INTERNATIONAL LOW-CARBON ENERGY TECHNOLOGY PLATFORM

ДЕРЖЕНЕРГОЕФЕКТИВНОСТІ УКРАЇНИ

State Agency on Energy Efficiency and Energy Saving of Ukraine

Turboden: ORC Solutions for Cogeneration and District Heating


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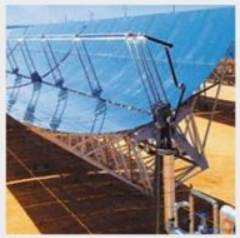


Alessandro Foresti – Senior Advisor

Workshop on Energy Efficiency in Buildings and Advanced District Heating

Kiev, 23 March 2015

LLOYD'S REGISTER · LRQA ISO 9001

More than 30 Years in ORC

'60-'70

- Prof. Mario Gaia makes experience in the field of ORC within his research group at *Politecnico di Milano*
- 1976 – First prototype of a solar thermodynamic ORC

1980-1999

- 1980 – Prof. Mario Gaia founds Turboden to design and manufacture ORC turbogenerators
- Turboden develops research projects in solar, geothermal and heat recovery applications
- 1998 – First ORC biomass plant in Switzerland (300 kW)

2000-2009

- Turboden installs ORC biomass plants, especially in Austria, Germany and Italy
- Turboden plans to enter new markets, with focus on North America
- First heat recovery applications

2009-2013

- **2009 – Turboden achieves 100 plants sold**
- United Technologies Corp. (UTC) acquires the majority of Turboden's quota. PW Power Systems supports Turboden in new markets beyond Europe
- UTC exits the power market forming strategic alliance with **Mitsubishi Heavy Industries**
- PW Power Systems becomes an MHI group company

2013…

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

2015…

More than **300 plants** in **32 countries** and **410 MW** installed

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Turboden ORC Plants in the World

Application	Size	Plants		Countries
	MW	In operation	Under construction	
Biomass	**0.2 - 8**	**218**	**39**	• **Germany (74)** • **Italy (68)** • **Austria (29)** • **Poland (11)** • **Other (75)**
Waste to Energy	**0.5 – 5.3**	**7**	**2**	• **France (2)** • **Italy (2)** • **Belgium (1)** • **Other (4)**
Heat Recovery	0.5 - 7.0	16	8	• Italy (10) • Germany (4) • Romania (2) • Other (8)
Geothermal	0.5 – 5.6	6	3	• Germany (4) • Austria (1) • Italy (1) • Other (3)
Solar Thermal Power	0.6 - 2		3	• Italy (3)
Total Turboden Plants	**0.2 - 8**	**247**	**55**	

Last update: March 2015

Turboden ORC applications and advantages

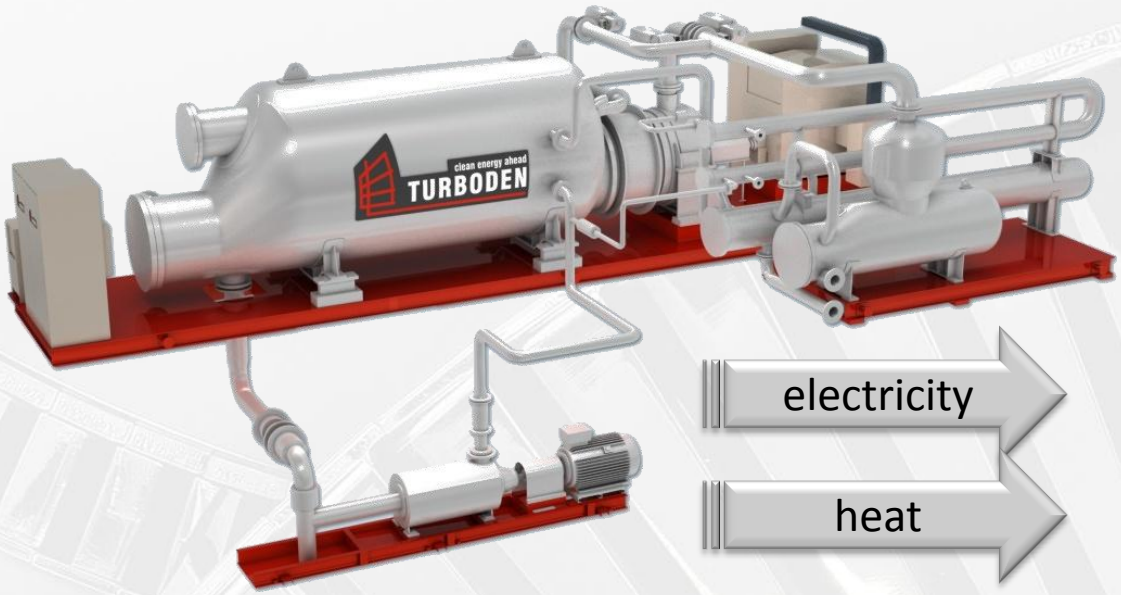
Biomass

Waste to energy

Heat recovery

Geothermal

Solar



ORC units: from 200 kW to 15 MW

Advantages

- ❑ Low temperatures
- ❑ Simple start up procedures
- ❑ High availability
- ❑ Partial load operation down to 10% of nominal power
- ❑ Low operation&maintenance requirements

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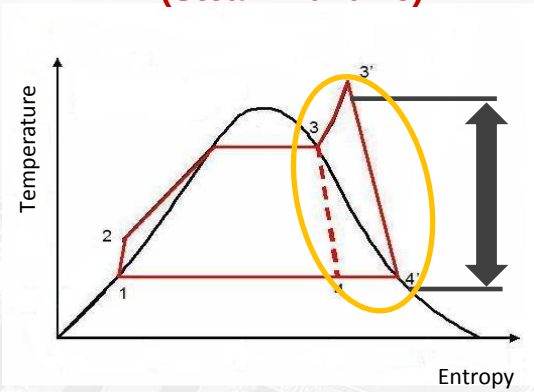
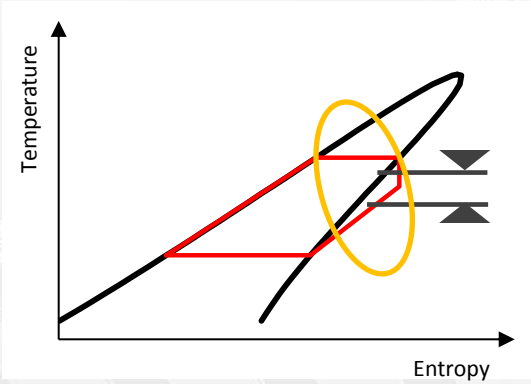
ORC significant advantages *versus* steam turbine

	Traditional Rankine Cycle (Steam Turbine)	Organic Rankine Cycle (ORC)
		
Thermodynamic features	• High enthalpy drop • Superheating needed • Risk of blade erosion	• Small enthalpy drop • No need to superheat • No risk of blade erosion
Operation and maintenance costs	• Water treatment required • Highly skilled personnel • High pressures and temperatures	• Non oxidizing working fluid • Minimum personnel • Completely automatic
Other features	• Convenient for plants > 10 MWe • Low flexibility • Lower performances at partial load	• High flexibility and good performances at partial load • Well proven in industrial heat recovery

ORC for cogeneration and district heating

HEAT SOURCE
biomass combustion,
waste incinerator..

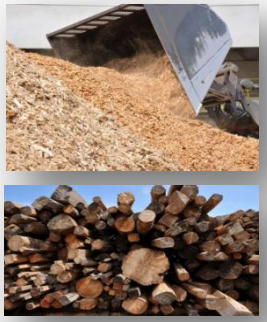
HEAT CARRIER
(thermail oil, hot water,
saturated steam)

ORC (Organic
Rankine Cycle)

ELECTRIC
POWER

hot
water

DISTRICT
HEATING



Biomass

Waste to
energy

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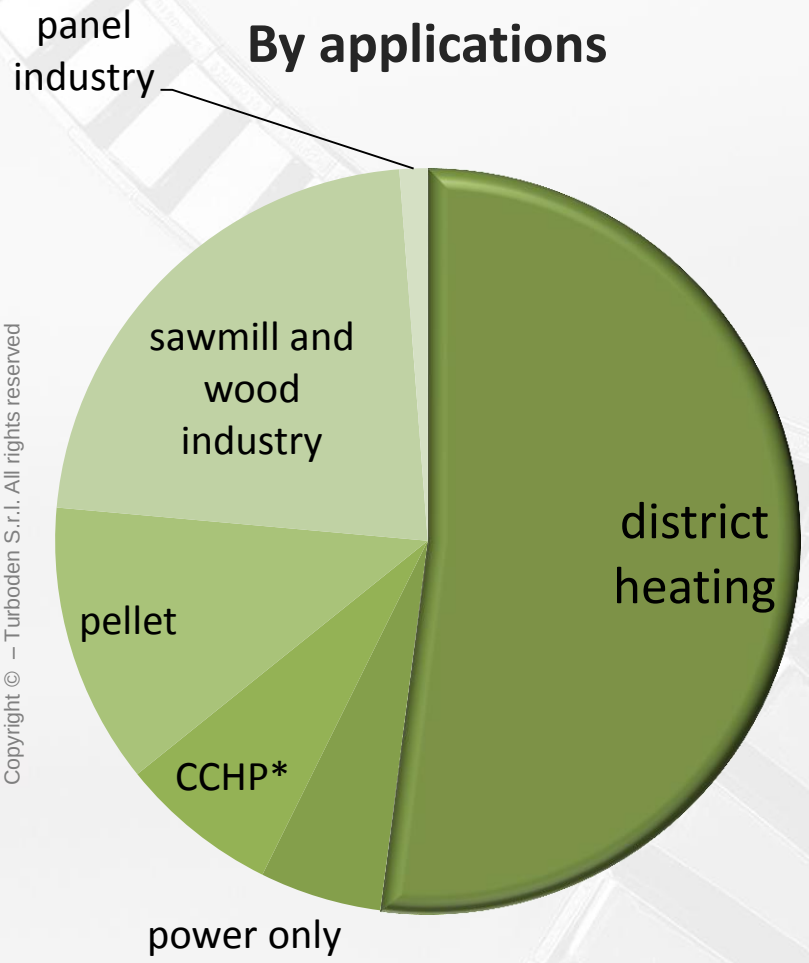
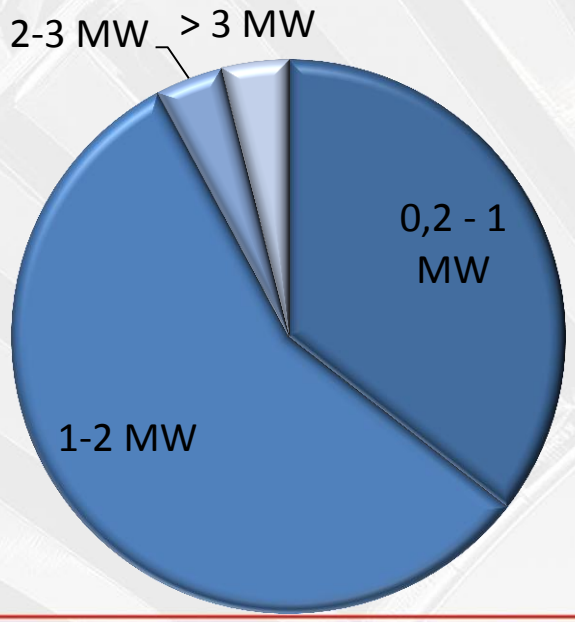
Turboden ORC in biomass (cogeneration, trigeneration, buildings)

By applications



BIOMASS REFERENCES	
Cogeneration (*Combined Heat and Power - CHP*)	227
CCHP in buildings	5
Other	25
TOTAL	257

By sizes



* Combined Cooling Heating Power

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Example of District Heating application

Ludwigsburg (Germany)

Model: T2000

Started up: November 2009

Fuel: Wood chips & Green cuttings

Electric power generated: **2.100 kWe**

Thermal power application: **district heating**

Thermal power generated: **9,85 MWth**

Water temperature: 60 - 90° C

Context / Special Feature

Power to district heating: 12,6 MWth

Yearly **CO_2 savings: 18.000 tons**

Km of district heating: about **20 km**

Customers served: about 200

Biomass storage for 2.000 m3

Employees: 2, working mainly for wood logistics

Example of District Heating application

Ostrow Wielkopolski (Poland)

Model: T1500

Started up: September 2007

Fuel: Wood chips

Electric power generated: **1.750 kWe**

Thermal power application: **district heating**

Thermal power generated: **8,2 MWth**

Water temperature: 60 - 85° C

Context / Special Feature

Total heat capacity production: about 100 MWth

- 4 coal fired boilers (12 MWth each)
- 2 nat gas boilers (15 MWth each, peak load)
- 1 gas turbine (5,2 Mwel + 11,6 Mwel)
- **1 new thermal oil heater for ORC: 10 MWth**

Shut-off of fifth coal fired boiler

Km of district heating: about **50 km**

Example of district heating application

Varna, Bozen (Italy)

Model: T800

Started up: December 2008

Electric power generated: **800 kW**

Thermal use: **district heating**

Water temperature: 60 - 90 C

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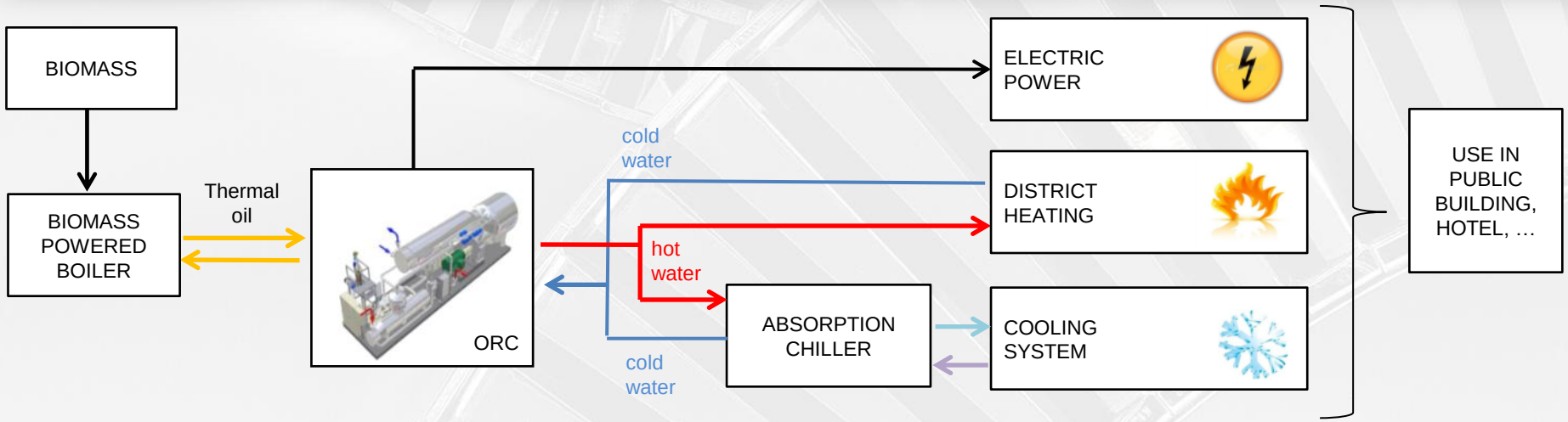
Trigeneration - Combined Cooling Heating Power (CCHP) in buildings



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Example of CCHP in buildings - Offices and TV Studios

West London (UK)

Model: Turboden 10 CHP Split

Client: Clearpower Limited

End user: **B SKY B**

Started up: November 2011

Fuel: waste clean wood

Electric power generated: **964 kW**

Thermal power application: **space heating/cooling**

Thermal power generated: **4142 kW**

Water temperature: 75-90 °C

Context / Special Feature

Television studios Sky headquarter in Europe

Space Area: 800 m2, 3200m3

Thermal power: 5% heat the building, 50% to chiller, 45% as heating to a district heating loop around the campus

Reduction of the building's carbon footprint: 20%

Thermal oil boiler capacity: 5140 kW

Cogeneration through ORC

Cooling power produced by chiller

Example of CCHP in buildings – Airport

Heathrow, London

Model: Turboden 18 CHP Split

Client: Morgan Sindall plc/Heathrow Airport

Started up: May 2014

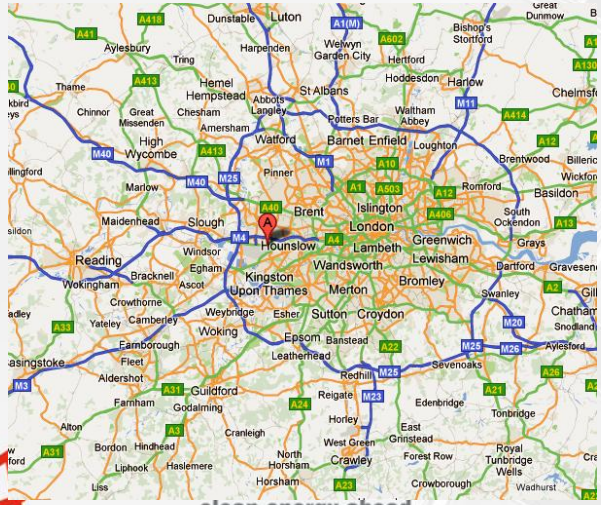
Fuel: waste clean wood

Electric power generated: **1862 kW**

Thermal power application: **space heating/cooling**

Thermal power generated: **7851 kW**

Water temperature:55-95 °C



Context / Special Feature

London main airport

Space Area: 20 000 m2, 100 000 m3

Thermal power: 75% heat and 25% to chiller

Thermal usage: heat and cooling to Terminals T2a and T2b heat only to Terminal T5

Reduction of the building's carbon footprint: 40%

Thermal oil boiler capacity: 9790 kW

Cogeneration through ORC

Cooling power produced by chiller

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Example of CCHP in buildings – Hotel and resort

Arlamow (Poland)

Model: Turboden 14 CHP Split

Client: Arlamow Hotel

Started up: February 2012

Fuel: virgin wood chips

Electric power generated: **1236 kW**

Thermal power application: **building heating/cooling**

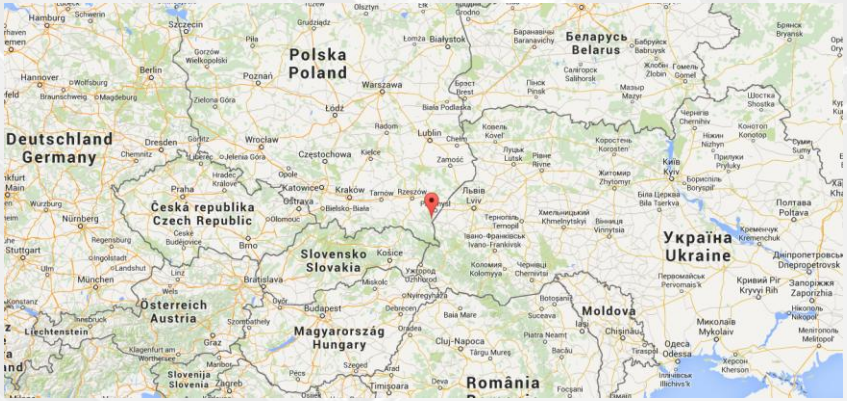
Thermal power generated: **5438 kWth**

Water temperature:80-95 °C

Context / Special Feature

Cooling devices: absorption chillers

Heating as hot water for hotel: 2,7 MWth



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Examples of Waste to Energy applications

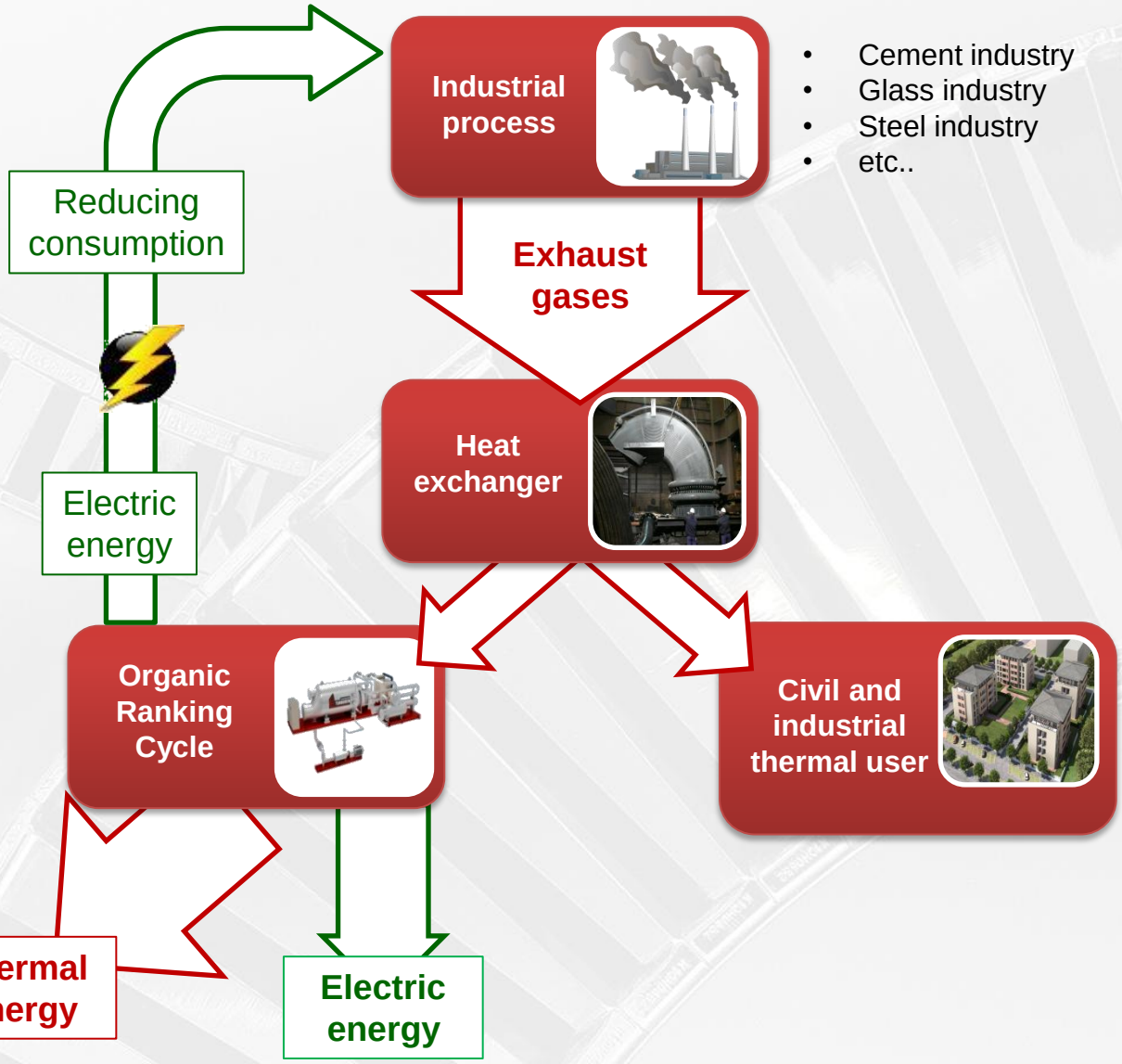
Mirom - Belgium

Heat recovery from **pressurized water** boiler in **waste incinerator**
Retrofit of **existing municipal solid waste incinerator** with **district heating** system
Site: Roeselare, Belgium
Started up: In operation since April 2008
Source: hot water at 180°C (back at 140°C)
Cooling source: air coolers
ORC electric power: **3 MW**
Net electrical efficiency: 16.5%
Availability: >98%

Waste Gasifier – ITC Turkey

Heat recovery from **exhaust gas** from the **waste gasifier**
Site: Ankara (Turkey)
Start up: First unit in operation since February 2014, second unit under construction
Heat carrier: thermal oil
ORC electric power: 2 ORC units of 5.5 MW each
ORC efficiency: up to 25% (power only)

ORC in heat recovery from industrial processes



- Cement industry
- Glass industry
- Steel industry
- etc..

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Reference papers & articles

Papers on biomass

- Duvia A., Guercio A., Rossi C., *«Technical and economic aspects of Biomass fuelled CHP plants based on ORC turbogenerators feeding existing district heating networks»*, 2009 http://www.turboden.eu/it/public/downloads/09A06400_paper_orc_turboden_clotilde.pdf
- Biedermann F, Carlsen H., Obernberger I., *«State-of-the-arte and future developments regarding small-scale biomass CHP systems with focus on ORC and stirling engine technologies»*, BIOS Bioenergiesysteme GmbH , Austria, and Technical University of Denemark, 2003 http://bios-bioenergy.at/uploads/media/Paper-Obernberger-SmallScaleCHP-NordicConference-2003-10-27.pdf
- Obernberger I., Reisenhofer E., Thonhofer P., *«Description and evaluation of the new 1,000 kWel Organic Rankine Cycle process integrated in the biomass CHP plant in Lienz, Austria»*, BIOS Bioenergiesysteme GmbH, Austria, 2002 http://www.turboden.eu/de/public/downloads/report_on_lienz_plant.pdf

Articles on BSkyB and Heathrow plants

- http://breakingenergy.com/2012/09/19/british-companies-go-onsite-with-renewable-energy-projects/
- http://www.clearpower.ie/case-studies/bioenergy-solutions/case-study-2
- http://www.environmentalleader.com/2012/01/17/bskyb-studio-to-get-40-of-energy-from-biomass-chp/
- http://www.theengineer.co.uk/channels/policy-and-business/business-briefs/bskyb-and-heathrow-select-turboden-for-cchp-plants/1012490.article
- http://professionalservices.morgansindall.com/projects/energy-infrastructure-project-uk/

Thank you for your attention!


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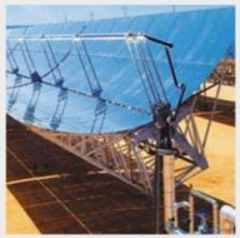


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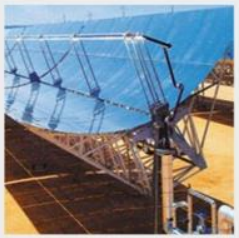


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Back up slides

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About Us

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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Over 30 Years of Experience

1984 – 40 kW_{el} ORC turbo-generator for a solar plant in Australia

1987 – 3 kW_{el} ORC turbo-generator for a biomass plant in Italy

1988 – 200 kW_{el} ORC geothermal plant in Zambia

2008 – 3 MW_{el} ORC turbo-generator for heat recovery on a waste incinerator in Belgium

2009 – First 100 plants and first installed 100 MW_{el}

2010 – First plant overseas

2014 – Over 280 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 $12 billion (in fiscal 2013)

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.

Mitsubishi Heavy Industries is one of the world's leading heavy machinery manufacturers, with consolidated sales of over $32 billion (in fiscal 2013).

Foundation July 7, 1884

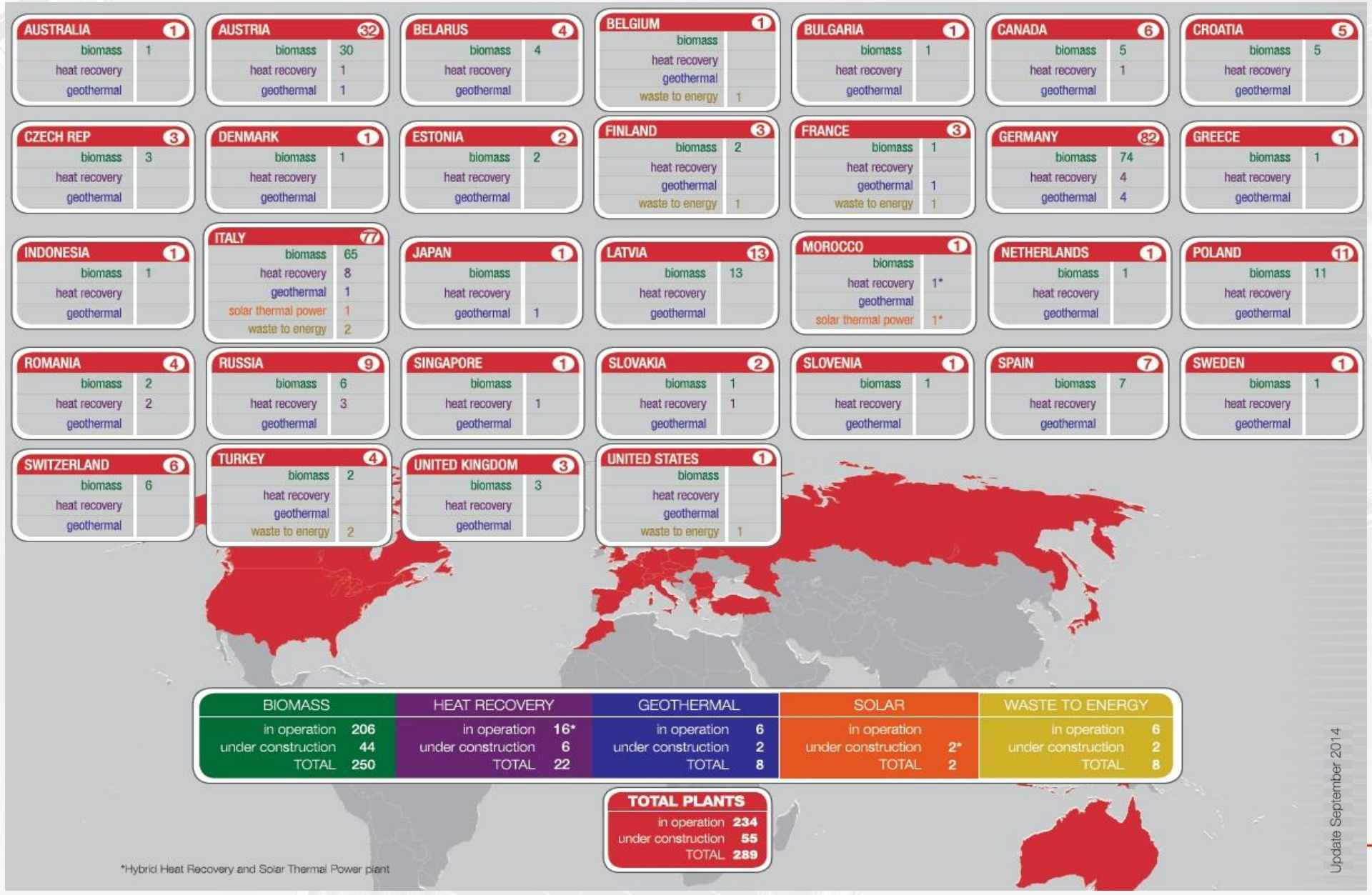
Commercial Aviation & Transport Systems

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

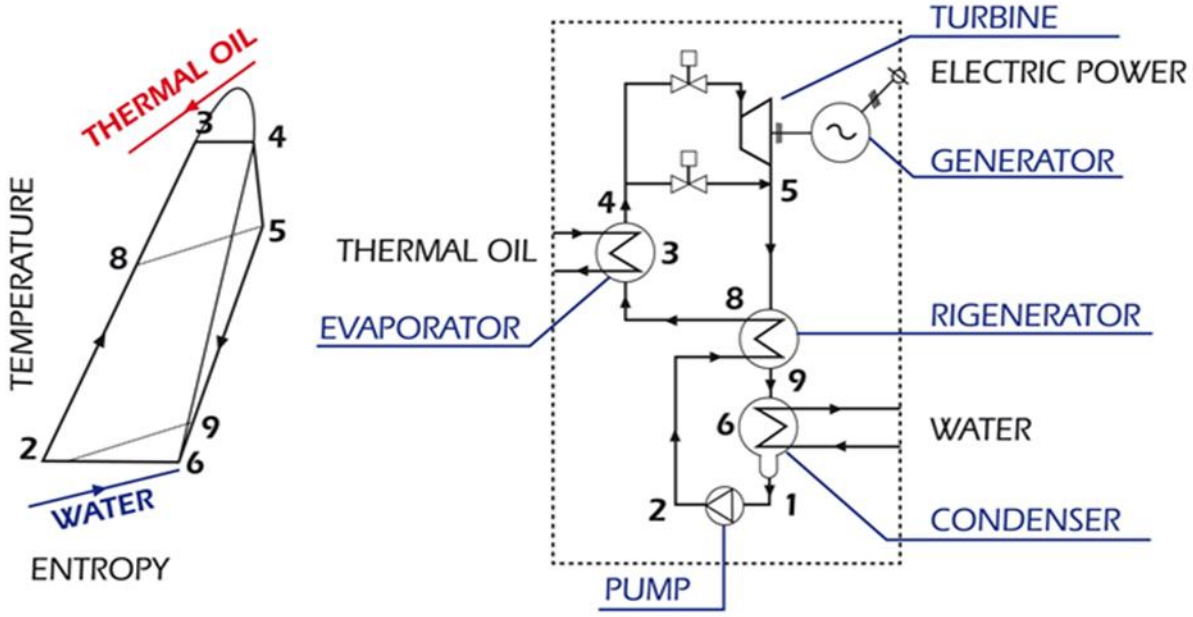
Integrated Defense & Space Systems

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

Turboden ORC Plants in the World

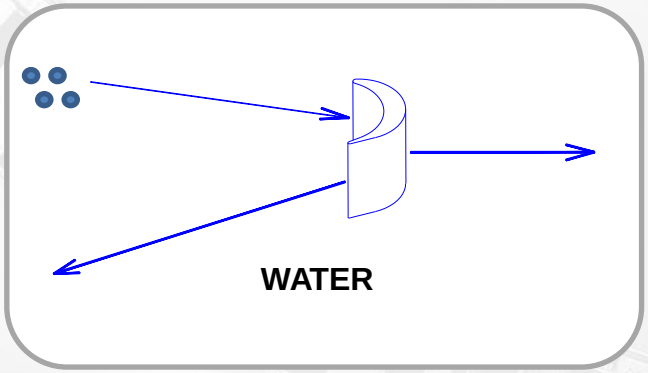


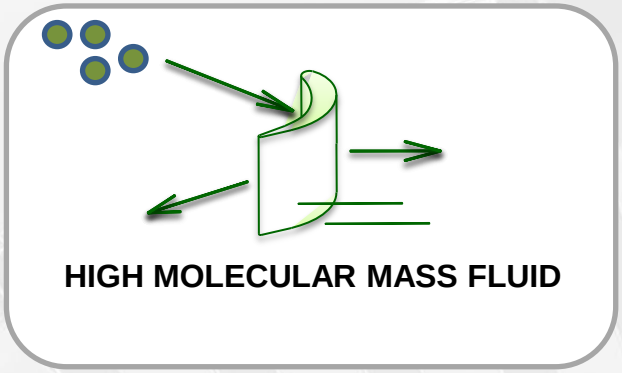
The Thermodynamic Principle: The ORC Cycle



The turbogenerator uses the 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) (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.

Why High Molecular Mass Working Fluid Instead of Water?





Water

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

Organic Fluid

- Very large flow rate
- Larger diameter turbine
- No wear of blades and metal parts

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

ORC Applications – Biomass

Biomass

Heat Recovery

Waste to energy

Geothermal

Solar Thermal Power

Biomass

Cogeneration plants with Turboden ORC can produce heat and electrical power from biomass with high efficiency and user friendly operation. The generated power usually ranges between 200 kW and 15 MW electric.

Biomass - sources and applications

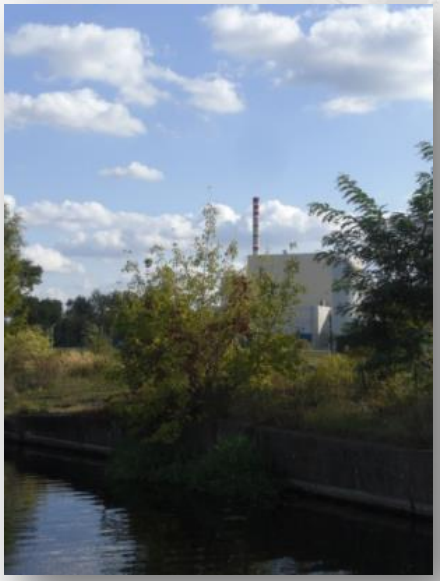
Fuels

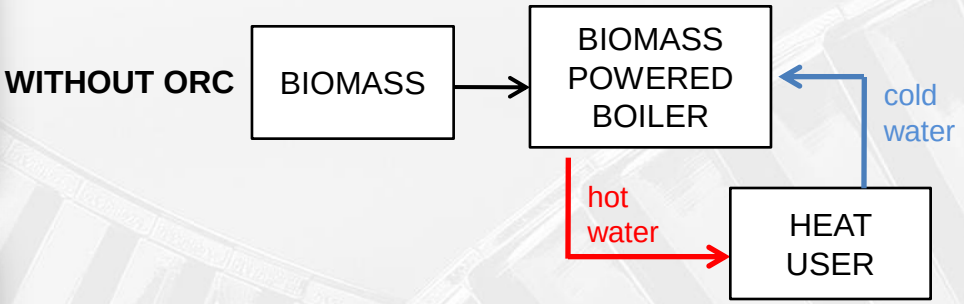
- Wood biomass: sawdust, woodchips, bark, treated wood
- Other biomass: dried sewage sludge, green cuttings, rice husk, vinasse and vine cuttings, wood industry waste material etc …
- Waste material, byproducts

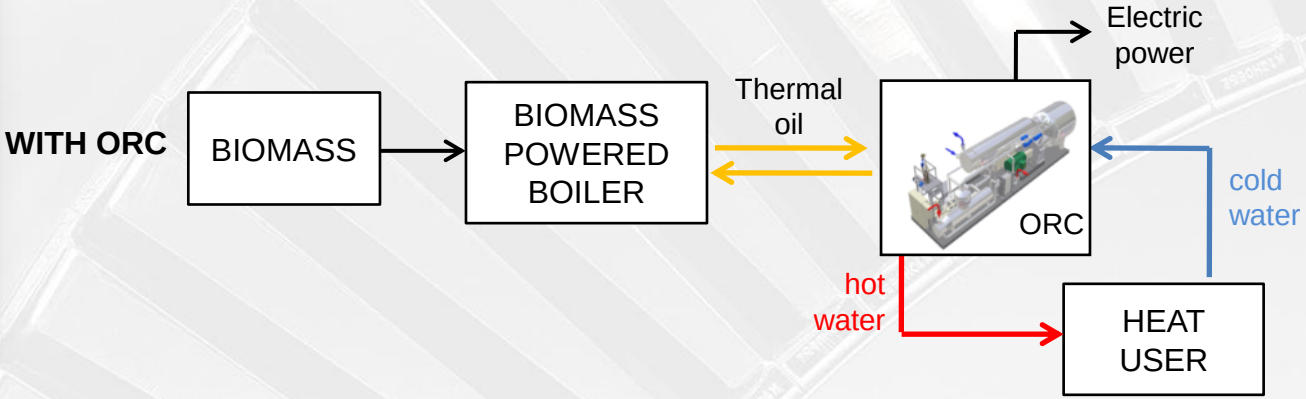
Heat Consumers

- District Heating networks
- Timber drying in sawmills
- Sawdust drying in wood pellet factories
- MDF/PB Producers
- Refrigeration
- Greenhouses
- Wine industry

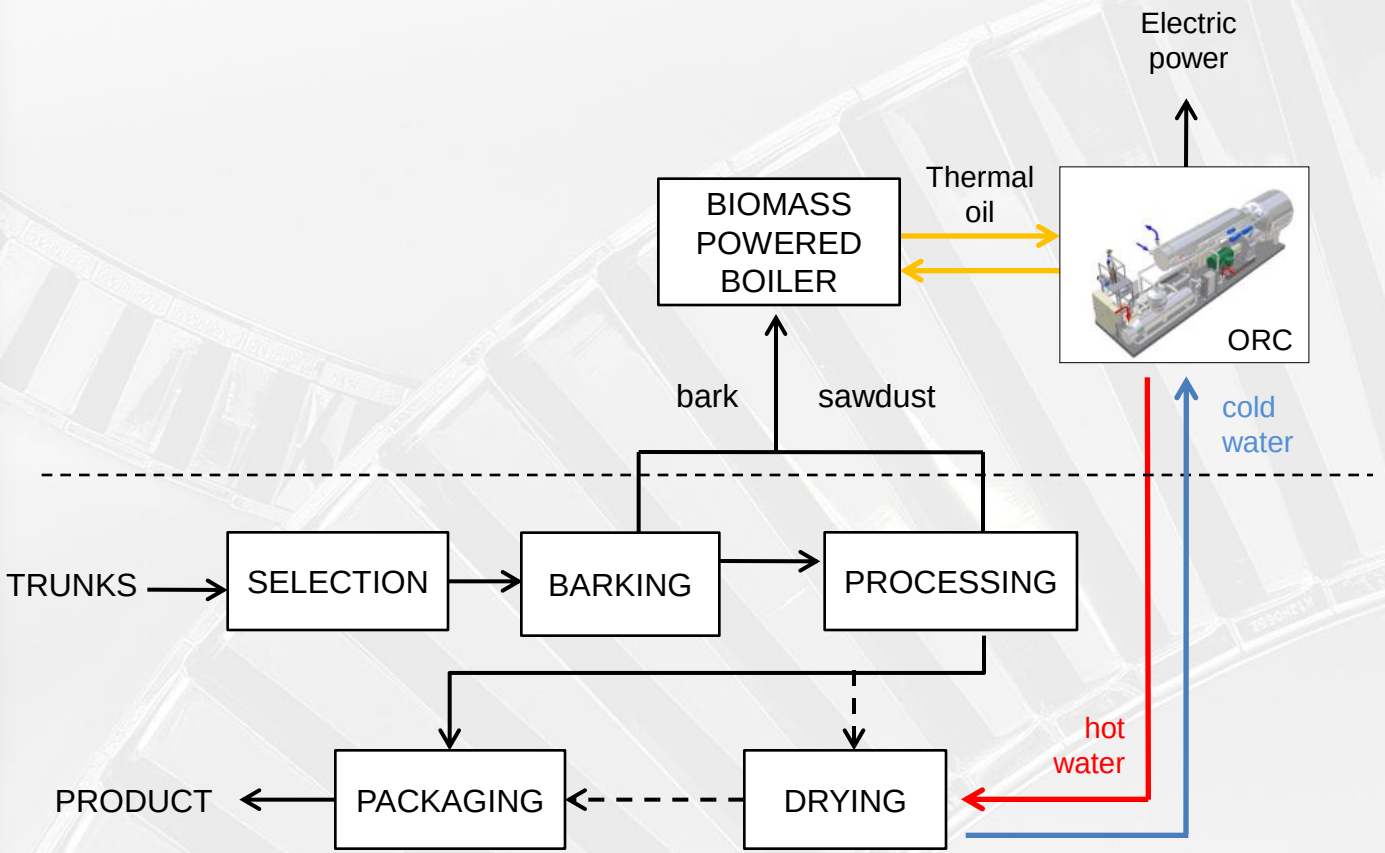
District Heating Networks



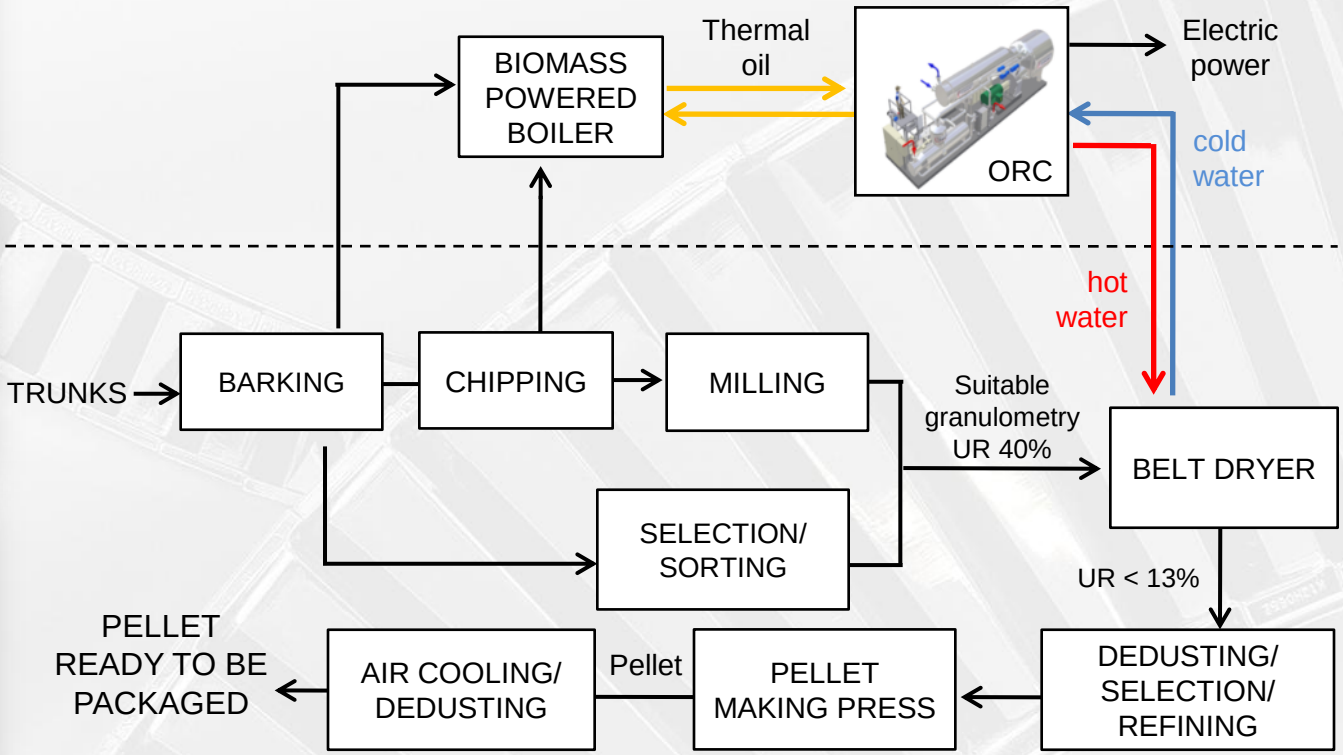




Sawmills



Wood Pellet Production



MDF Production

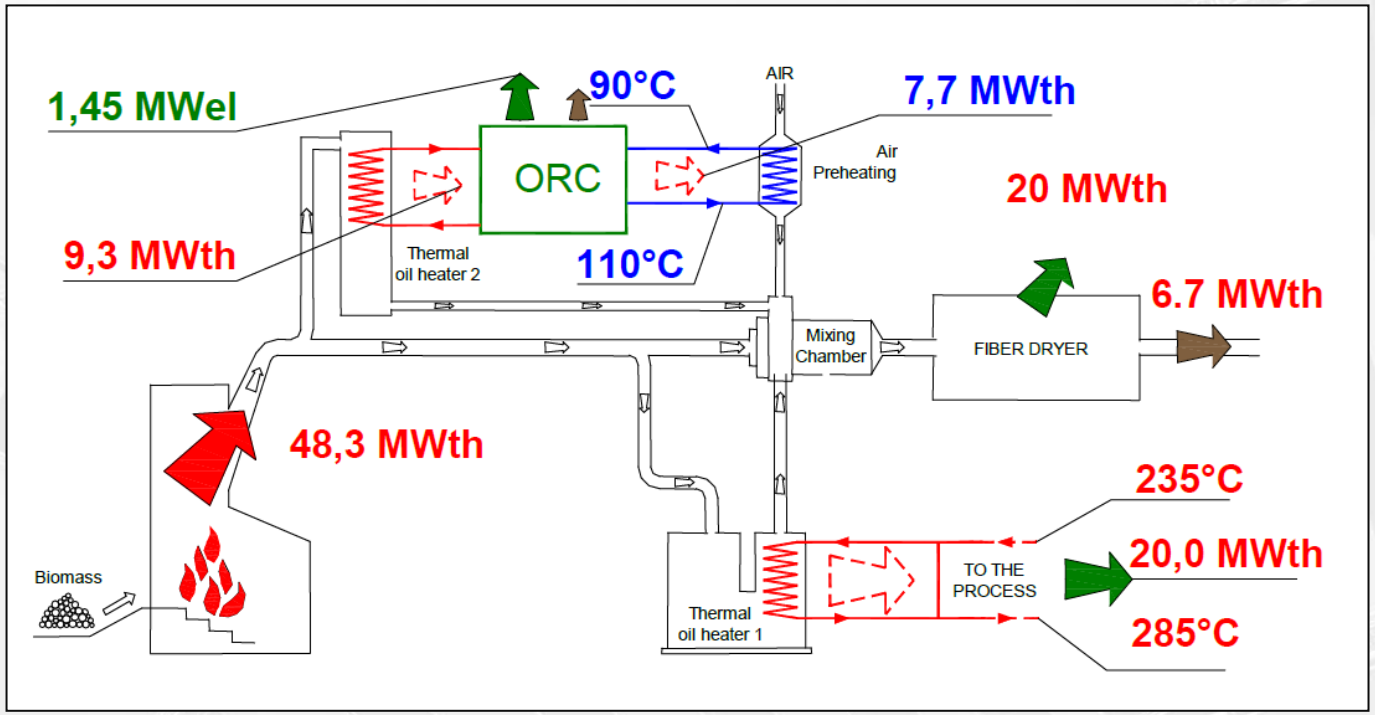
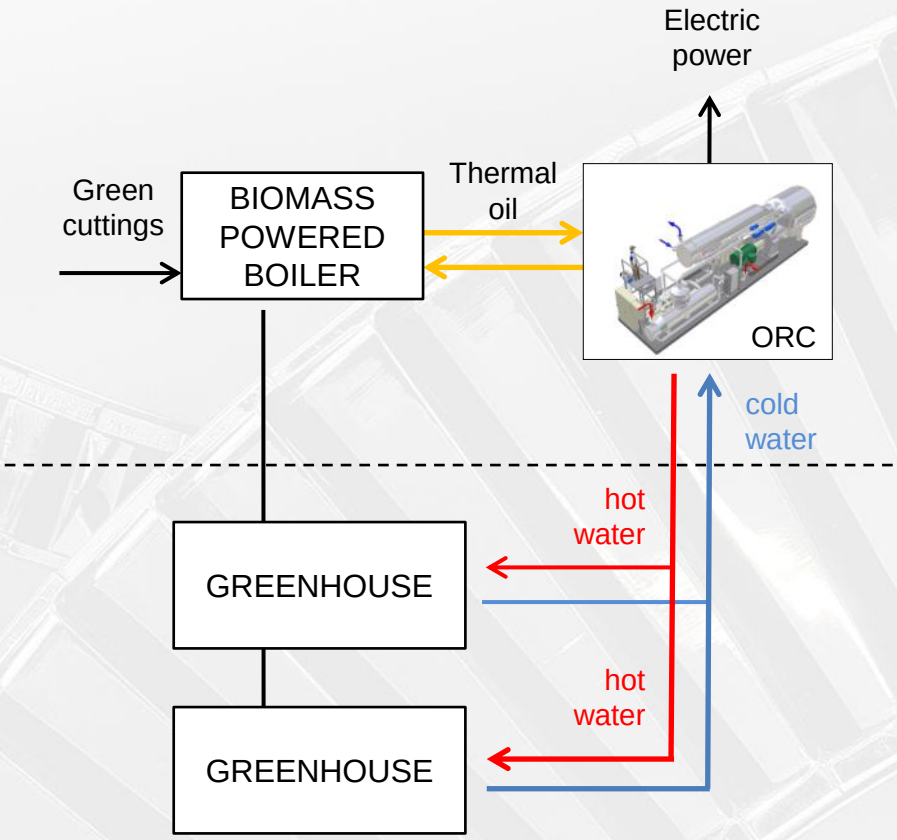


Figure: Proposed scheme for MDF plant with ORC cogeneration unit

Greenhouses



Reference projects - biomass for district heating

Biogenera SrL

Site: Calenzano, Florence (Italy)

Start-up: October 2009

Electric power generated : 800 kW

Thermal use: district heating

Water temperature: 70 - 90 C

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Example of District Heating applications

Zatec (Czech Republic)

Model: T1500 CHP Split

Started up: August 2010

Fuel: Wood chips

Electric power generated: 1.862 kWel gross

Context / Special Feature

Thermal power application: municipal district heating of Žatec

Thermal power generated: 7.851 kWth

Water temperature: 60 - 90° C

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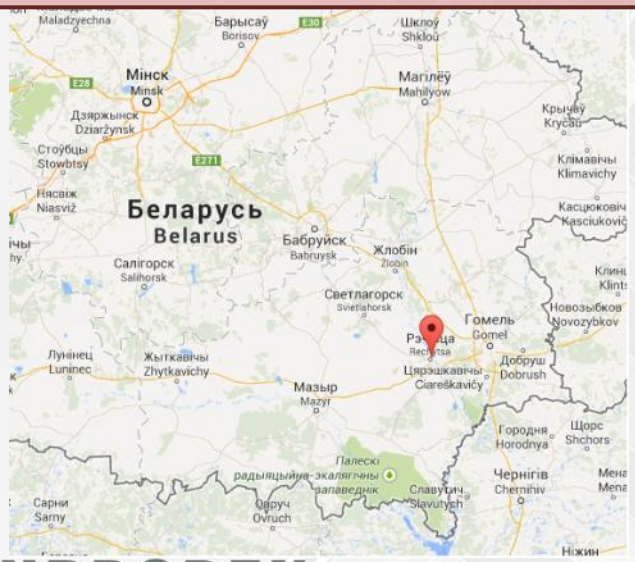
Example of cogenerative application

Rechytsa in Belarus – GG & GT

Model: 2 x TD 22
End user: GOMELENERGO
Start-up: June 2011
Localisation: Rechytsa – Belarus
Fuel: peat briquettes, wood chips
Electric power generated: 2 x 2200kWe
Thermal power application: district heating
Thermal power generated: 19 MWth
Water temperature: 60 - 90°C
Boiler supplier: Polytechnik



Context / Special Features

- **Biomass-fueled thermal oil boiler:**
  - 2 x 12 MW thermal oil output power
- **2 x Turboden 2,2 MWe units:**
  - el. capacity 4,4 MWe
- **Heat users:**
  - District heating

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Reference projects Canada and USA

Nechako Green Energy (a subsidiary of Nechako Lumber)

Site: Sawmill in Vanderhoof, BC, Canada
ORC Unit: Turboden 22 CHP
Started up: February 2013
Electric power generated: 2 MW
Thermal power application: hot water temperature (60-90 °C) for future belt dryer connection

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West Fraser Timber

2 Sites: Chetwynd and Fraser Lake, BC, Canada
ORC Unit: 4 x units Turboden 65 HRS (high efficiency - up to 26 %)
Electric power generated: 13 MW each site (total of 26 MW)
Status: Fraser Lake site in operation since November 2014, Chetwynd site under construction

Client: Manning Diversified Forest Products Ltd

Site: Manning, Alberta, Canada
ORC Unit: Turboden 32 HRS (high efficiency - up to 26 %)
Electric power generated: 3 MW
Started up: February 2015

Client: Athens Energy LLC

Site: Athens – Maine, USA
ORC Unit: Turboden 80 HRS
Electric power generated: 8 MW
Status: Under Construction

ORC Applications – Heat Recovery

Biomass

Heat Recovery

Waste to energy

Geothermal

Solar Thermal Power

Heat Recovery

Turboden ORC can produce electricity by recovering heat from industrial processes, reciprocating engines and gas turbines. The power of Turboden turbogenerators in this application generally ranges between 200 kW and 15 MW electric.

Reference projects – heat recovery from industrial processes

Cement industry

Holcim Romania

Heat source: exhaust gas @ 360°C (PH) and hot air @ 250 °C (CC)
ORC electric power: **~ 4 MWe**
Started up: July 2012 (4,200 working hours)
Availability: >98%

Glass industry

AGC Glass Europe

Heat source: gas @ 500°C from glass production process
Heat carrier: thermal oil
Cooling: water condenser + air-coolers
ORC electric power: 1.3 MWel
Started up: March 2012

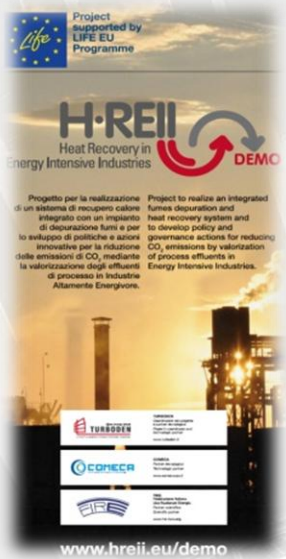
Steel industry

NatSteel – TATA Group - Singapore

Heat source: exhaust gas from LFO combustion, @ 400 from Billet reheating furnace at steel rolling mill
Direct exchange between exhaust gas and working fluid
ORC electric power: 0.7 MWel
Started up: February 2013

WHAVES project (2013 – 2015)

Waste Heat Valorisation for more Sustainable Energy Intensive IndustrieS



«successor» of the projects
H-REII (2010-2012)
H-REII DEMO (2012-2014)

Objectives

- **Standardize** heat recovery systems from steel production process with ORC technology
- **Disseminate results to other industrial sectors**
- **Promote innovative funding models** of heat recovery from industrial processes

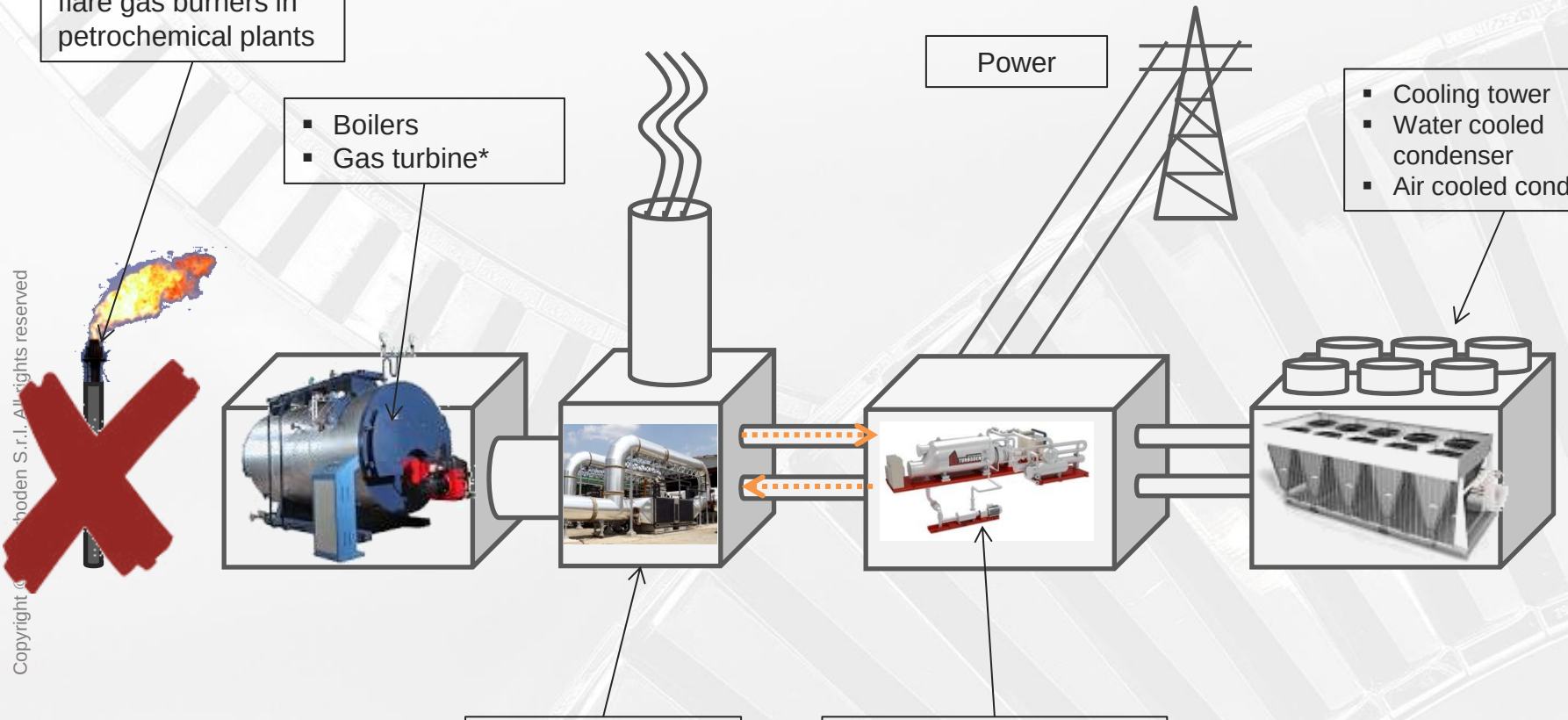
Heat recovery – Oil & Gas application

Exhaust gases of flare gas burners in petrochemical plants

- Boilers
- Gas turbine*

Power

- Cooling tower
- Water cooled condenser
- Air cooled condenser



Heat exchanger
Thermal oil

Organic Rankine Cycle
25% efficiency

* Low heating value gas turbine

Turboden references

- **Russian Oil & Gas company**
  Flare Gas: 3.5 MWe
  ORC Power : **1.8 MWe**
  burner + thermal oil circuit
  Start up: Q3 2014

Heat recovery from Gas Turbines

Gas Compressor Station – Trans Gas

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 MWe
General contractor: IST
Final client: TransGas
Started up: 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 MWe direct exchange cogenerative solution
ORC thermal power 15 MWth for hot water at 90°C
General Contractor**:** Energo development LCC
Final Client: Polympex
Expected start up: Q4 2014

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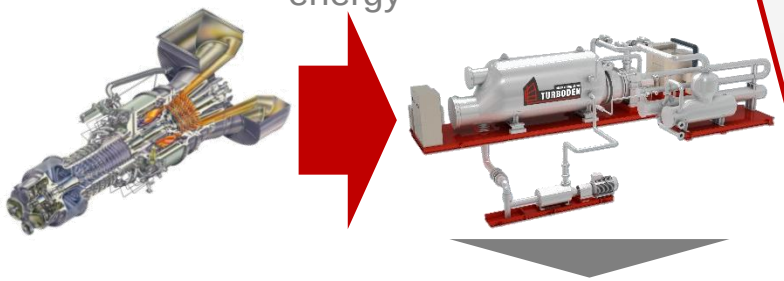
Example: heat recovery on open cycle gas turbines exhaust gases

Exhaust gases energy



- Gas compressor stations
- Gas storage facilities
- Oil pumping stations
- Sea water injection systems
- Power generation
- …

20-35% additional power output*

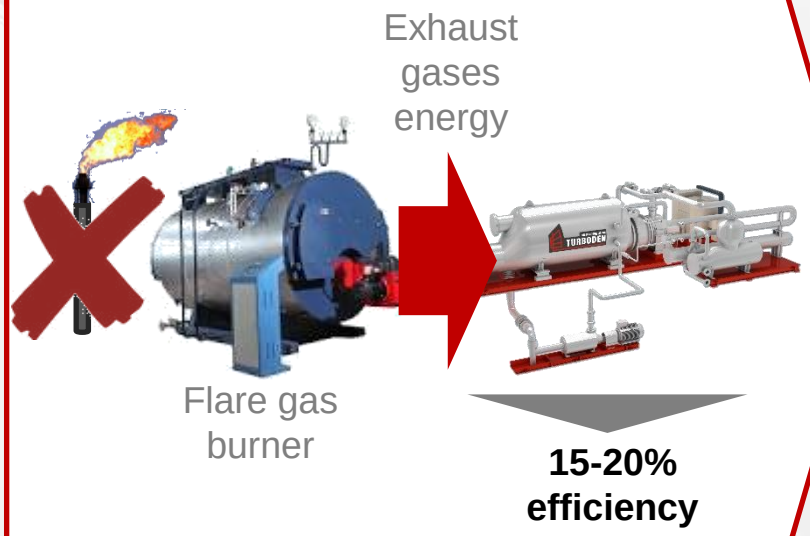
Example: waste heat recovery projects in Saudi Arabia

Facility	Saved energy ktoe/year	Saved CO_2 ktons/year
• Gas pipeline	80	430
• Oil pipeline	45	240
• Oil extraction - sea water injection facilities	85	450
	210	**1'120**

* Referred to the gas turbine shaft power output

SOURCE: internal estimates, websites, press clippings

Example: exploitation of associated gas (currently flared)



Example: flare gas exploitation in Nigeria (2009)

	Saved energy ktoe/year	**Saved CO_2** ktons/year
• Nigeria overall	1'530	8'170
• **Shell**'s **footprint** in Nigeria	**215**	**1'150**

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SOURCE: internal analysis on GE Flare Gas reduction Recent global trends and policy considerations

A huge potential resides in waste heat recovery on Oil & Gas infrastructures

Reference case:

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%**

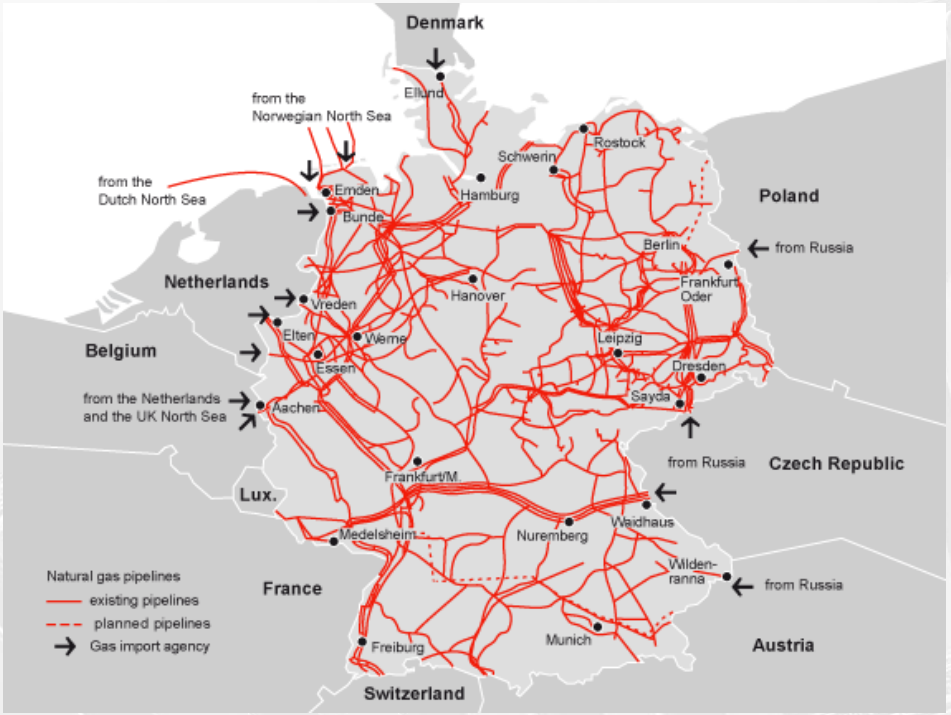
ORC potential: **135 MWe**

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)



(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)

ORC Applications - Geothermal

Biomass

Heat Recovery

Waste to energy

Geothermal

Solar Thermal Power

Geothermal

ORC technology is particularly suitable for the exploitation of medium to low enthalpy sources. Cost-effective solution with power output up to 15 MW_{el} and water temperature above 100°C*.

* 212 °F

New generation of geothermal Turboden plants

Turboden geothermal plants offer the following **key features**:

Since the very beginning…

- ❑ Maximum electrical efficiency (evaluation of all the possible termodynamic cycles)
- ❑ Flexibility in fluid choice (matching the customer's needs)
- ❑ High reliability and availability guarantee

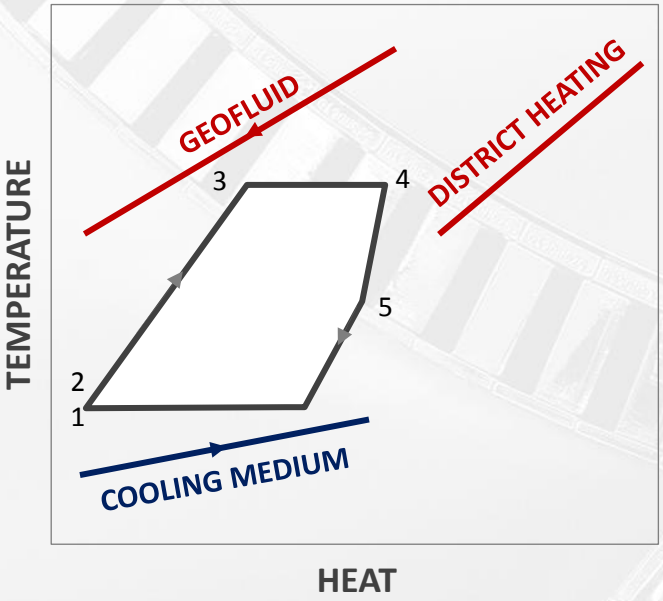
…to the new generation

- ❑ Flexibility in district heating coupling
- ❑ Grid supporting by power regulation
- ❑ Stability during the low voltage ride through
- ❑ Island mode capability

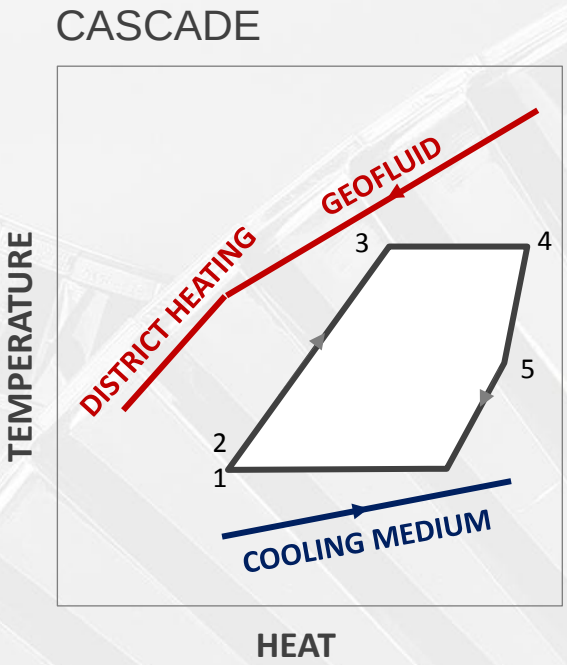
Geothermal CHP: Different Possible Schemes

Turboden standard ORC combined to district heating networks: more than 100 customers among Municipal Companies, Multi-utilities, private investors.

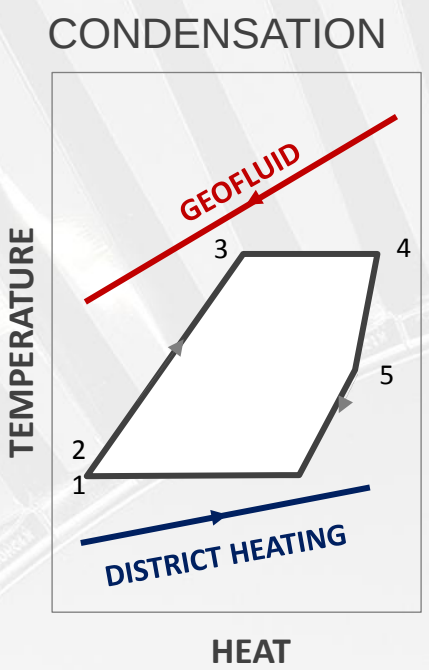
PARALLEL



CASCADE



CONDENSATION



- In Parallel (Altheim, Simbach-Braunau)
- In Series (cascade uses, New Mexico)
- From the Condensation Heat (classic cogeneration concept)

Reference Plant - Sauerlach

Plant type: Two-level cycle geothermal unit

Customer: SWM - StadtWerke München (public utilities company)

Location: Bavaria, Germany

Start-up: February 2013

Accepted: November 2013

Heat source: geothermal fluid at 140 C

Cooling device: air condensers

Total electric power: 5+ MW_{el} plus 4 MW_{th} decoupling for district heating

Working fluid: refrigerant 245fa (non flammable)

Off grid mode capable

Reference Plant - Dürrnhaar

Customer Name: Hochtief Energy Management GmbH

Location: Dürrnhaar (München), Germany

Start-up: December 2012

Accepted: December 2013

Heat source: geothermal fluid at 138 C

Total electric power: 5.6 MW

Scope of supply: EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant

Reference Plant - Kirchstockach

Customer: Hochtief Energy Management GmbH

Location: Kirchstockach (München), Germany

Start-up: March 2013

Accepted: November 2013

Heat source: geothermal fluid at 138 C

Total electric power: 5.6 MW

Scope of supply: EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant

Reference Plant - Traunreut

Customer: Geothermische Kraftwerksgesellschaft Traunreut GmbH

Location: Bavaria, Germany

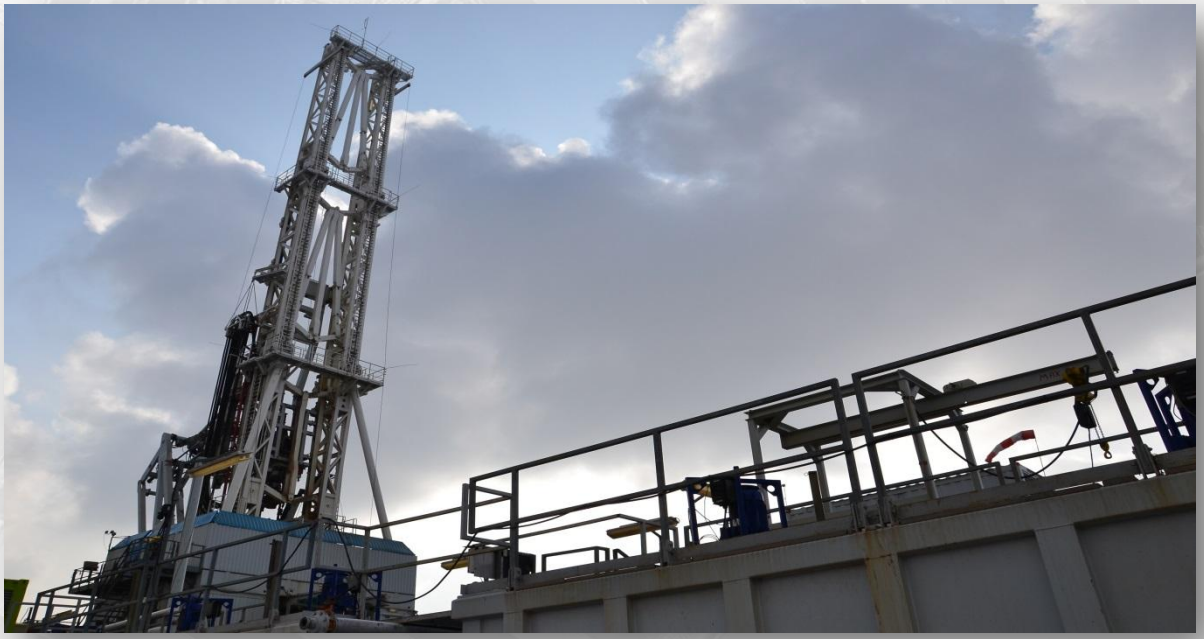
Status: under construction

Heat source: geothermal fluid at 118 C

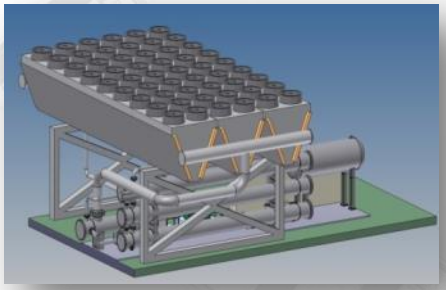
Total electric power: 4.1 MW

Total thermal power: 12 MW (to the district heating)

Scope of supply: Supply of the complete ORC unit, including the Air Cooled Condenser and control system of geothermal site



Reference Plant - Enel supercritical



Plant type: geothermal prototype with supercritical cycle

Customer: Enel Green Power

Location: Livorno, Italy

Started-up: March 2012

Heat source: hot water at 150 C nominal

Cooling device: 'dry & spray' condenser

Total electric power: 500 kW_{el}

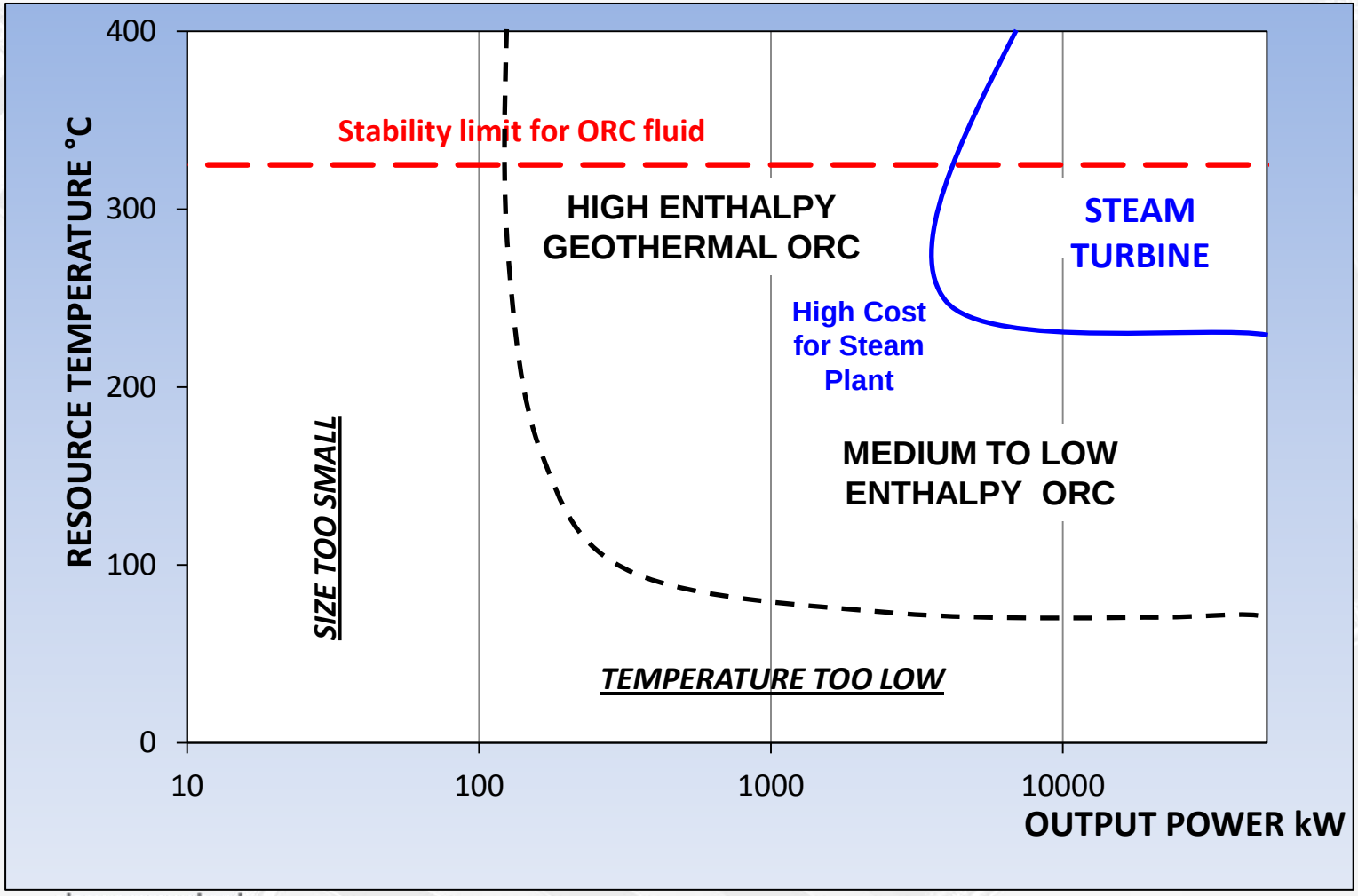
Working fluid: refrigerant (non flammable)

Turboden Geothermal key features

Geothermal energy from Turboden's ORC is the **energy of the next generation** as:

- it has **zero emissions** (binary cycle with **total reinjection**)
- it is high **predictable** (small seasonal and daily trends)
- it can work both in **island mode** or connected to the grid
- it can support the grid (different possible power regulations)
- it can remain stable during the Low Voltage Right Trough (**LVRT**)
- it can be connected to a **district heating**
- It has maximum electric efficiency (total flexibility in the choice of the working fluid and of the thermodynamic cycle)
- it starts from 100 C

Turboden + MHI: Ranges of Application



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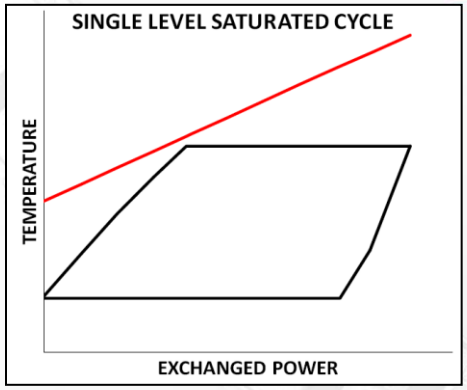
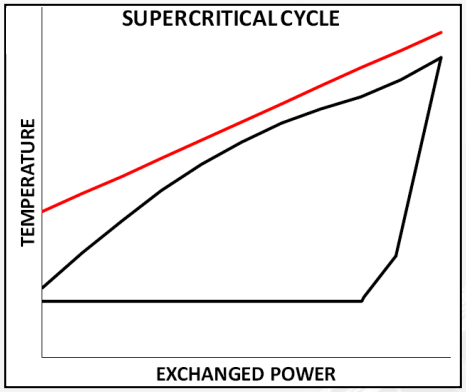
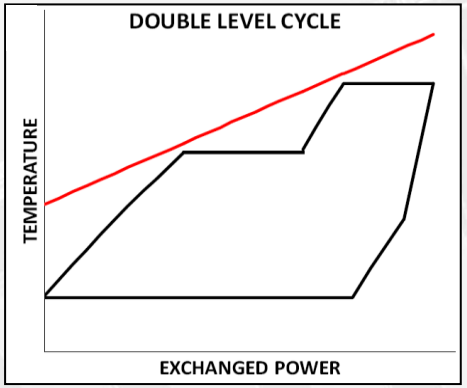
ORC Design Experience

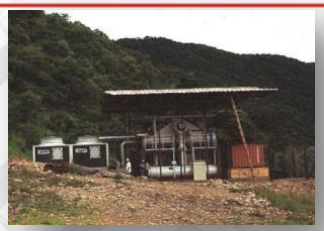






Every geothermal resource is unique.
Turboden has experienced the possible solutions to exploit efficiently the geothermal variable temperature heat source, by selecting the optimum fluid and cycle configuration.

Early Demonstration Projects



Location: **DAL – Kapisya, Zambia**

Year: 1988

Heat source: Geothermal fluid at 88 C

Total electric power: 2 x 100 kW

Location: **Castelnuovo Val di Cecina, Italy**

Year: 1992

Heat source: Geothermal fluid at 114 C

Total electric power: 1.3 MW

Plant type: geothermal low enthalpy, coupled with a geothermal district heating system

Location: **Marktgemeinde, Altheim, Austria**

Started up : March 2001

Heat source: hot water at 106 C

Cooling source: cold water from a nearby river (cooling temperature 10/18 C)

Plant type: geothermal, 1st EU operating plant on EGS (Enhanced Geothermal System)

Location: **Soultz-sous-Forêts, Alsace, France**

Started up: II quarter 2008

Heat source: hot water at 180 C

Total electric power: 1.5 MW

Plant type: geothermal low enthalpy, coupled with a geothermal district heating system

Location: **Simbach – Braunau, German-Austrian border**

Started up: III quarter 2009

Heat source: hot water at 80 C

Design electric power: 200 kW