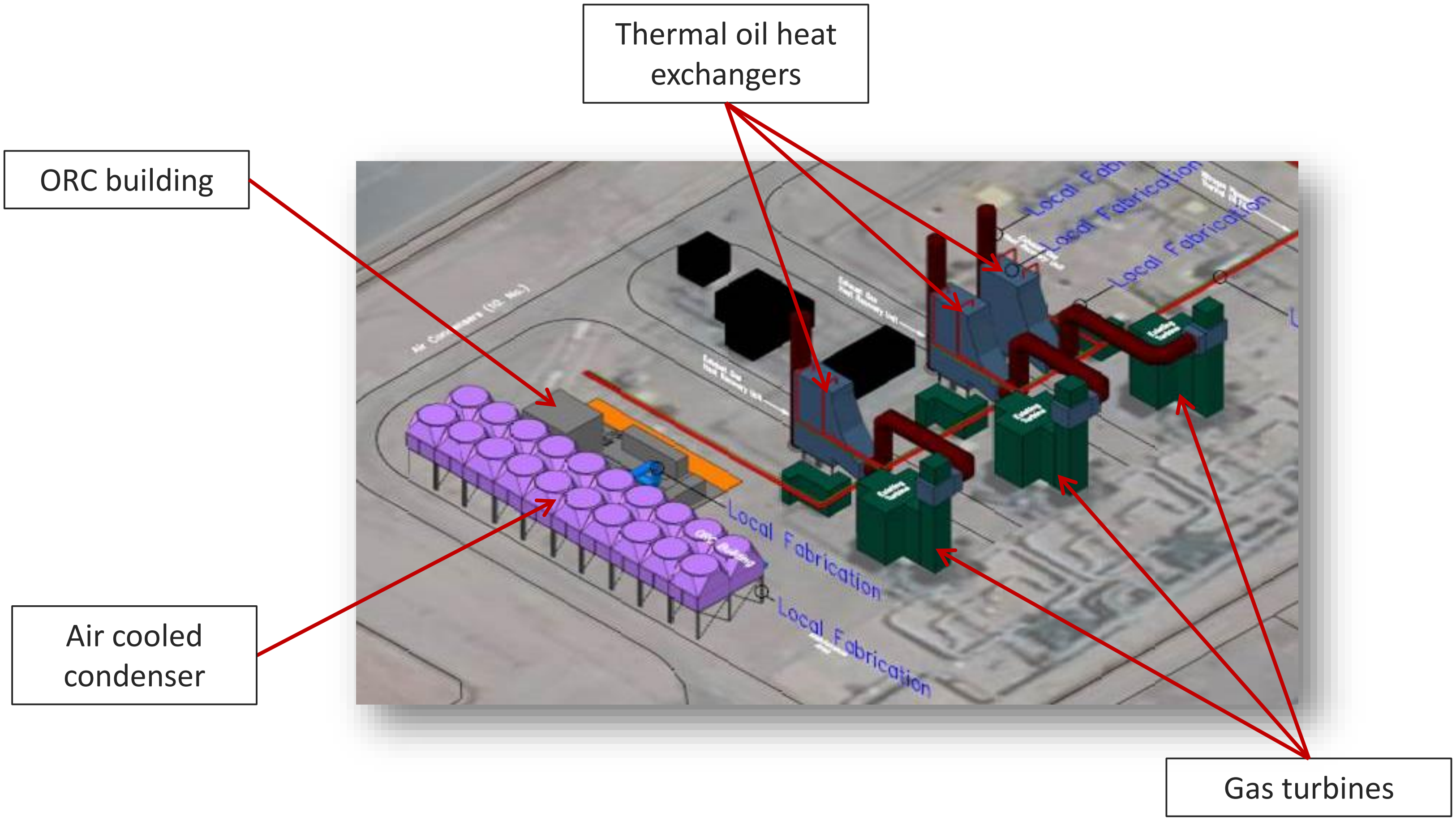
Case study – Heat recovery from GTs (2/2)



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

Turboden at a Glance

Turboden strong points

R&D

- 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

Sales/marketing

- Pre-feasibility studies: evaluation of technical & economical feasibility of ORC power plants
- Customized proposals to maximize economic & environmental targets

Design

- 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

Operations & manufacturing

- Outsourced components from highly qualified suppliers
- Quality assurance & project management
- In-house skid mounting to minimize site activities

Aftermarket service

- Start-up and commissioning
- Maintenance, technical assistance to operation and spare parts service
- Remote monitoring & optimization of plant operation

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Notes

Notes