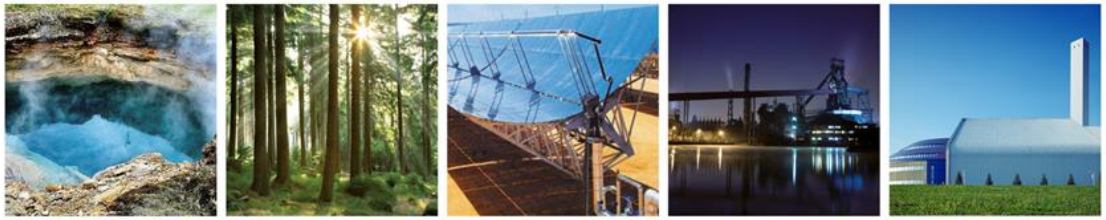
Enhanced Efficiency, Sustainable Power Generation, and CO2 Emission Reduction through Organic Rankine Cycle Technology



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Simone Passera

Dallas, April 26 th 2016

POWER PLAYS™
GEOTHERMAL ENERGY IN OIL AND GAS FIELDS
Conference & Workshop | April 25-26, 2016 | SMU Campus, Dallas, TX

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Turboden ORC turbogenerator– fields of application

Biomass

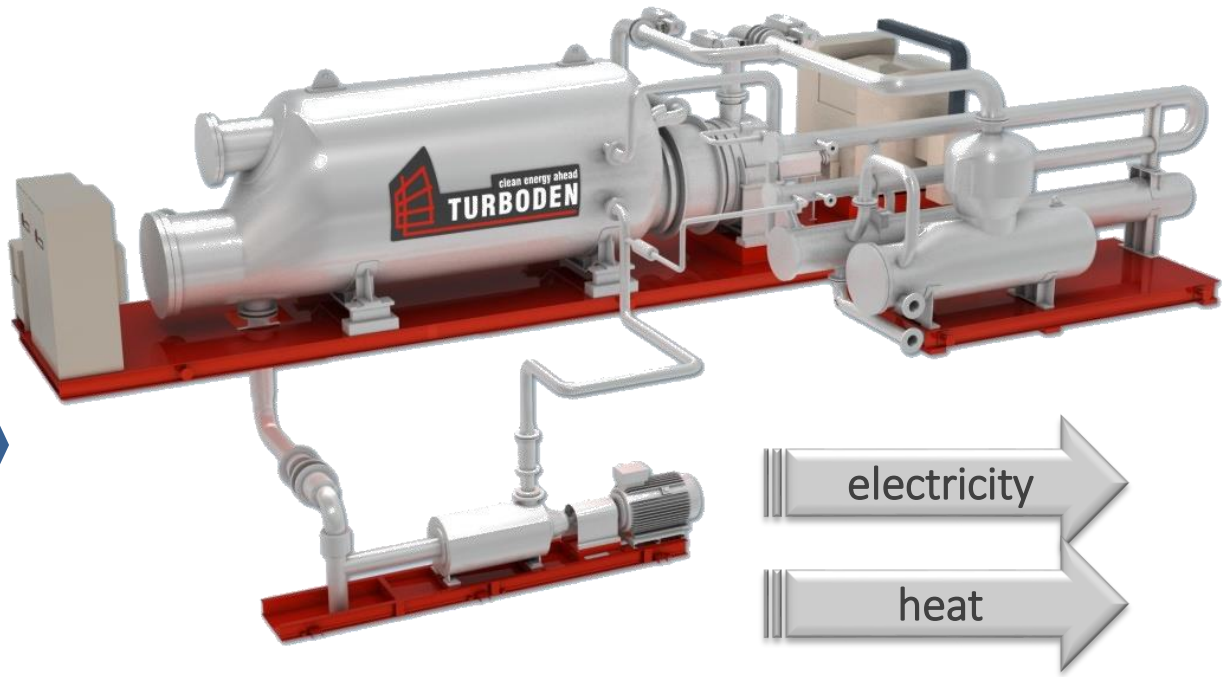
Heat recovery

Waste to energy

Geothermal

Solar

"Fuel"



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 : custom-made solutions up to 20 MW electric power output per single turbine

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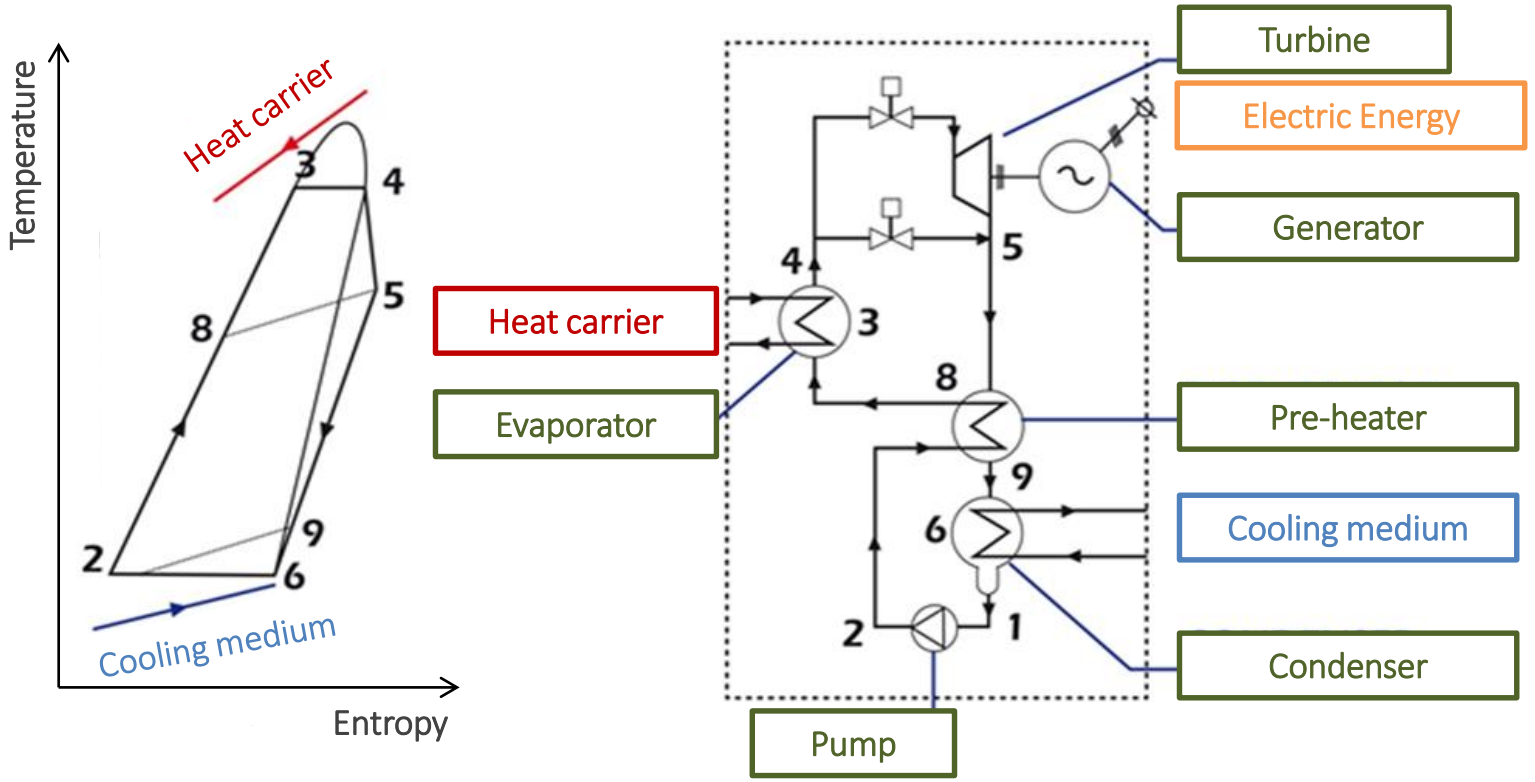
Organic Rankine Cycle: Thermodynamics



- ✓ Closed thermodynamical cycle (Rankine cycle)
- ✓ Working fluid in closed loop
- ✓ Working fluid is a suitable organic fluid

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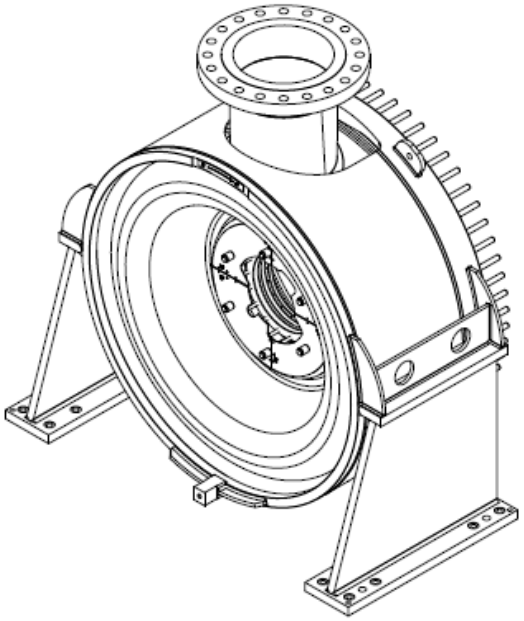
Technical Advantages of Turboden proprietary Turbine & Process



A PROVEN SOLUTION

- The design of the turbine (casing, blading) is carried out by Turboden representing the core know-how since its foundation in 1980
- 300 Turboden ORC turbines successfully implemented with sizes from 200 kW to 20 MW
- Proven experience with 10 different ORC fluids
- Axial geometry is a traditional configuration, the most widely adopted in turbomachinery design
- Axial is the reference design for ORC, proven with millions of working hours worldwide

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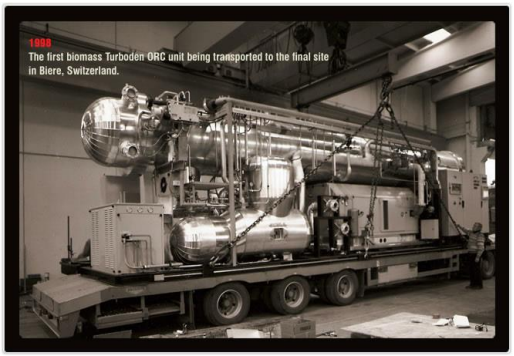
35 Years of Experience in ORC turbogenerators

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 HEAVY INDUSTRIES, LTD.

Today - Over 300 plants in the world, **240 in operation**, 200 employees, ~100 M€ turnover (2012)

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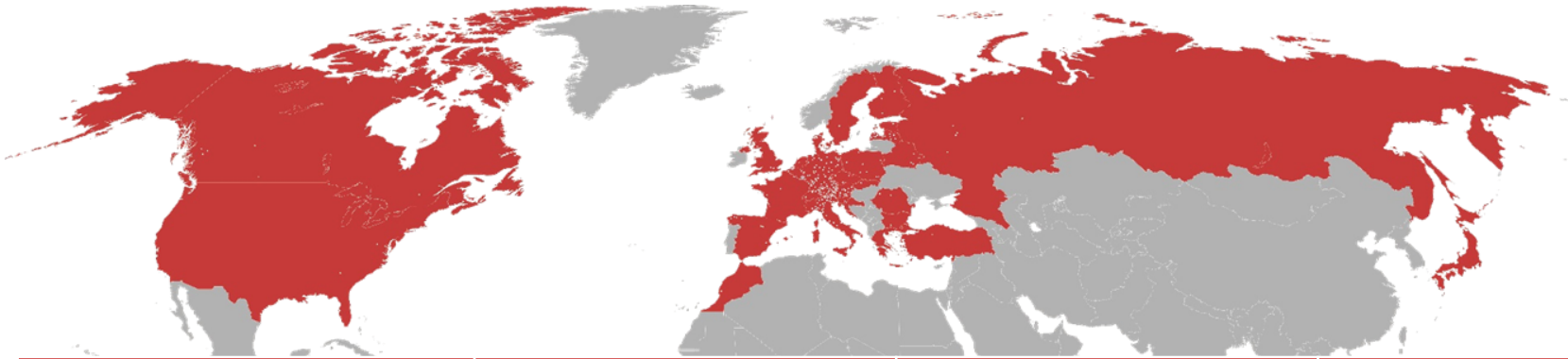
Turboden ORC a proven worldwide experience



Application	Plants in Operation		Under Construction		Total	
	no.	MW	no.	MW	no.	MW
Wood Biomass	233	274,8	45	87,3	278	360,1
Geothermal	7	27,8	3	21,2	10	49
Solar thermal power	1	2	3	2	4	4
Heat Recovery	20	35,3	6	20,1	26	55,5
Waste to Energy	9	20,3	0	0	9	20,3
Total Turboden Plants	270	360,2	57	130,3	327	488,6

270 power plants in operation use Turboden ORC technology
More than 8 million hours of operation cumulated and 7,800 GWh produced
Average availability of our fleet > 98%

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Last Update: April 2016

ORC gives significant advantages in different O&G fields

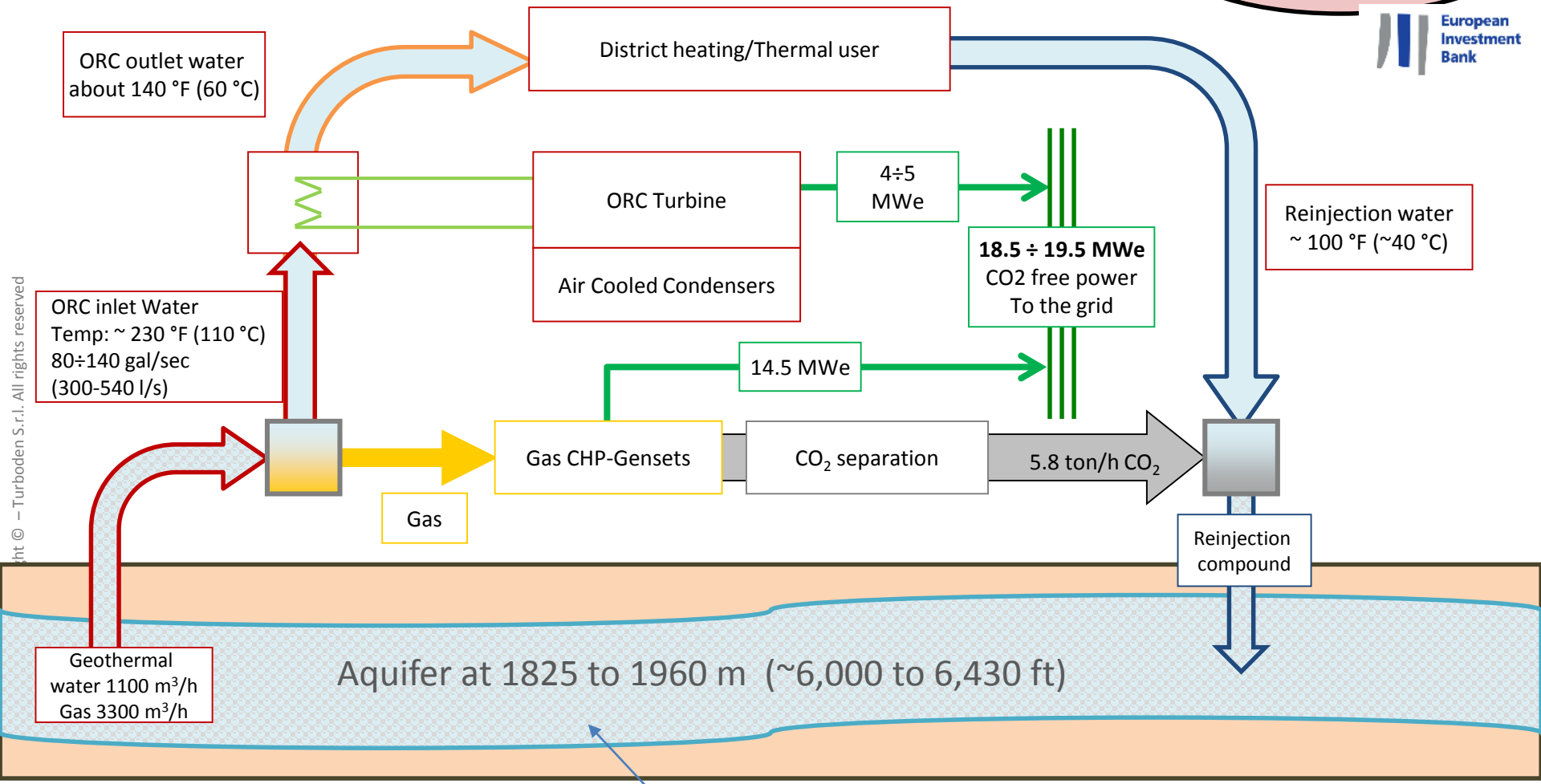
- ✓ **High efficiency even with low enthalpy sources and with variable loads**
- ✓ **Low O&M – minimum needs of dedicated operators (unmanned system)**
- ✓ **Remote support and control**
- ✓ **No water consumption/water treatment**
- ✓ **Compactness and simplicity**
- ✓ **No influence to the main process – by-pass and automatic load following**

1. Hot water from exhausted oil/gas wells (binary geothermal)
2. Gas turbines exhaust gas Gas compressor stations, natural gas liquefaction, gas storage, etc.
3. Associated Petroleum Gas (APG)
4. Refinery hot streams Distillation columns, Oil/Gasoline/Kerosene production, etc.

Reference project – Intelligent use of aquifer gases

Pilot project in Croatia with BEI support – starting phase of project on-going

European Investment Bank



Gas composition: 94% CH4; 6% CO2
Gas content: 3÷3,5 Nm3/m3

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Reference project – Intelligent use of aquifer gases

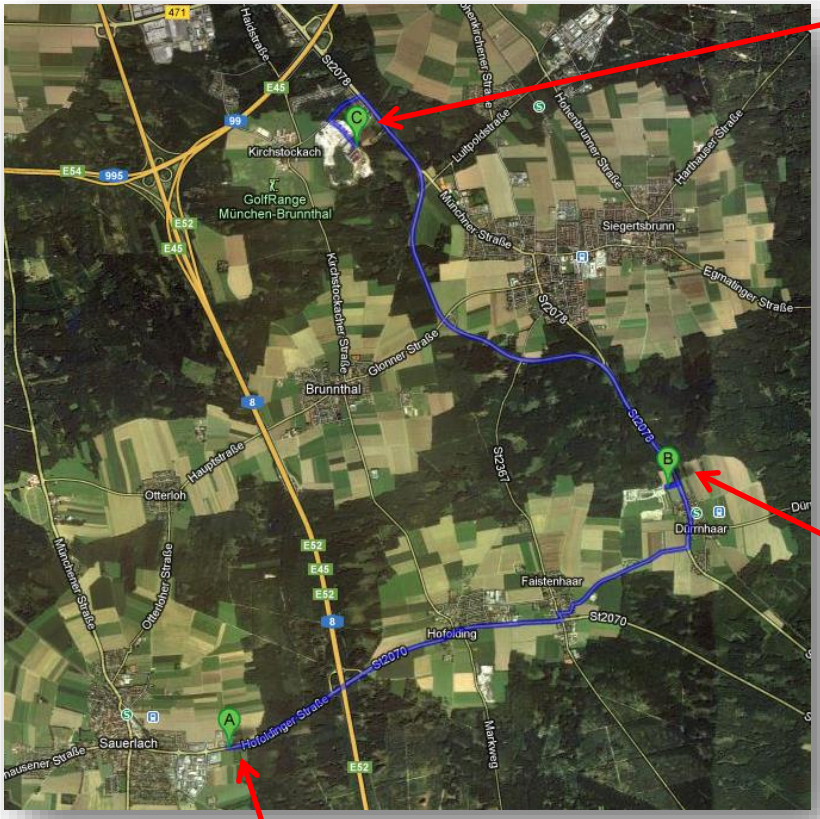
1. Hybrid geothermal/gas power plant for combined electric and heating generation (20 MWe with zero CO2 emission)

2. Turboden ORC binary technology improves of around 30% the electrical efficiency of the power plant

3. Valorization of an “unconventional” source (i.e. thermal aquifer with methane content)

4. Pilot project is the result of intensive researches combining different expertise and the best technologies from different fields

Turboden Geothermal Plants in operation in Bavaria



Kirchstockach:
5,6 MWel

Dürrnhaar:
5,6 MWel

Sauerlach:
5 MWel + 13.6 MMBtu/h

Traunreut:
4 MWel + 41 MMBtu/h

- 4 Geothermal power plants
- ~20 MW electric power output
- ~54.6 MMBtu/h thermal power (district heating)
- Geothermal water temperature 245 °F ÷ 285 °F (118 °C – 140 °C)
- 5 km (~3 miles) deep geothermal reservoir

Layout example of Turboden reference plant

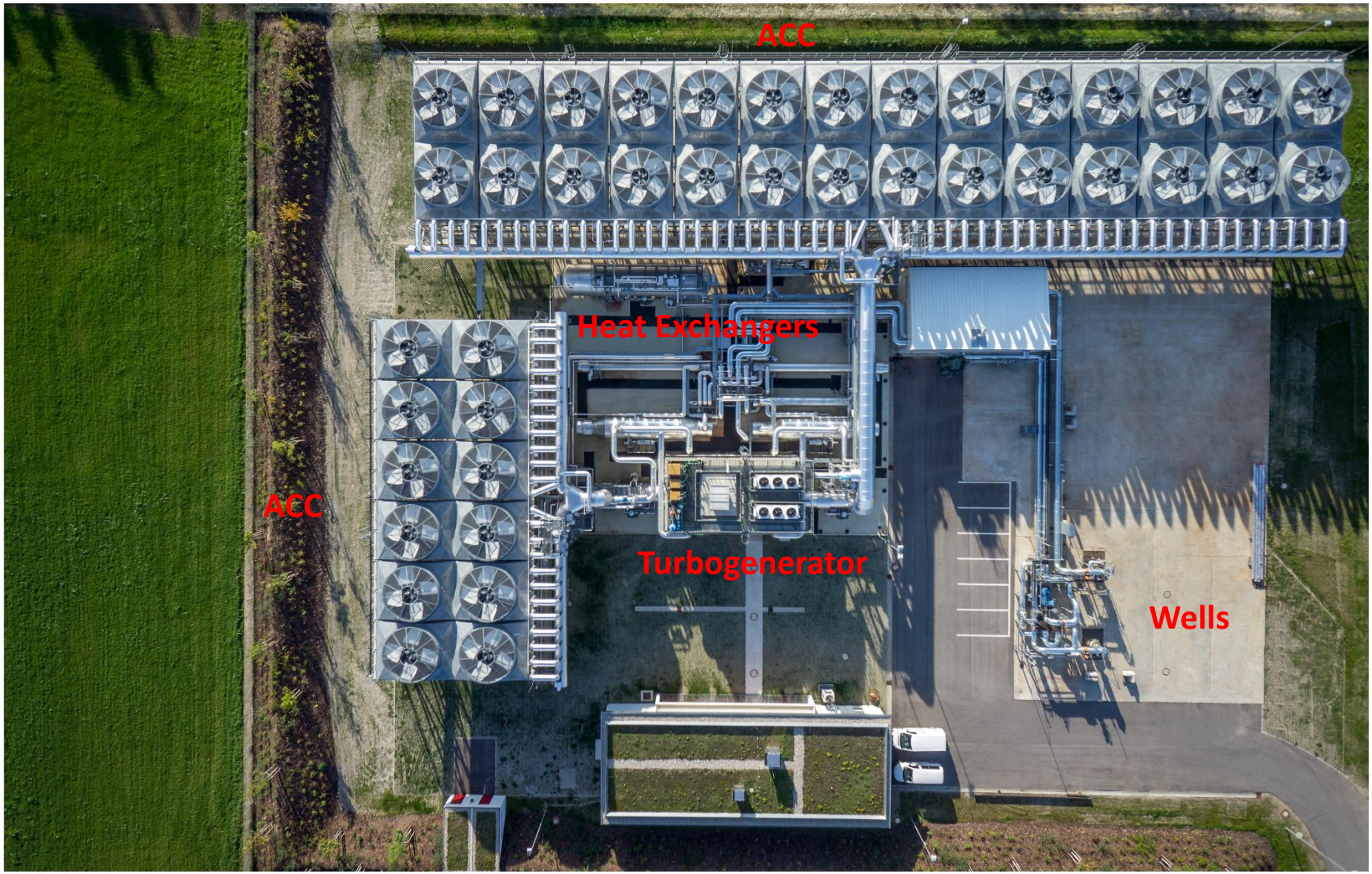


Foto www.ottaviotornasini.it

5.6 MWe geothermal ORC Turboden plant for Hochtief Energy Management. Dürrnhaar – Munich, Germany – 2012

Reference Plant - Sauerlach

Plant type: Two-level cycle geothermal unit

Customer: SWM - StadtWerke München (public utilities company)

Site: Sauerlach, Munich, Germany

Start-up: December 2012

Heat source: geothermal fluid at 140°C

Cooling device: air condensers

Total power: 5+ MW_e plus 4 MW_{th} (13.6 MMBtu/h) decoupling for district heating

Working fluid: refrigerant 245 fa (non flammable)

Custom-made solution according customer requests

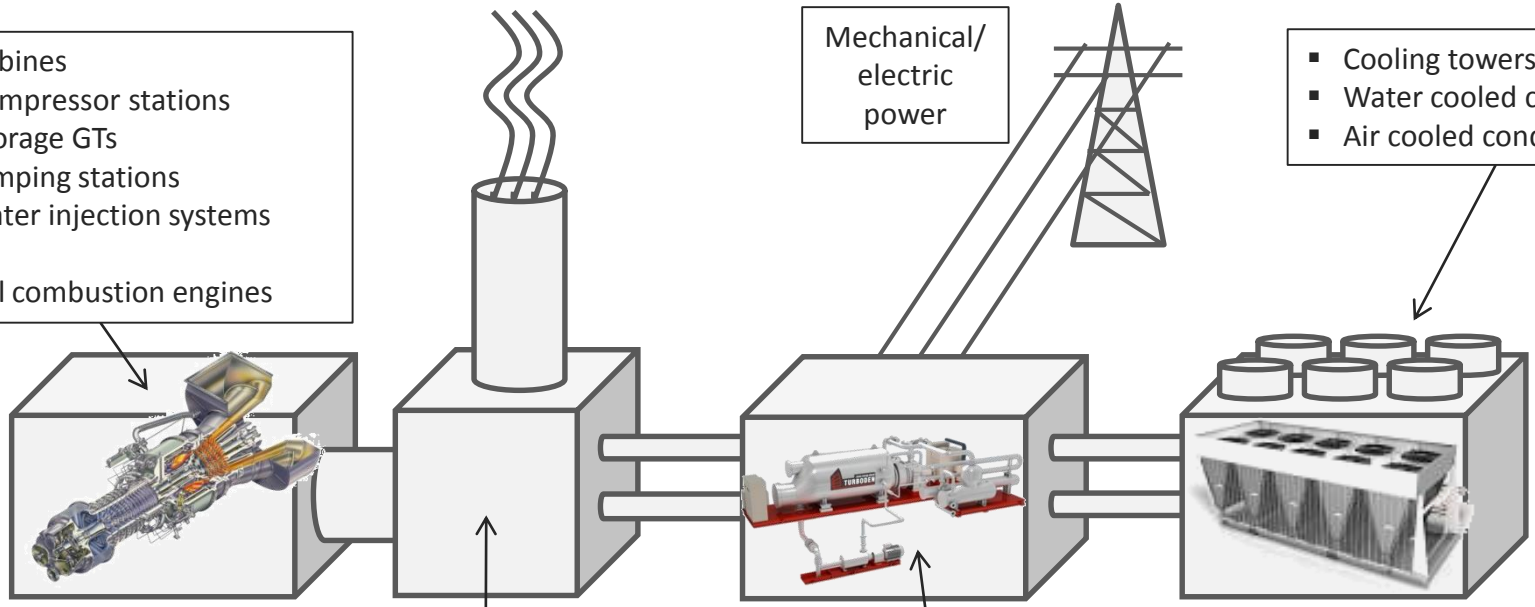
Oil&Gas applications

2. 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

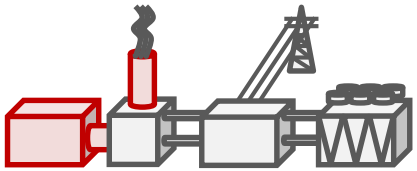


Heat exchanger
- Direct exchange
- Thermal oil

Organic Rankine Cycle
25 ÷ 35% additional power (1)

Turboden References

- **TransGas – Canada**
  GT power: 3.5 MWe
  ORC power: **1 MWe**
  Thermal oil circuit
  Start up: Q4 2011
- **Polympex – Russia**
  GT power: 25 MWe
  ORC power: **3 MWe**
  CHP th. power: 15 MWth
  Direct Exchange
  Start up: Q4 2014



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(1) Percent of the prime mover nominal power

Oil&Gas applications

3. Associated Petroleum Gas (APG) explotation

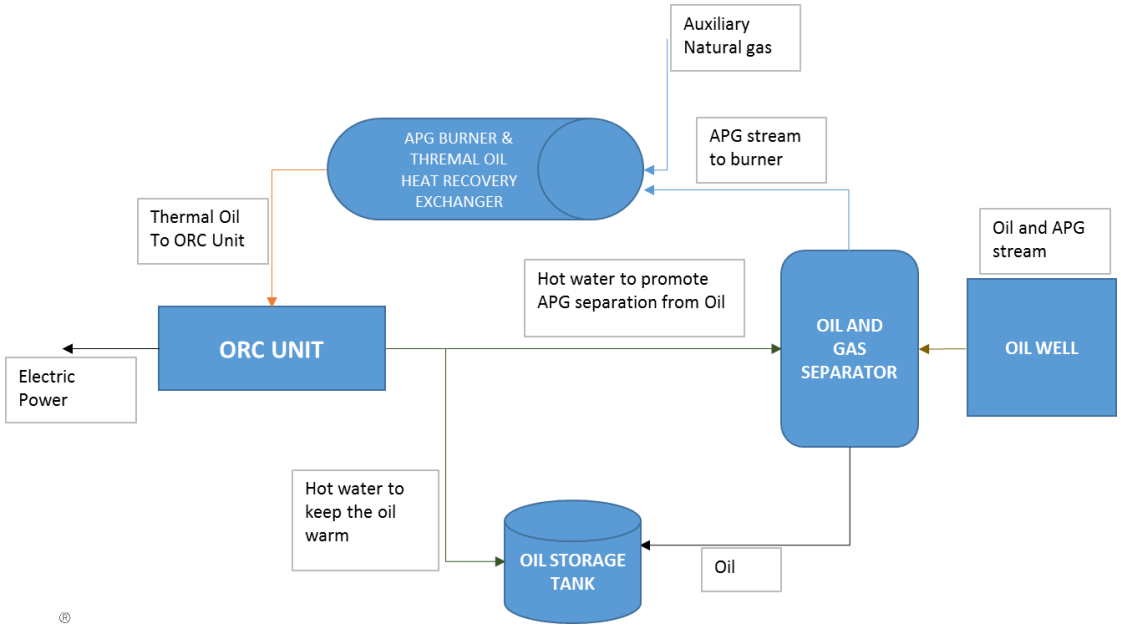
APG produced in oil extraction fields is often flared to the atmosphere because its economic valorization as hydrocarbon is unfeasible

Main reasons:

Cycling availability, low calorific value, variable composition, high sulfur content, etc.

→ Difficult employment in high conversion efficiency power systems (e.g. gas turbines and reciprocating engines).

Turboden ORC characteristics (such as flexibility, excellent partial load behavior and unmanned operation) allows the exploitation of flare gases to produce electricity



Example of flare gas utilization: Turboden ORC unit coupled with gas burner and a thermal oil loop

3. Associated Petroleum Gas (APG) explotation: reference plant in Russian refinery of Lukoil

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 (149/203°F)

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.

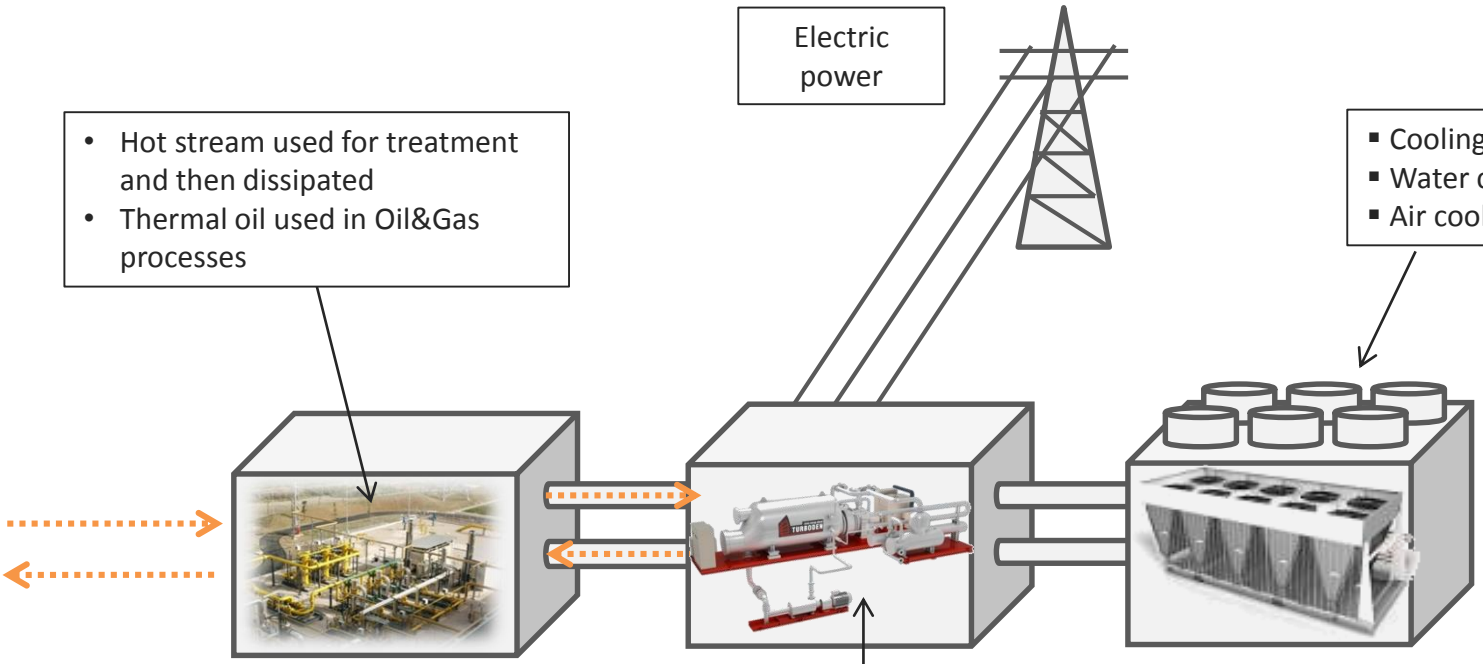
Oil&Gas applications

4. Refinery hot streams

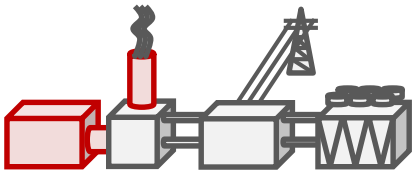
Electric power

- Hot stream used for treatment and then dissipated
- Thermal oil used in Oil&Gas processes

- Cooling towers
- Water cooled condensers
- Air cooled condensers



Organic Rankine Cycle
Efficiency up to 25+% (1)



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(1) Heat carrier temperature above 300°C

O&G facilities present different low enthalpy sources:

- **Kerosene hot streams in refineries**
- **Exhaust gases of distillation columns**
- **Condensing steam in gas treatment process**
- **Exhausted or not used wells**
- **others…..**

Conclusion

- ORC technology offers various potential opportunities for the efficiency and CO2 reduction in the Oil&Gas different fields
- ORC technology suitable for the exploitation of the low enthalpy geothermal potential in Oil&Gas fields
- Important to identify attractive opportunities from a technical and economic point of view
- Turboden has proven experience worldwide and can help you in the identification and development of the best solutions for your case

Thanks for your attention

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Official YouTube Channel: https://www.youtube.com/user/TurbodenItaly

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