# ORC INSTALLATIONS

## JOURNÉE D'ÉTUDE - VISITE INSTALLATIONS - BRICKER – LE LIFTING TECHNOLOGIQUE D’UN IMMEUBLE CINQUANTENAIRE

September 13th 2018

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*Laboratoire de Thermodynamique, ULiege*

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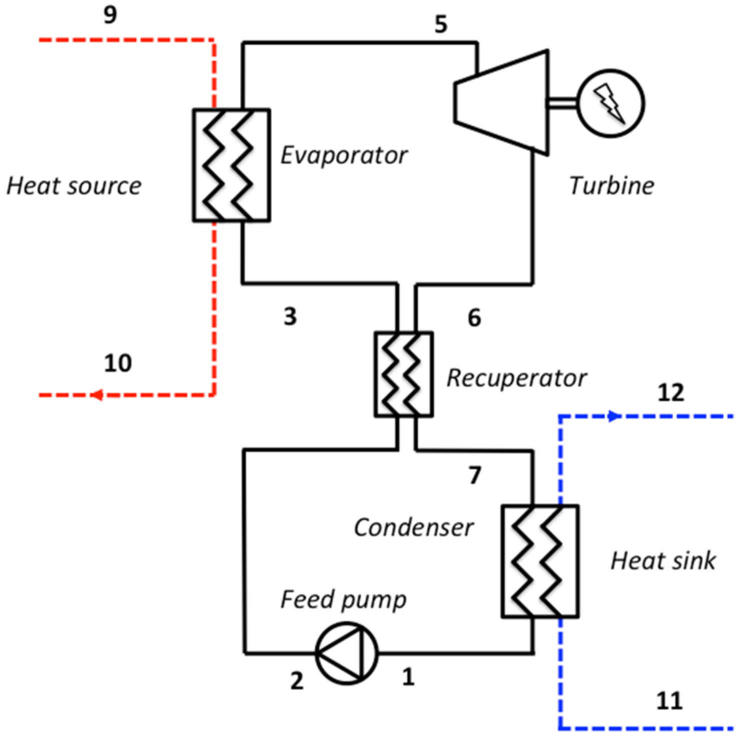
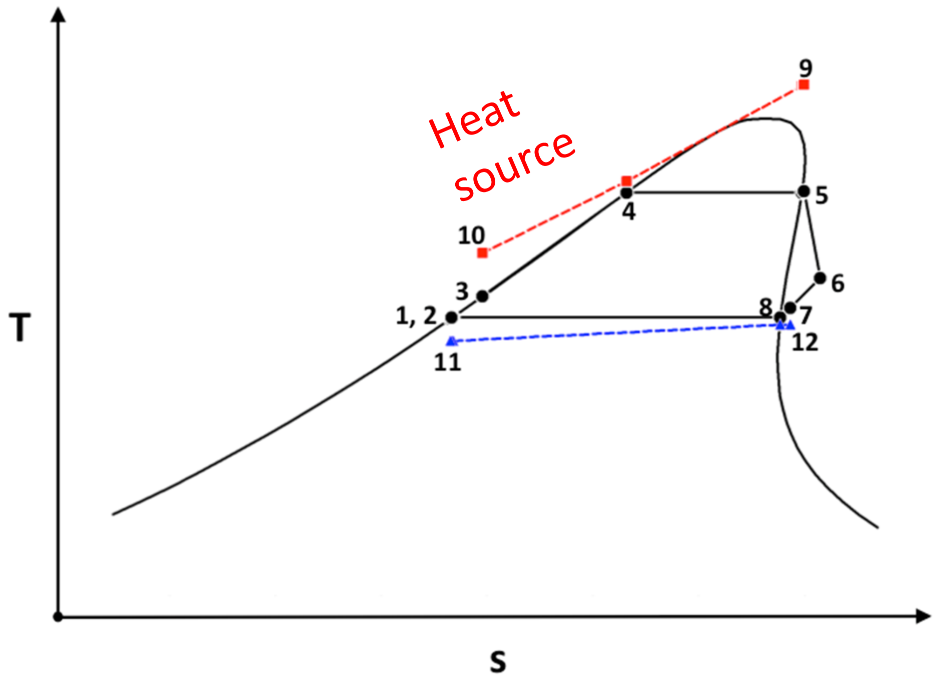
# Introduction

*ORC working principle*



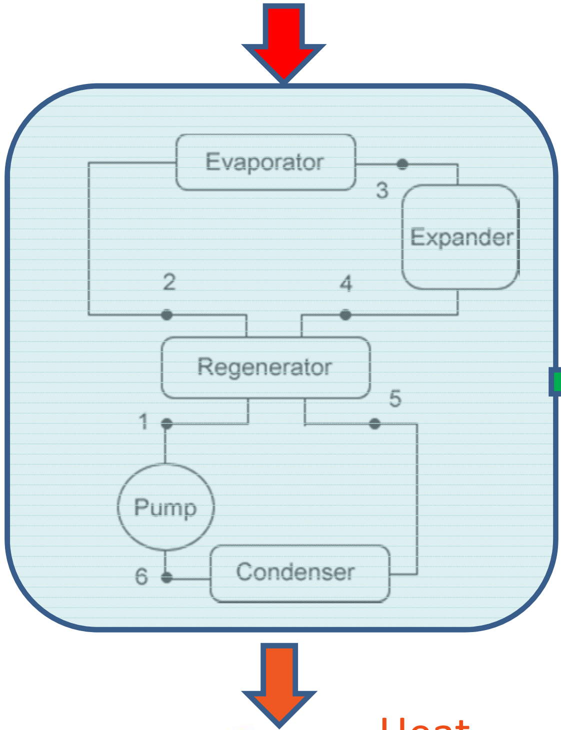




Working fluid: organic compounds (lower boiling points)
Better suited to low temperature heat sources

# Introduction

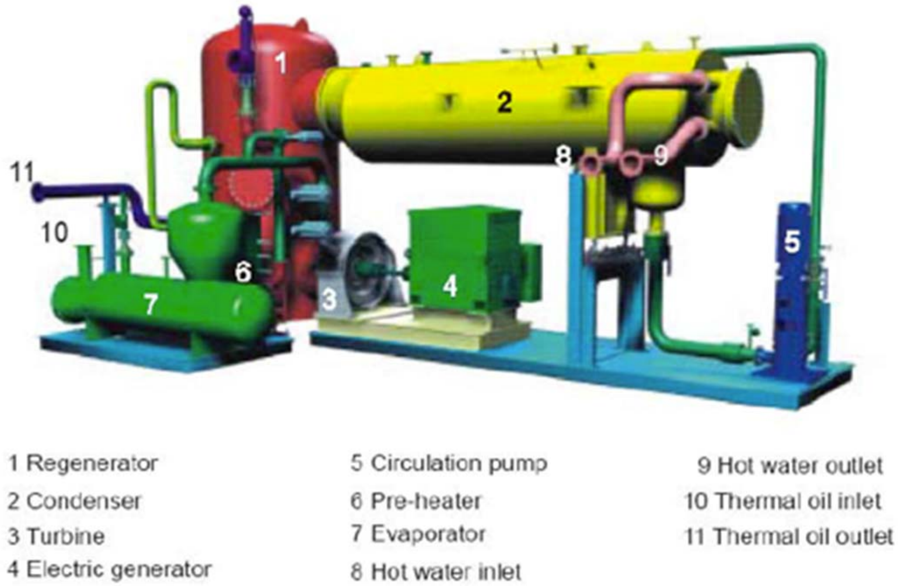
*ORC working principle*

Waste heat recovery or renewable energies: solar, biomass, geothermal




Electricity/ mechanical power

Heat




- External combustion engine
- CHP operation by recovering heat from the condenser

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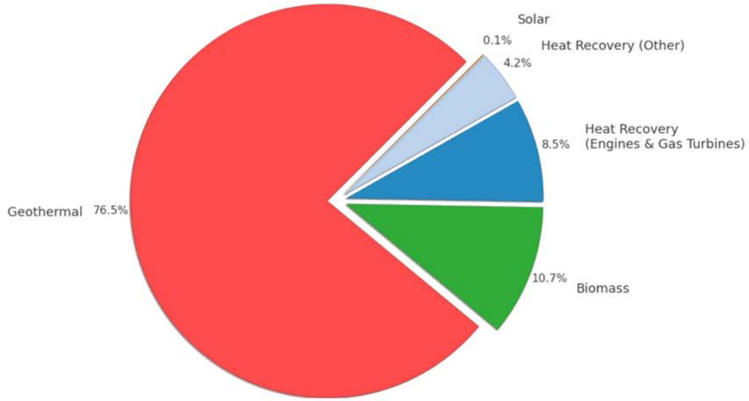
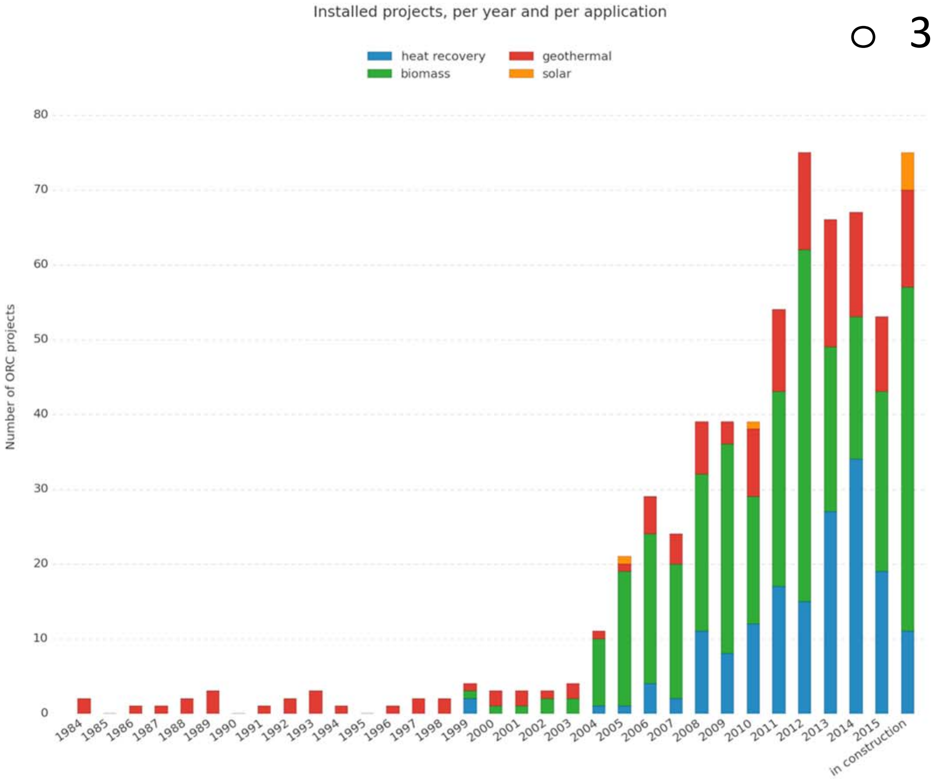
# Introduction

## *ORC market*




- In 2016:
  - Total installed capacity : 2749.1 MWel, in 563 power plants
  - New capacity planned : 523.6 MWel in 75 plants
- Growing market
- 3 important specific markets:
  - Waste heat recovery (WHR)
  - Biomass combined heat & power (CHP)
  - Geothermal energy

(Source: http://orc-world-map.org/analysis.html)

# Content of the presentation

1. Introduction
2. Comparison with steam cycles
3. Selection of the working fluid
4. Selection of the expansion machine
5. Major market
6. R&D at ULiege
7. Conclusions

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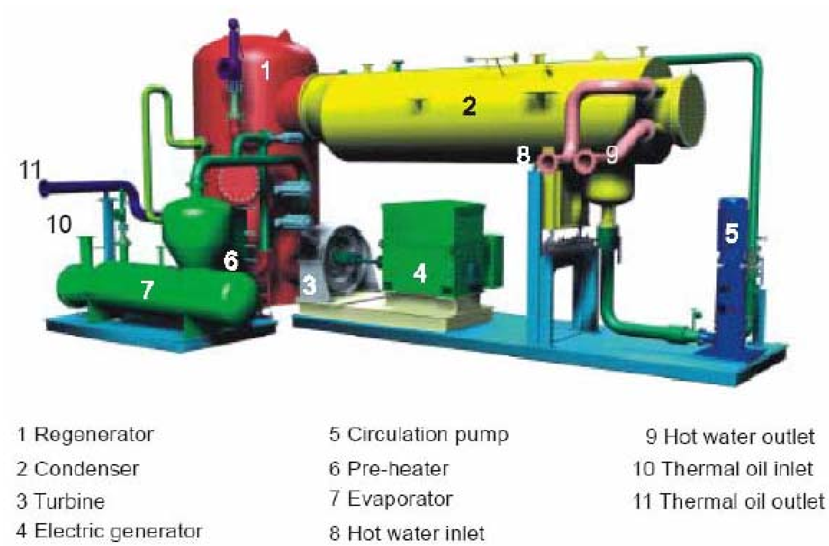
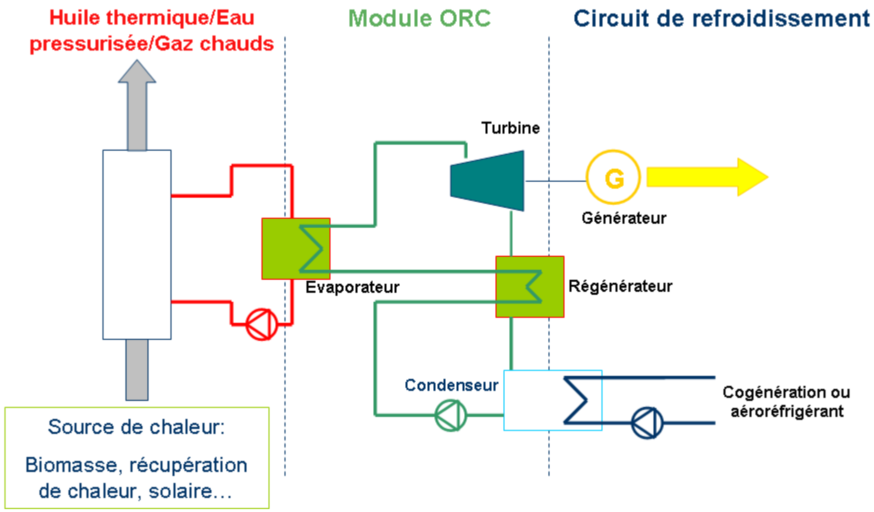
# Comparison with steam cycles




✓ ORC systems: more economically profitable than steam cycles (SRC) for powers **lower than 3-5 MWe** :

- Investment
  - ORC is a standardized system, while SRC are tailor-made
  - ORC are assembled/optimized in factory, while SRC are assembled on-site
  - ORC is designed by a manufacturer, while SRC is designed by a engineering office
  - Small turbines (<3MWe) are expensive and long delivery delay, because few manufacturers in Europe
- Operation
  - Management of a water treatment unit (necessary for the turbine and boiler) has a cost
  - Control of the superheat at the turbine inlet increases operating cost
- Performance
  - Performance are similar down to 1 MWe. For lower powers, the performance of the SRC are sharply decreasing.

# Comparison with steam cycles




✓Heat source t° between **100°C and 450°C**

✓ **Easy to install** (in a pre-assembled squid), compact and reliable

✓ Cheaper and less complex boiler, since

- Heats a thermal oil at low pressure up to 350°C (“non-pressurized”)
- Steam cycle: high pressure (60-70 bar) and necessary to superheat (450°C)

✓ **Working fluid** at **low pressure**(<20 bar)

✓ Autonomous system

✓Pressure in the condenser higher than ambient pressure (**no infiltration**)

✓ Dry fluids => no threat of damage for the turbine

✓Electrical **efficiency** : η~5-24%

✓Steam: large pressure ratio and enthalpy drop: multi-stage turbines

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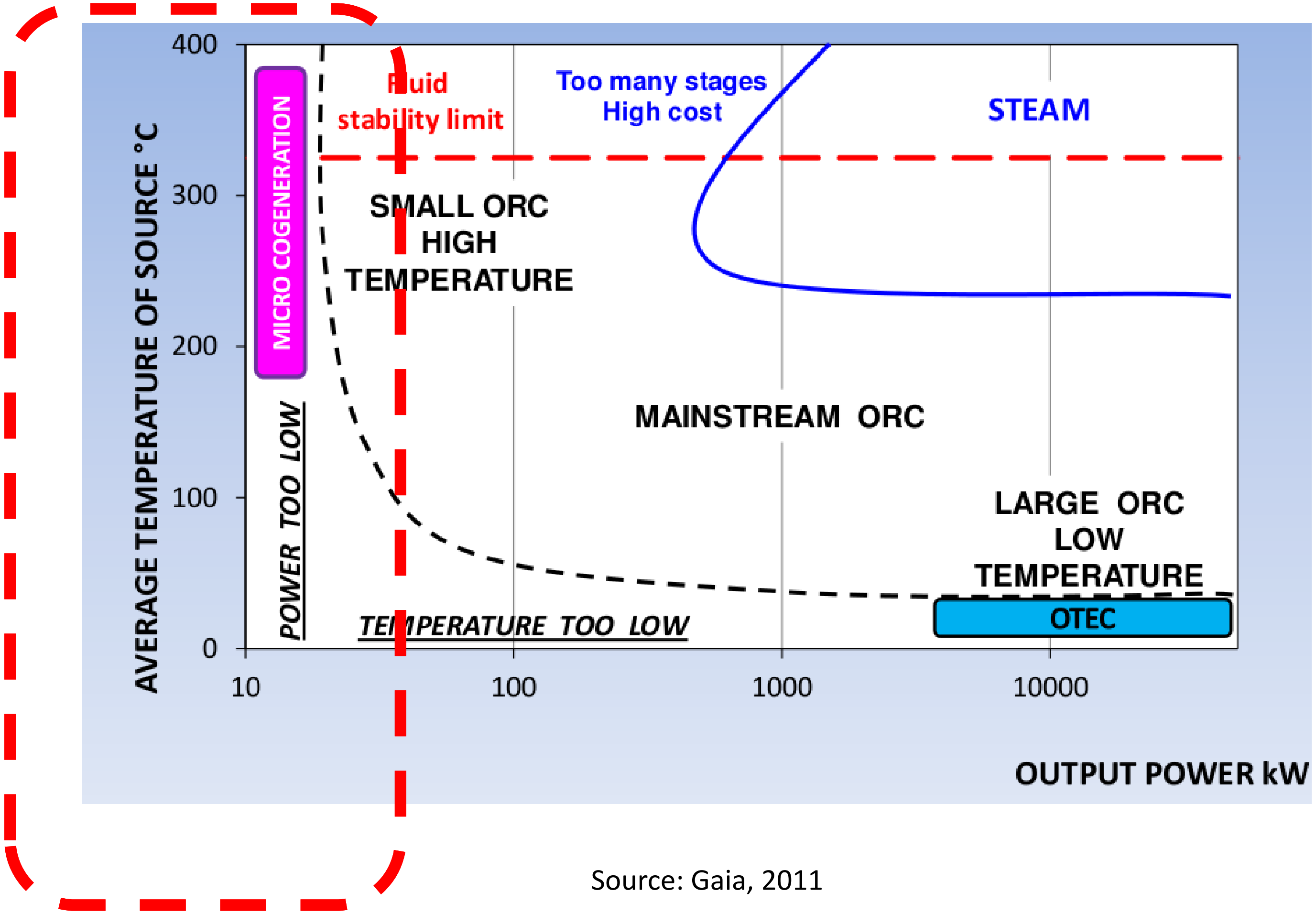
# Comparison with steam cycles

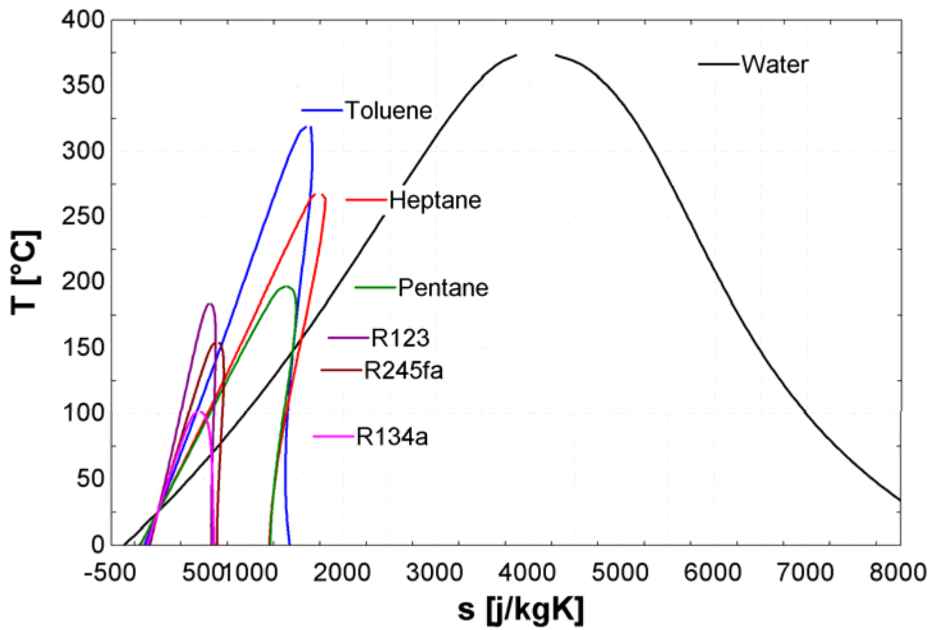



Source: Gaia, 2011

- ✧ Small-scale ORCs show a lower technical maturity (still niche market)
- ✧ However, the potential market is large

# Selection of the working fluid

The selection of the working fluid is one of the key issues when designing an ORC system




- ✓ **High thermodynamics performance**
- ✓ Positive slope of the saturation curve
- ✓ High vapor density (size expander!)
- ✓ No deep vacuum in condenser
- ✓ Low volume ratio on the expander
- ✓ Low mass flow rate (size pump!)
- ✓ Evaporating pressure lower than 30 bar
- ✓ Backwork ratio
- ✓ Large availability and price
- ✓ Low environmental impact (ODP, GWP) and high security level

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# Selection of the expansion machine

**Volumetric expanders**

**Turbomachines**

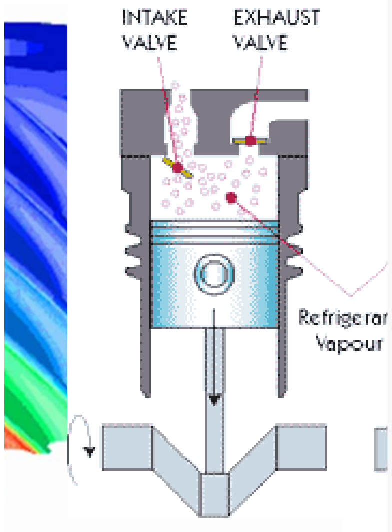
Scroll

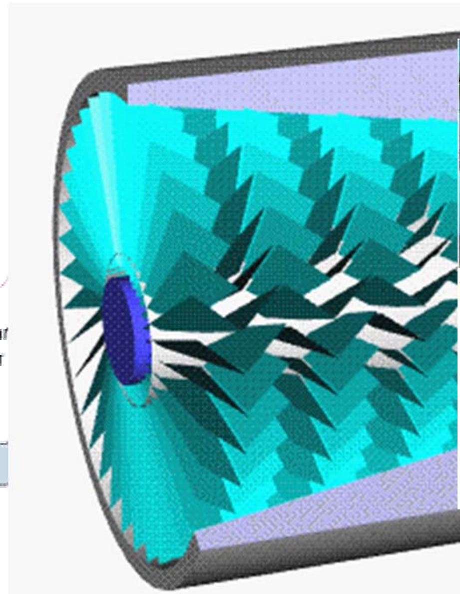
Screw

Reciprocating

Axial

Radial



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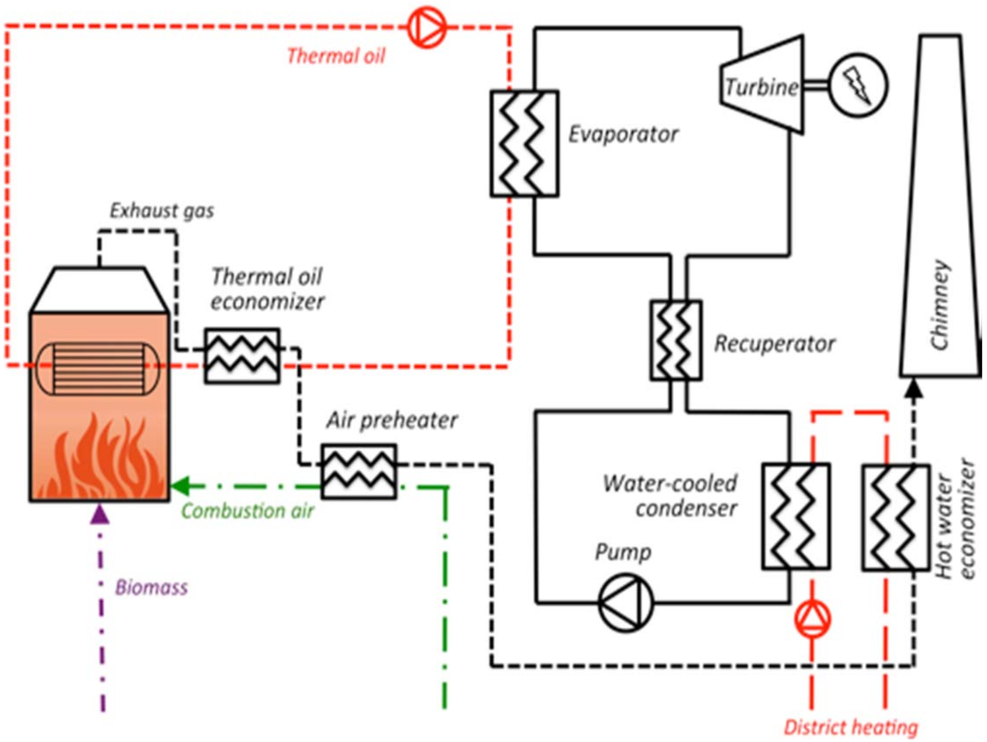
# Major market

## *Biomass*




- Up to a few Mwe (with district heating)
- Micro-CHP also investigated

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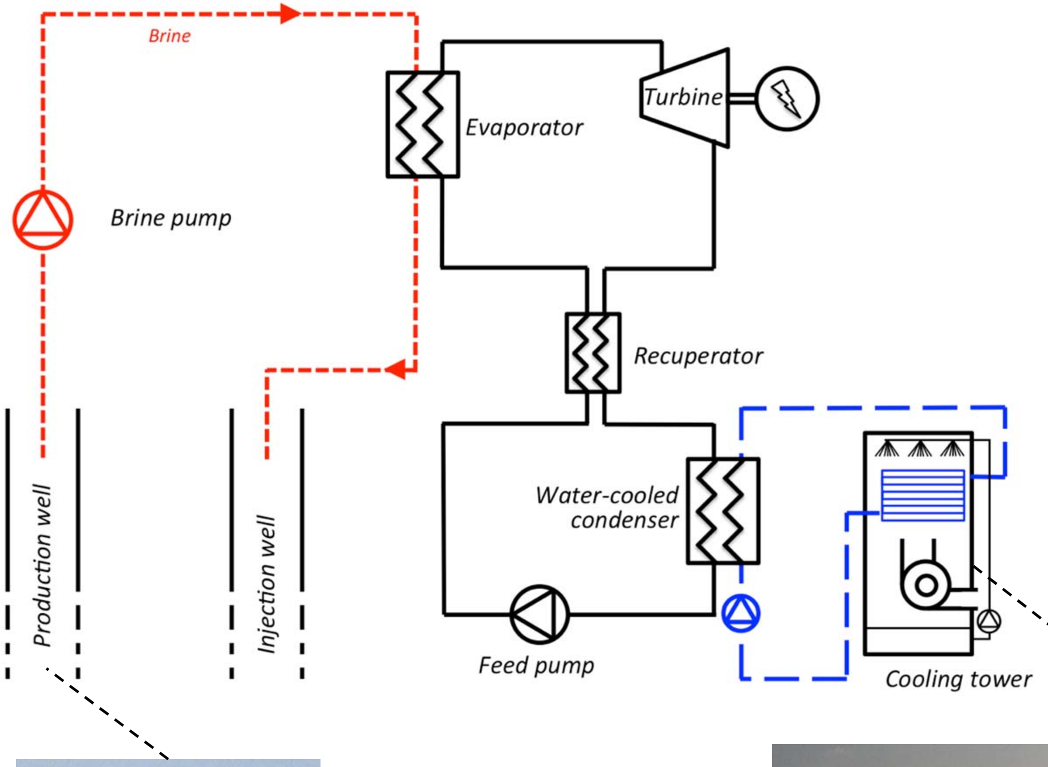
# Major market
## *Geothermal energy*

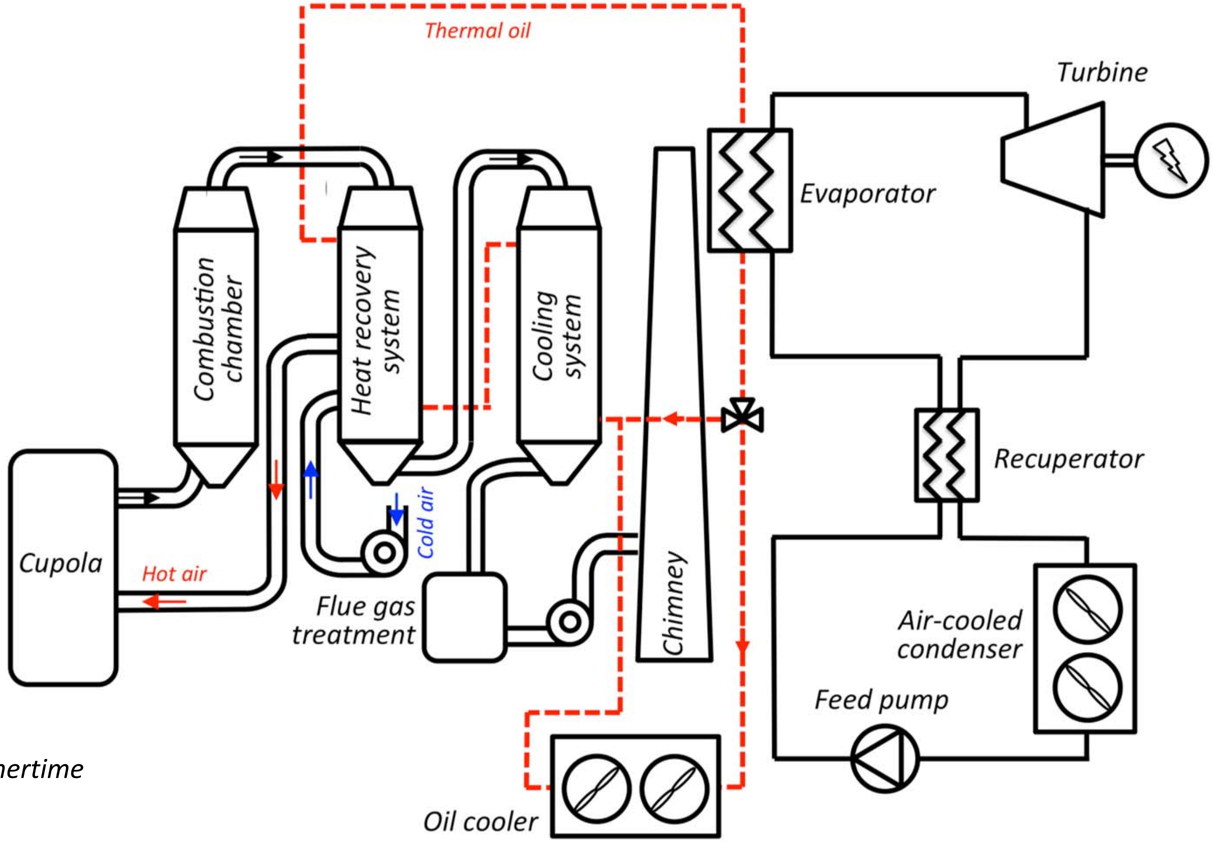



*Example: Soultz-sous-Forêts power plant*

- Extraction well: 5 km
- 1.5 MWe
- Geothermal fluid: 175°C
- ORC fluid: iso-butane

# Major market

## *Waste heat recovery from industry*


*Source Enertime*

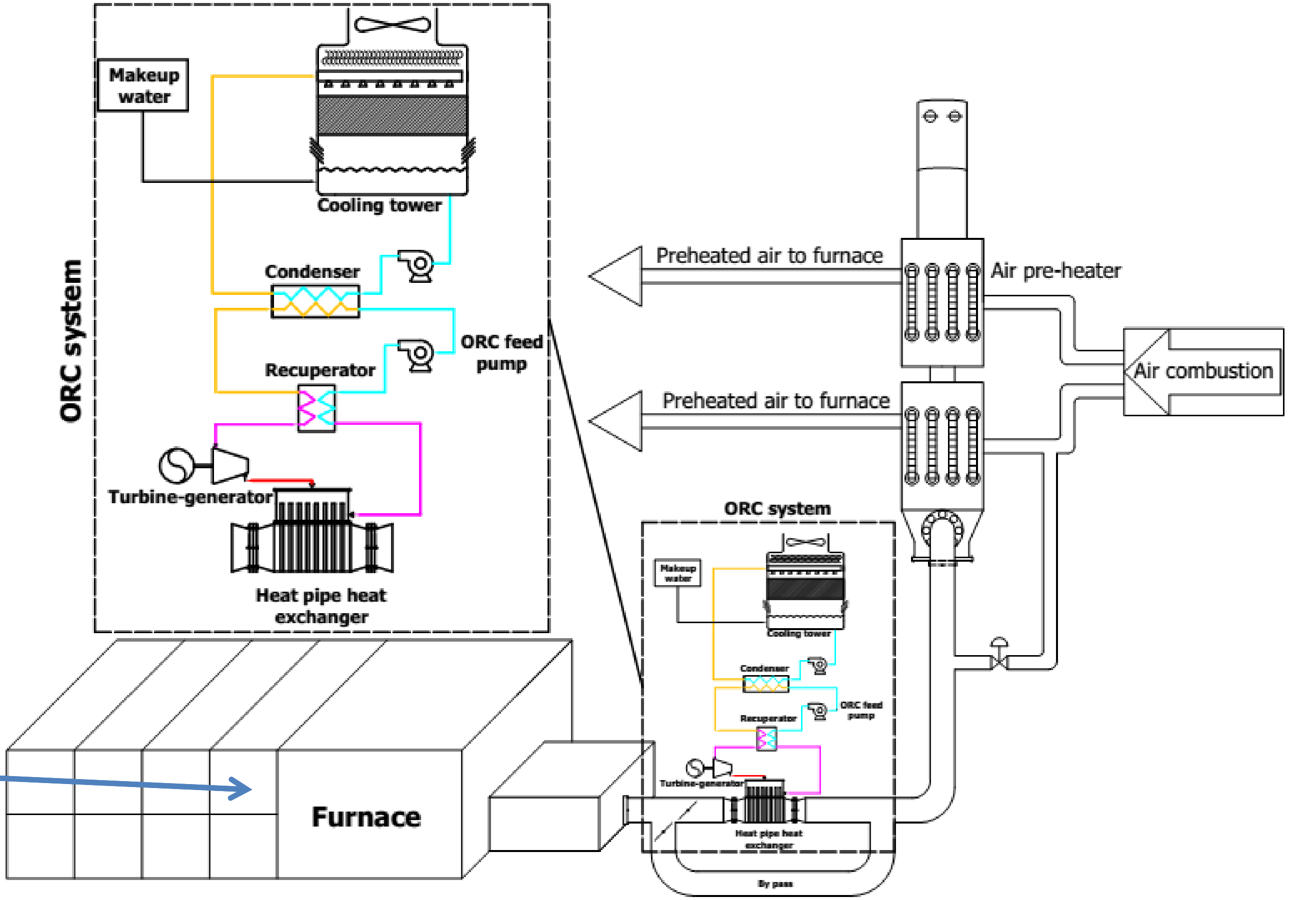
- ✧ 5.6 $MW_{th}$ recovered from exhaust gases
- ✧ Net power production: 870 $kW_e$
- ✧ 30 % of the factory electricity consumption can be covered by the ORC

# Major market

*Waste heat recovery from industry*

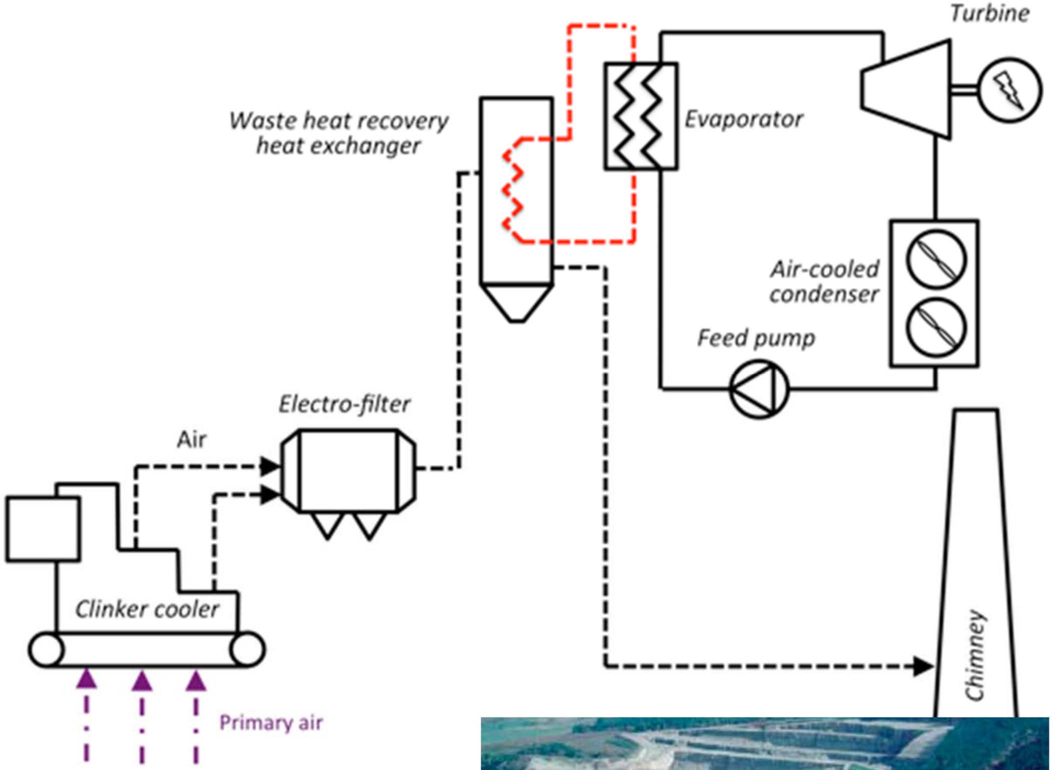
- Gas t° at the outlet of the reheating furnace: 820°C
- Investigation of the use of heat pipes connected to the the ORC.

Source: Comeca



# Major market

## *Waste heat recovery from industry*




Example

- 8.2 MW are recovered from the clinker cooler air (supply/exhaust temperatures: 275/125°C; flow rate: 150,000 Nm³/h), through a thermal oil loop (supply/exhaust temperatures: 85/230°C).
- Heat sink is ambient air.
- The ORC system, operating with pentane, generates 1.3 MW, what represents 12% of the plant electrical consumption.

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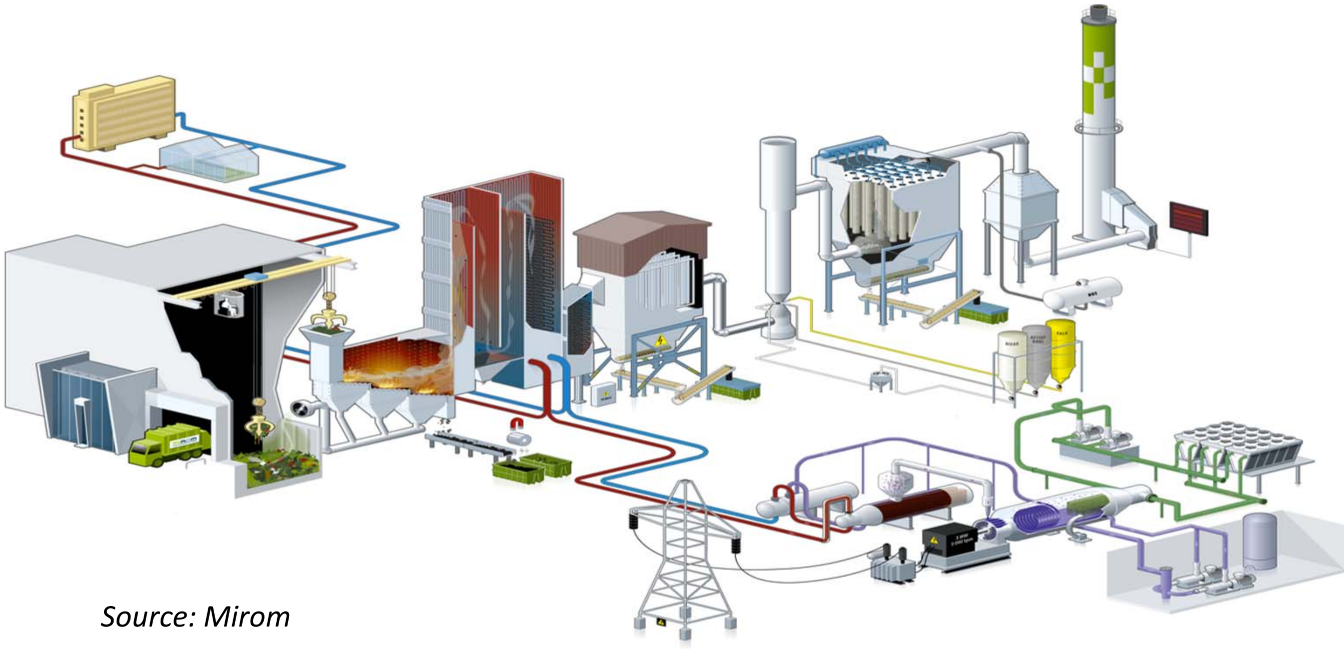
# Major market

## *Waste heat recovery from industry*

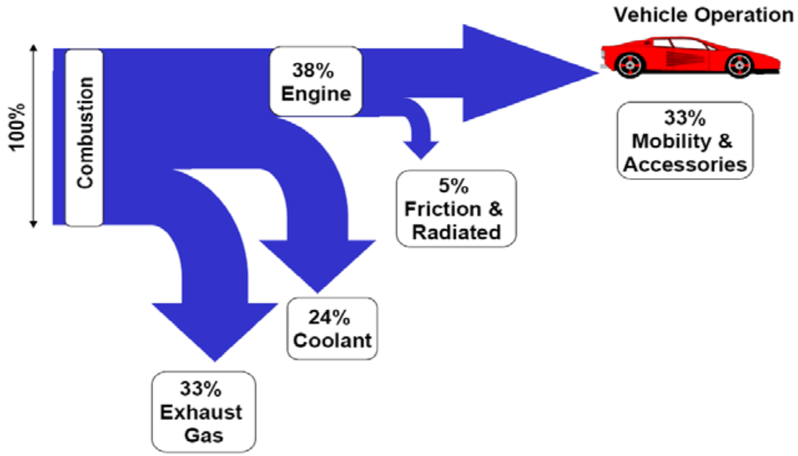


*Source: Mirom*

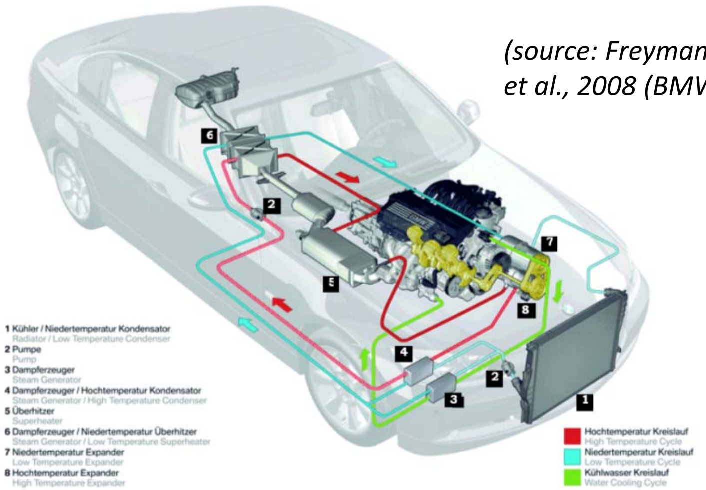
- Waste heat from an incinerator (Roeselare, Belgium) wih a pressurized water loop at 175°C
- Water loop feeds a greenhouse, buildings and one ORC (3MWe)
- In 2011, the ORC ran during 8364 hours, producing 16930 MWhe, with an average efficiency of 15.8%

# R&D at ULiege

## *Waste heat recovery from ICEs*

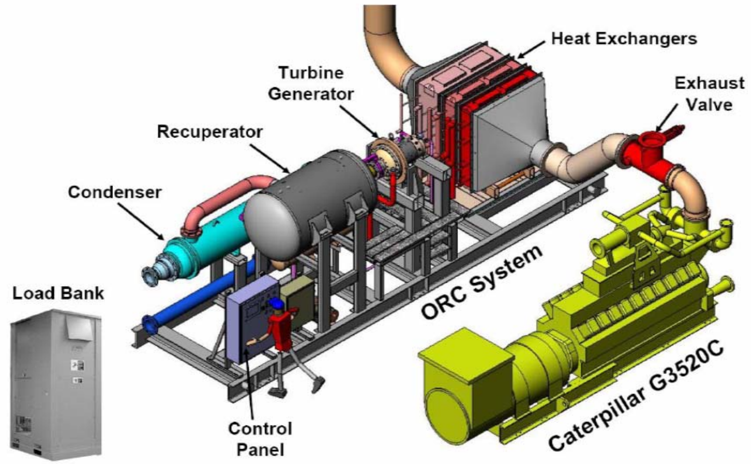



ICE converts ~1/3 of fuel energy into mechanical power



*(source: Freymann et al., 2008 (BMW))*

**Mobile application**




**Stationary application (CHP)**

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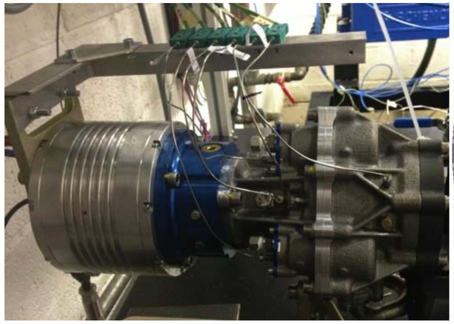
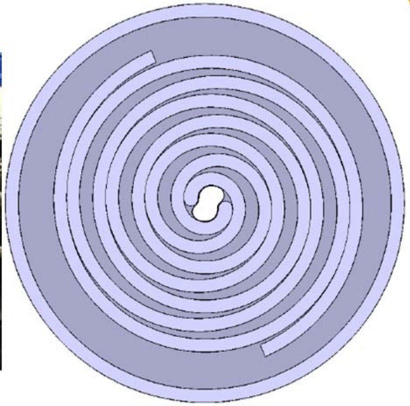
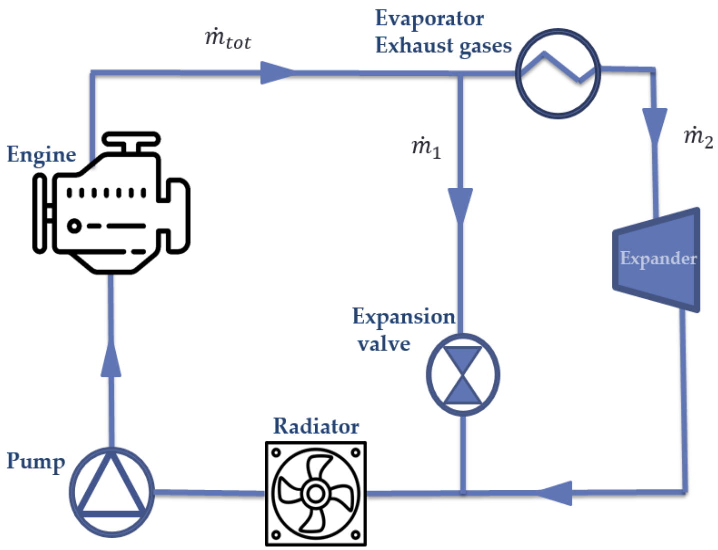
# R&D at ULiege

## *Waste heat recovery from ICEs*

- Tailor-made **expander**
  - based on detailed geometrical/thermodynamic simulation
  - Solid lubrication
  - Successful operation at 250°C with limited efficiency (explained by large leakages)
- Combine the Rankine cycle and the engine coolant loop (**innovative architecture**).
  - Recover heat from both engine coolant jacket and exhaust gas
  - Simplify the complexity of the system in vehicles (one single fluid)



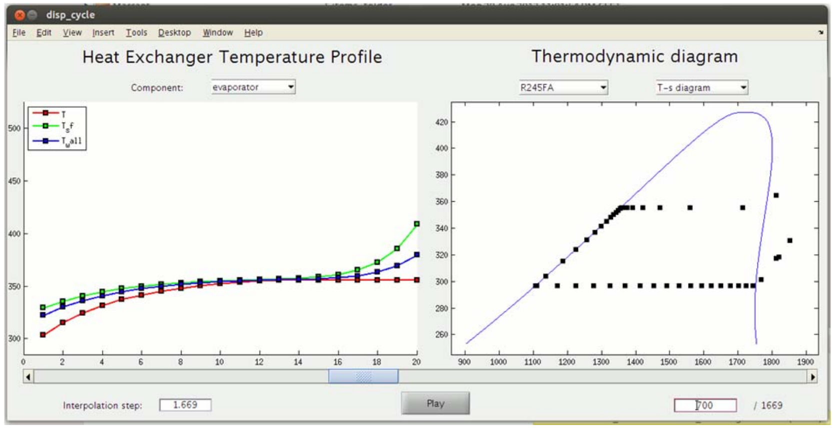


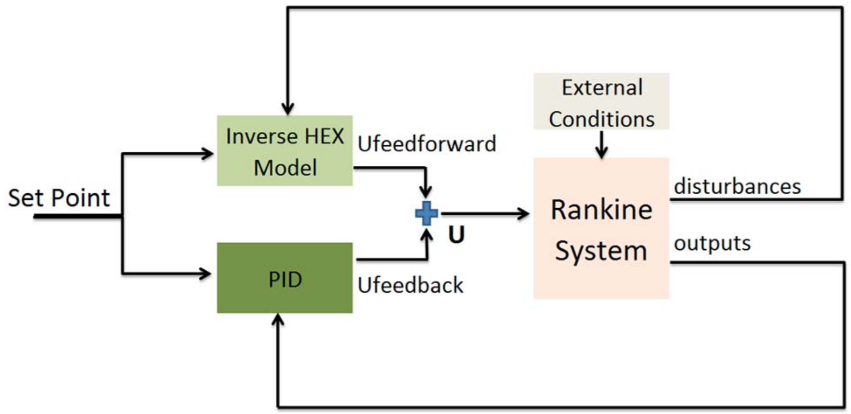


# R&D at ULiege

## *Waste heat recovery from ICEs*

- Highly transient heat sources requires **advanced control**
  - Based on dynamic simulation tools
  - Collaboration with colleagues from control departments



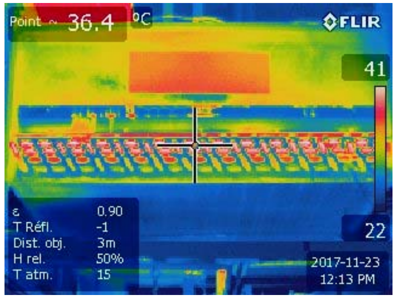



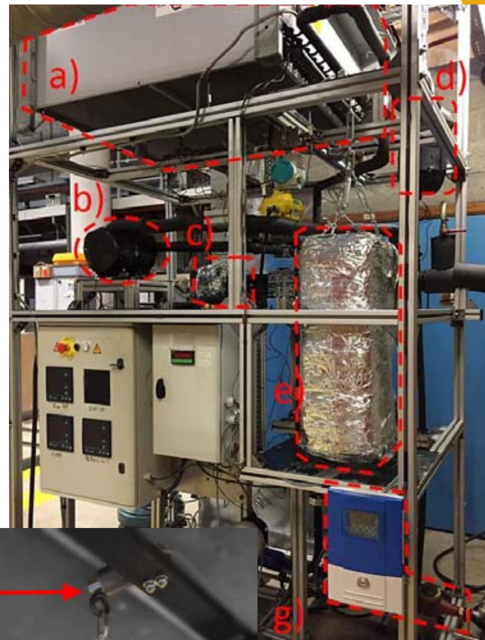

Source: V. Grelet et al.. Model based control for waste heat recovery heat exchangers Rankine cycle system in heaving duty trucks. 3rd International Seminar on ORC Power Systems, Brussels, 2015.

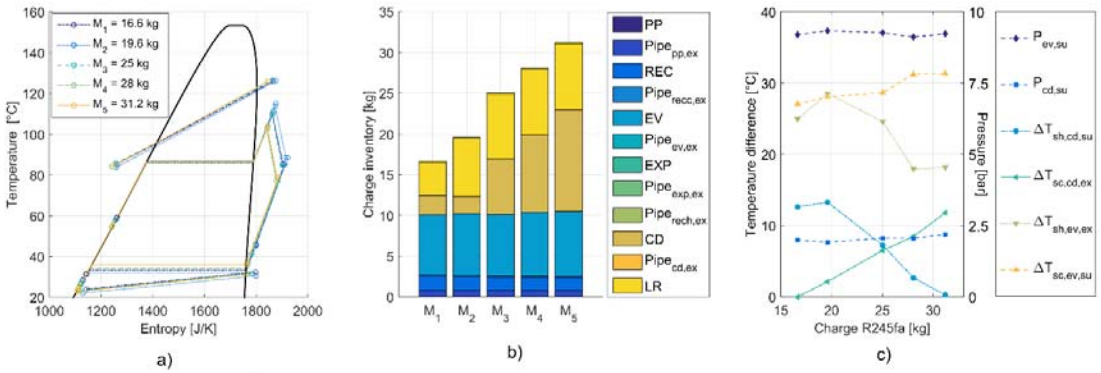
# R&D at ULiege

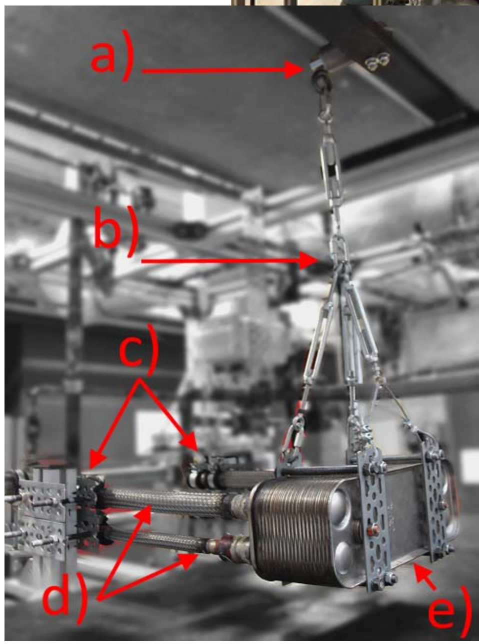
## *Waste heat recovery from ICEs*

- Better characterization of ORC in **off-design** conditions by measuring the fluid repartition among components
  - Better knowledge of heat transfer coefficients
  - Better knowledge of two-phase flow behavior

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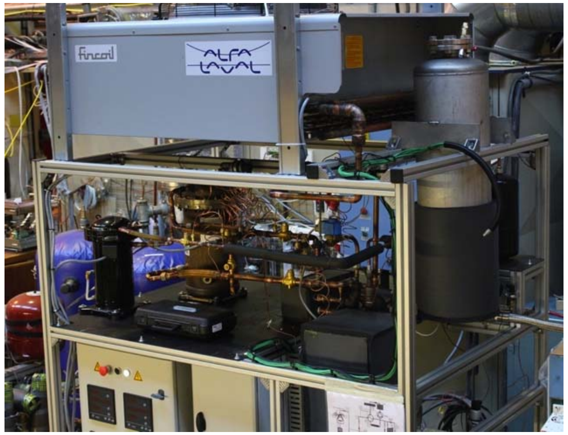
# R&D at ULiege

## *Solar energy*




- First micro solar power plant in Belgium (3kWe) based on an ORC + cylindro-parabolic trough collectors
- ORC and collectors tested separately
- Should be operational in Summer 2019

| Best cycle performance | | |
|---|---|---|
| Highest expander isentropic efficiency | 68 | % |
| Lowest expander filling factor | 105 | % |
| Highest cycle efficiency | 4.5 | % |
| Highest expander power generation | 1780 | W |
| Highest ORC net power generation | 915 | W |

- Not competitive with PV panels, but hybrid configurations (solar+biomass) promising

sun2power

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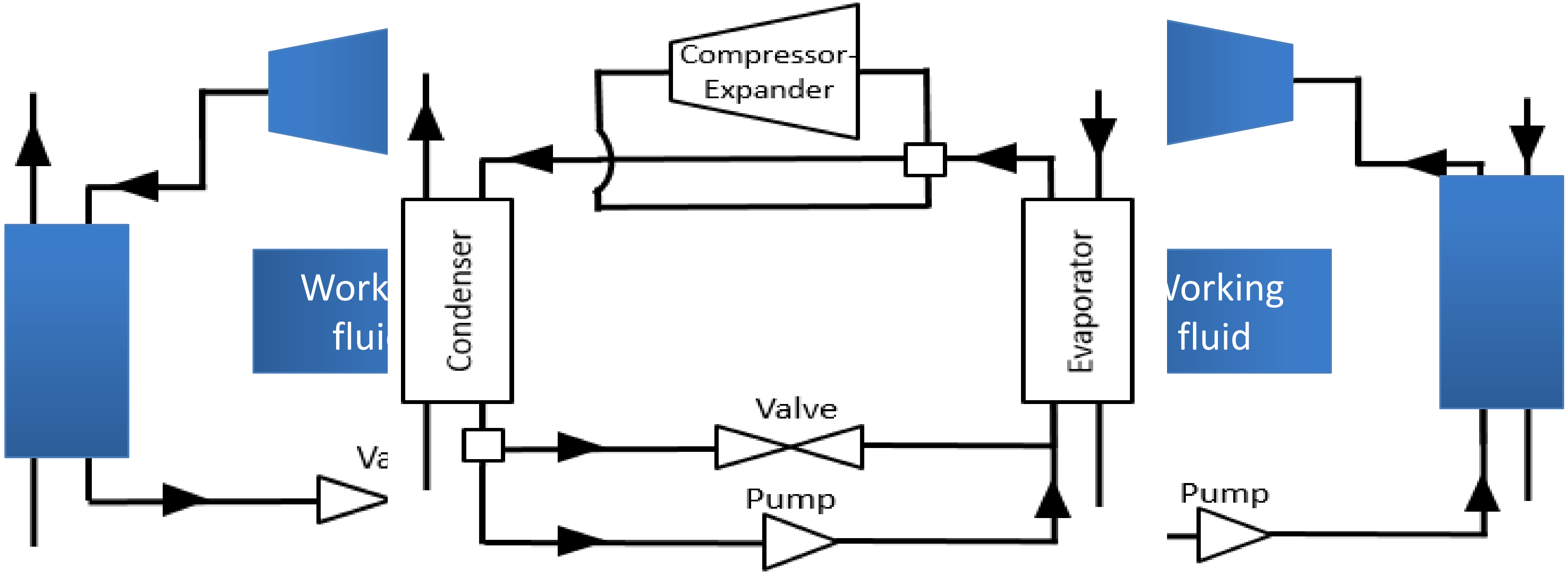
cmi ACTE enertime EMERSON Honeywell

# R&D at ULiege

## *Reversible Heat Pump - ORC*

Heat Pump → ORC → Reversible HP/ORC



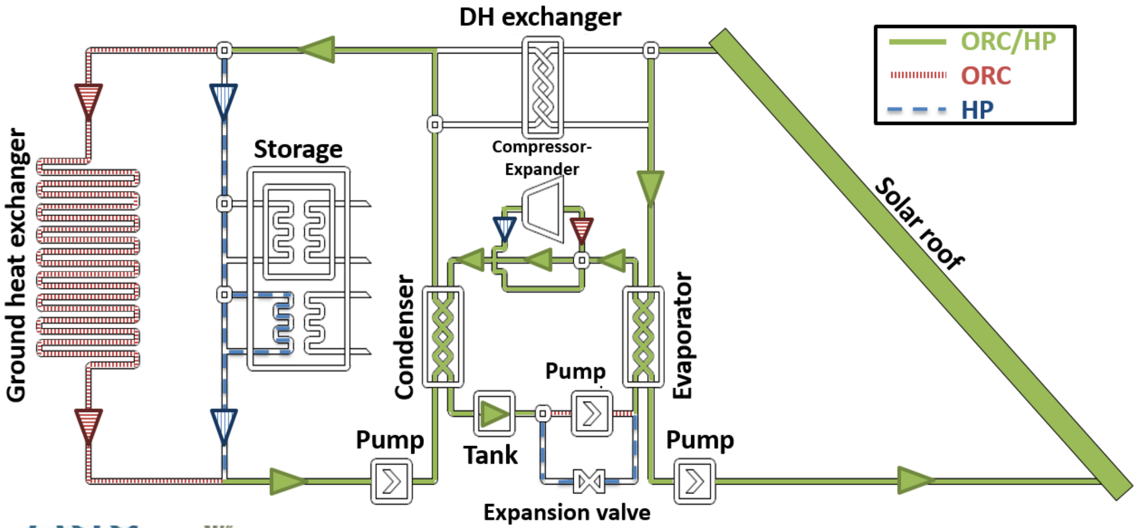

Cheap & flexible the system!

# R&D at ULiege

## *Reversible Heat Pump - ORC*

Reversible HP/ORC unit instead of a classical residential heat pump

- Components and costs close to a classical residential heat pump (cheap)
- Large solar roof (absorber) + horizontal ground heat exchanger
- 3 operating modes (DH,HP,ORC) with low cost architecture

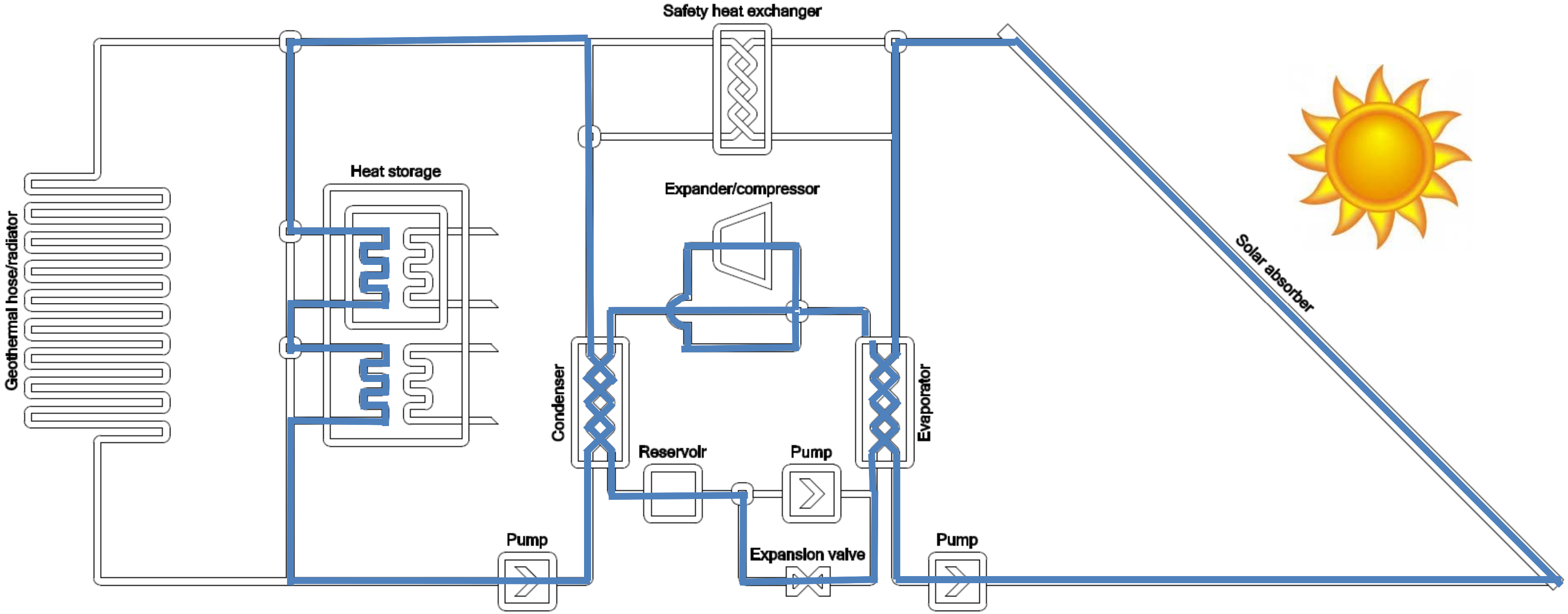



(Innogie 2014)

# R&D at ULiege

## *Reversible Heat Pump - ORC*

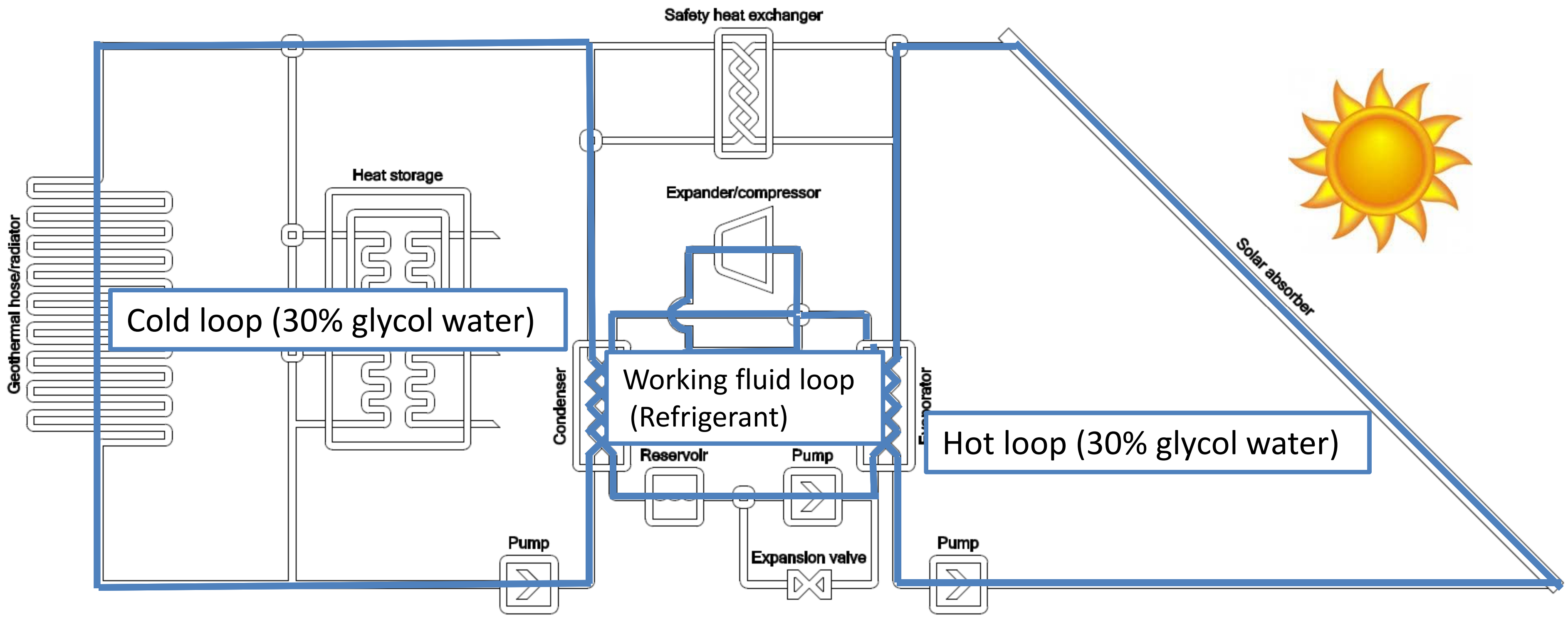
**Heat pump mode**



# R&D at ULiege

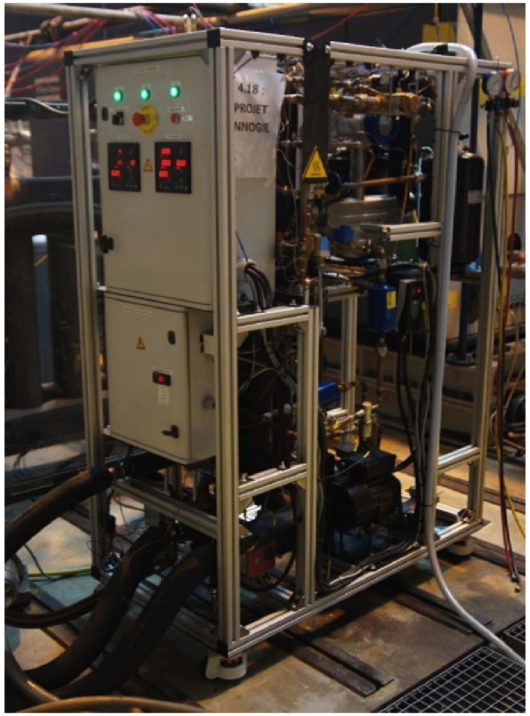
## *Reversible Heat Pump - ORC*

**ORC mode**



# R&D at ULiege

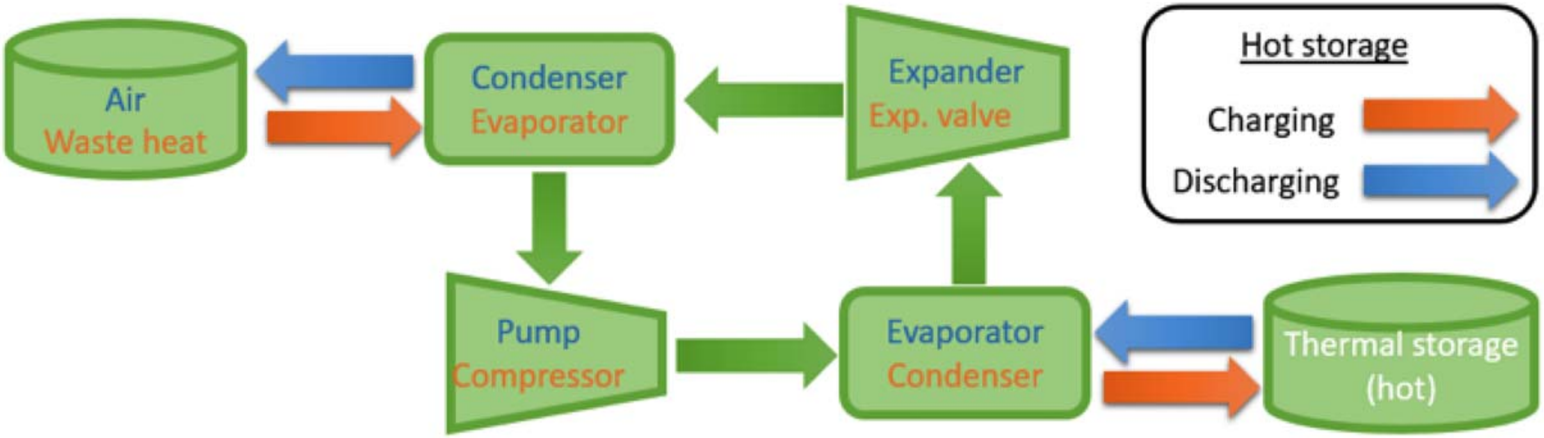
## *Reversible Heat Pump - ORC*



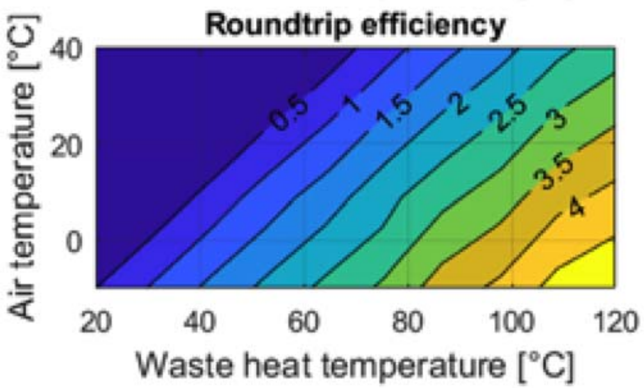
- Prototype:
  - Sized to produce 4030 kWhe per year
  - COP of 4.21 (Tev=21°C/Tcd=61°C)
  - ORC efficiency of 5.7% (Texcd=25°C/Tsuev=88°C)
- Economical profitability not demonstrated versus PV + heat pumps
- Looking to other applications of reversible heat pumps/ORCs.

# R&D at ULiege

## *Reversible Heat Pump - ORC*




- Pumped Thermal Energy Storage
- Combined with waste heat recovery (or geothermal energy), round-trip efficiencies alrger than 1 could be achieved.



# Conclusions

- Large scale ORCs is a mature technology with some profitable markets
- Today, small-scale (<50 kWe) ORCs are still used in niche markets
  - Micro and small-scale CHP markets could beneficiate from the development of the mobile applications (Trucks/cars) market (=mass production market)
  - There is room for improvement => still many scientific opportunities (advanced control, 2-phase flows, advanced modeling tools)
  - No perfect choice for expansion machine (nor for the working fluid). Turbines?
- Reversible HP/ORC: promising applications is Pumped Thermal Energy Storage