Very high-temperature heat pumps applied to energy efficiency in industry

Application of industrial heat pumps

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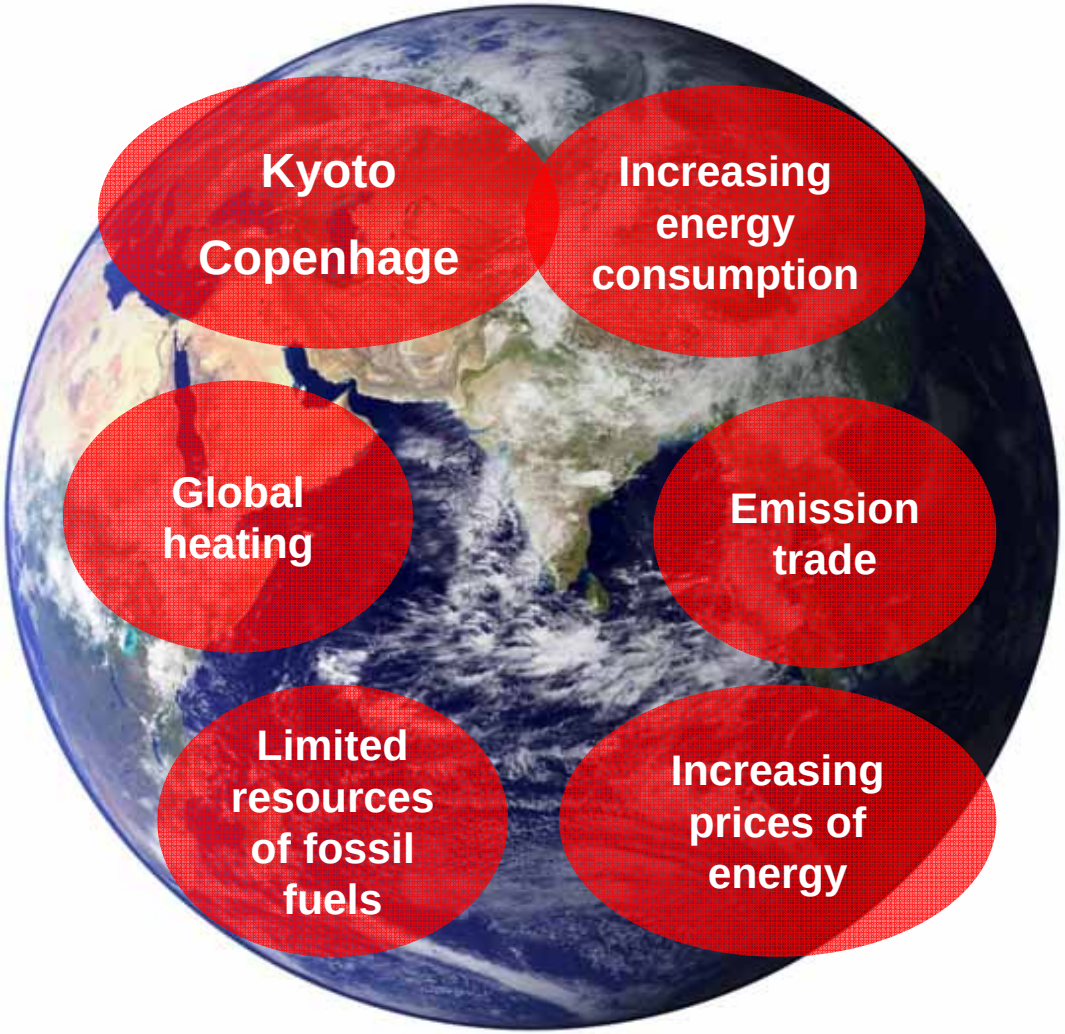
EDF R&D

CHANGER L'ÉNERGIE ENSEMBLE

Energy efficiency :
A contribution to environmental protection

Challenges !

- Reduce energy consumption
- Reduce CO_2 emissions
- Increase the process profitability



French Industry : Energy consumption

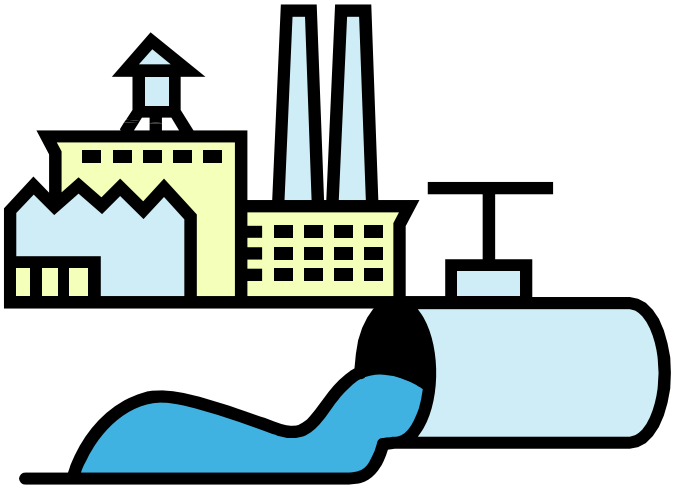
Energy consumption in French industry

~ 450 TWh/year with 150 Elec

300 TWh Fossil fuels

Nat Gaz 46%
Oil 30%
Coal 14%
Biomass 8%
Others 2%

Thermal losses



~ 140 TWh/year

=

High temperature thermal losses (waste heat)
250-300°C……1100°C

~ 100 TWh/year

+

Low temperature thermal losses (waste heat)

~ 40 TWh/year

Waste heat recovery (1)

In a decreasing energetic interest order

There are thermal requirements in the industrial plant

$T_{req} < T_{waste}$

Heat exchanger
=
Cons ~ 0
CO2 ~ -100%

$T_{req} > T_{waste}$

Heat Pump

COP 3 to 5
CO2 ~ - 80 à 95%

$T_{req} >> T_{waste}$

If possible Preheating by heat exchanger or Heat Pump

Waste heat recovery (2)

In a decreasing energetic interest order

There is no interesting thermal requirement in the industrial plant

Look for outside thermal requirements

Neighbor industrial plant, thermal network…

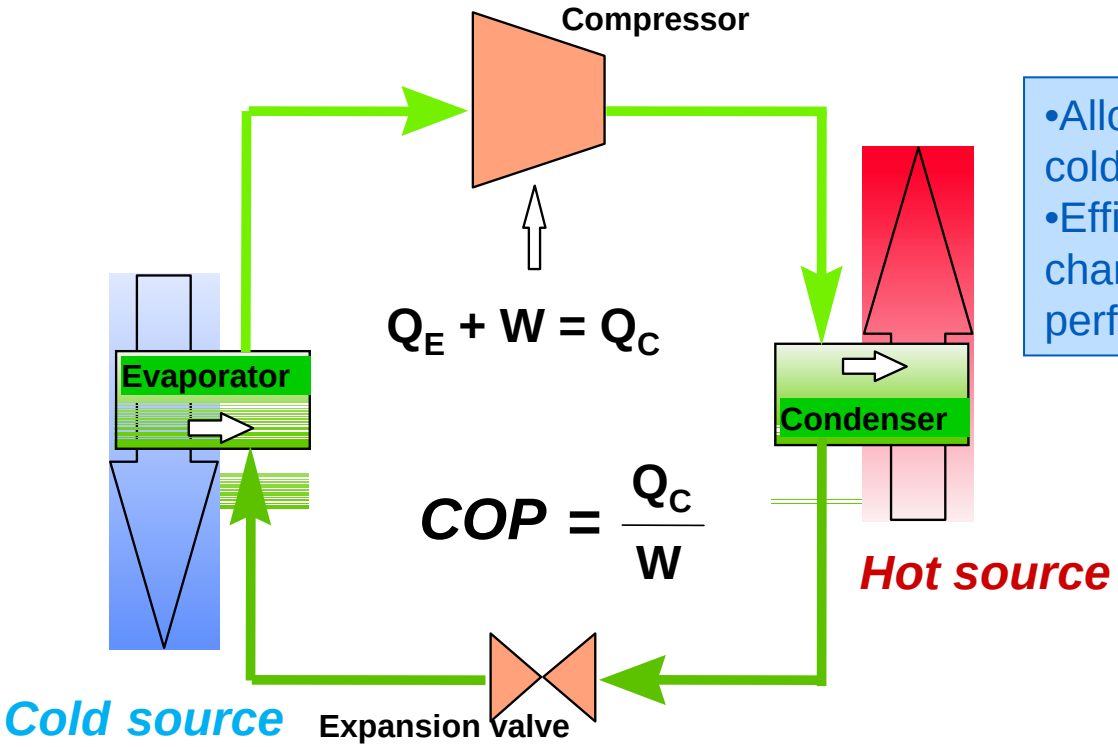
There are cold requirements

Absorption
=
COP
0,3 to 0,7

Not any thermal need

Electrical valorization
ORC
=
COP
0,1 to 0,2

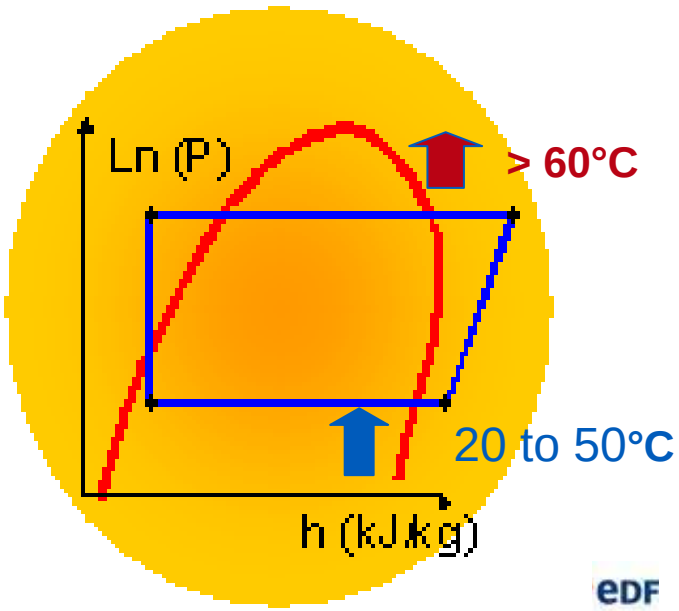
Heat Pump



$$Q_E + W = Q_C$$

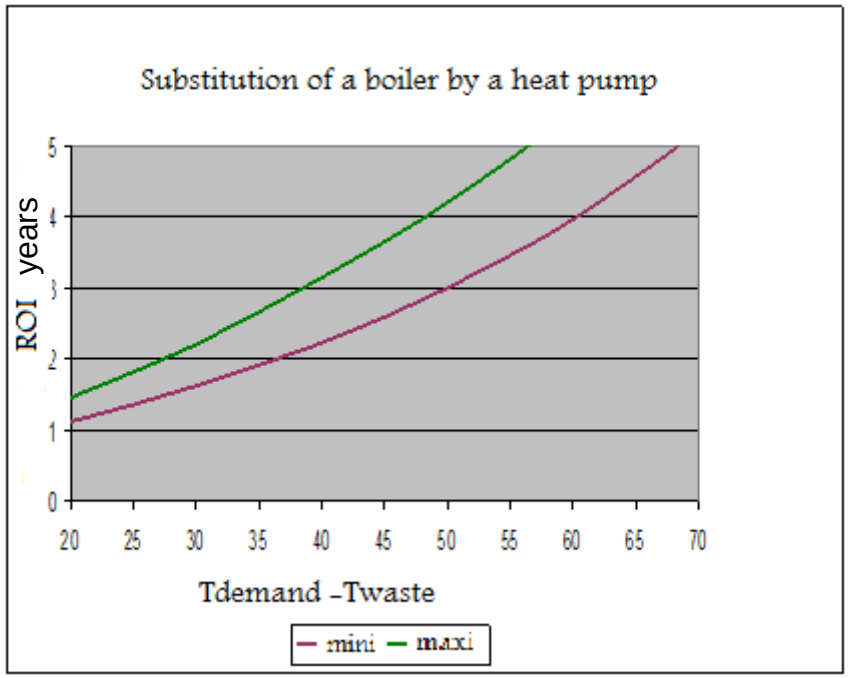
$$COP = \frac{Q_C}{W}$$

- Allows to transfer thermal energy from a cold source to a hot source
- Efficiency of the installation is characterized by a coefficient of performance : COP



HP Interest :

Economic point of view

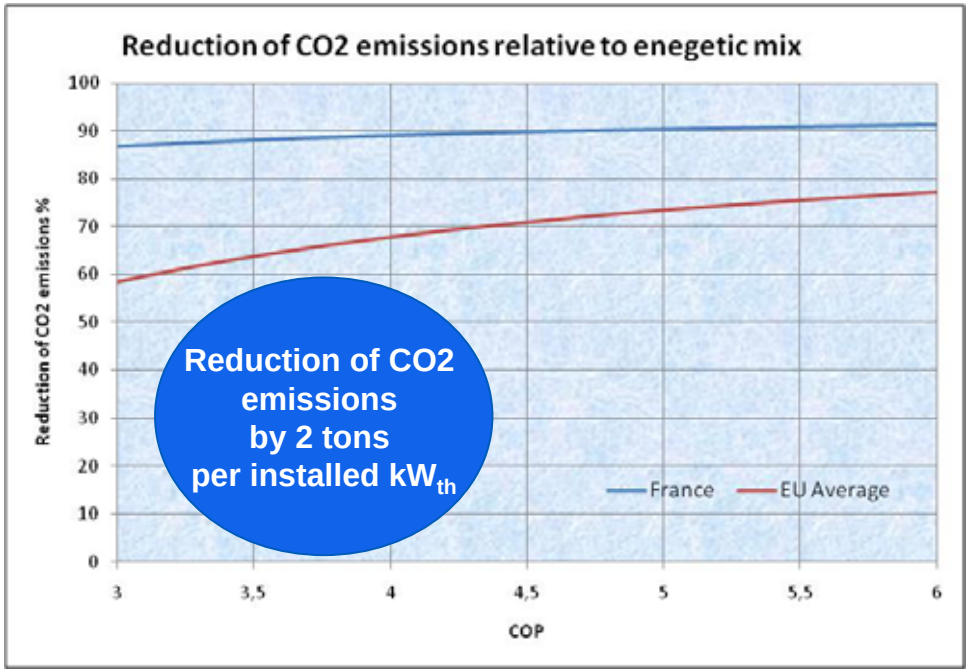


Substitution of a boiler by a Heat Pump
8000h/year (Steam efficiency : 0,85%)

I = 1500 €/kW$_{elec}$

Gas cost: 30 €/MWh
Electricity cost : 60 €/MWh

Environmental point of view



Substitution of a boiler by a Heat Pump
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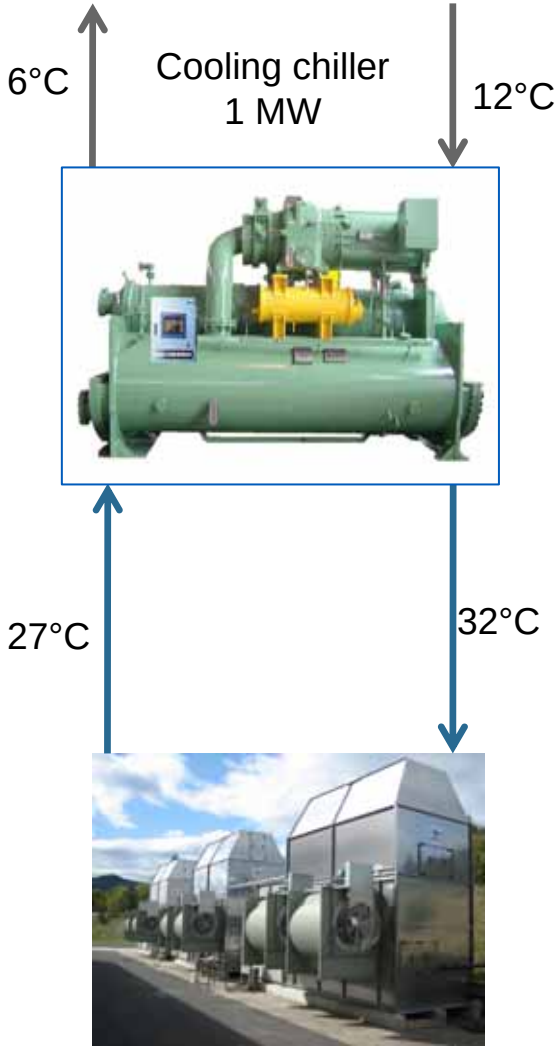
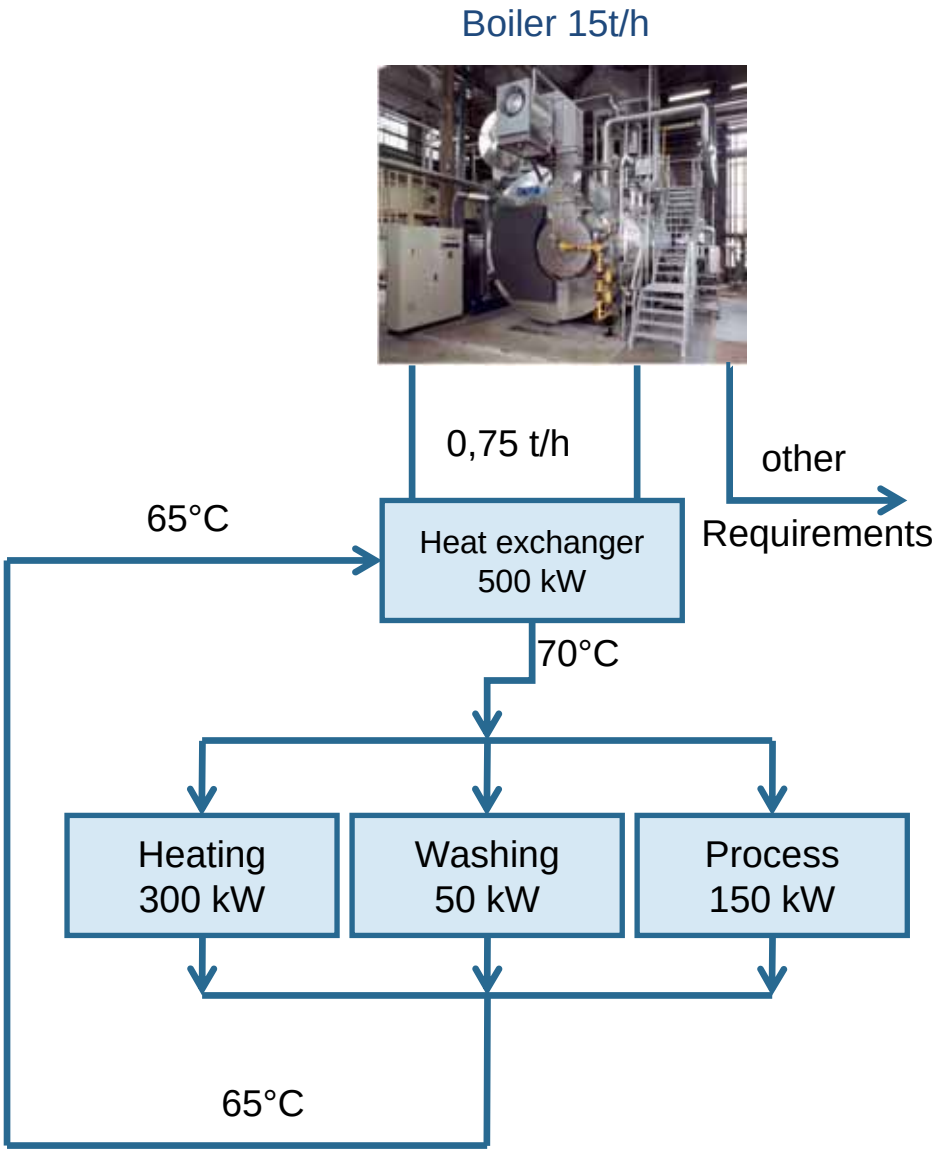
Industrial HP: Waste heat recovery study case





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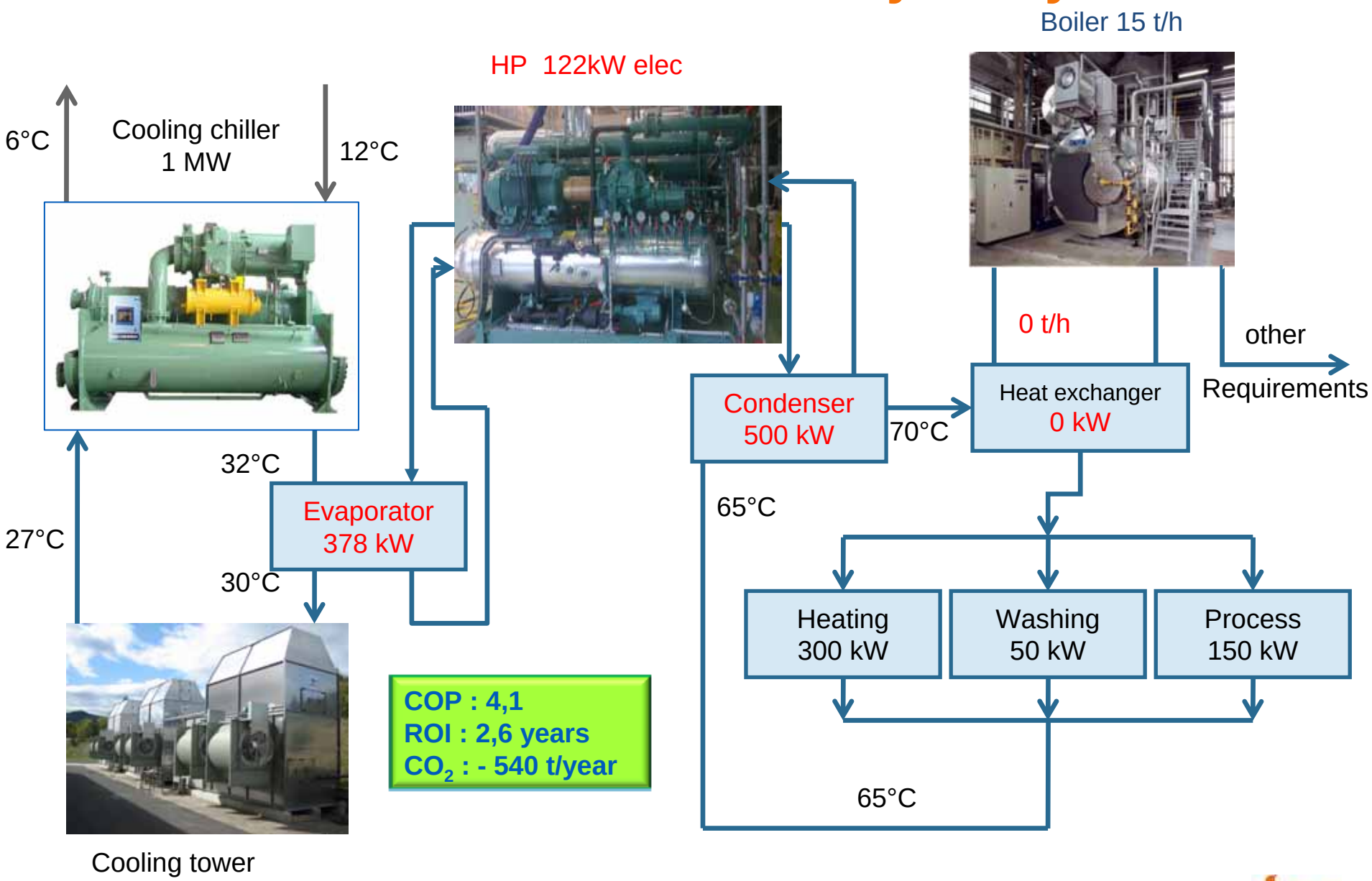
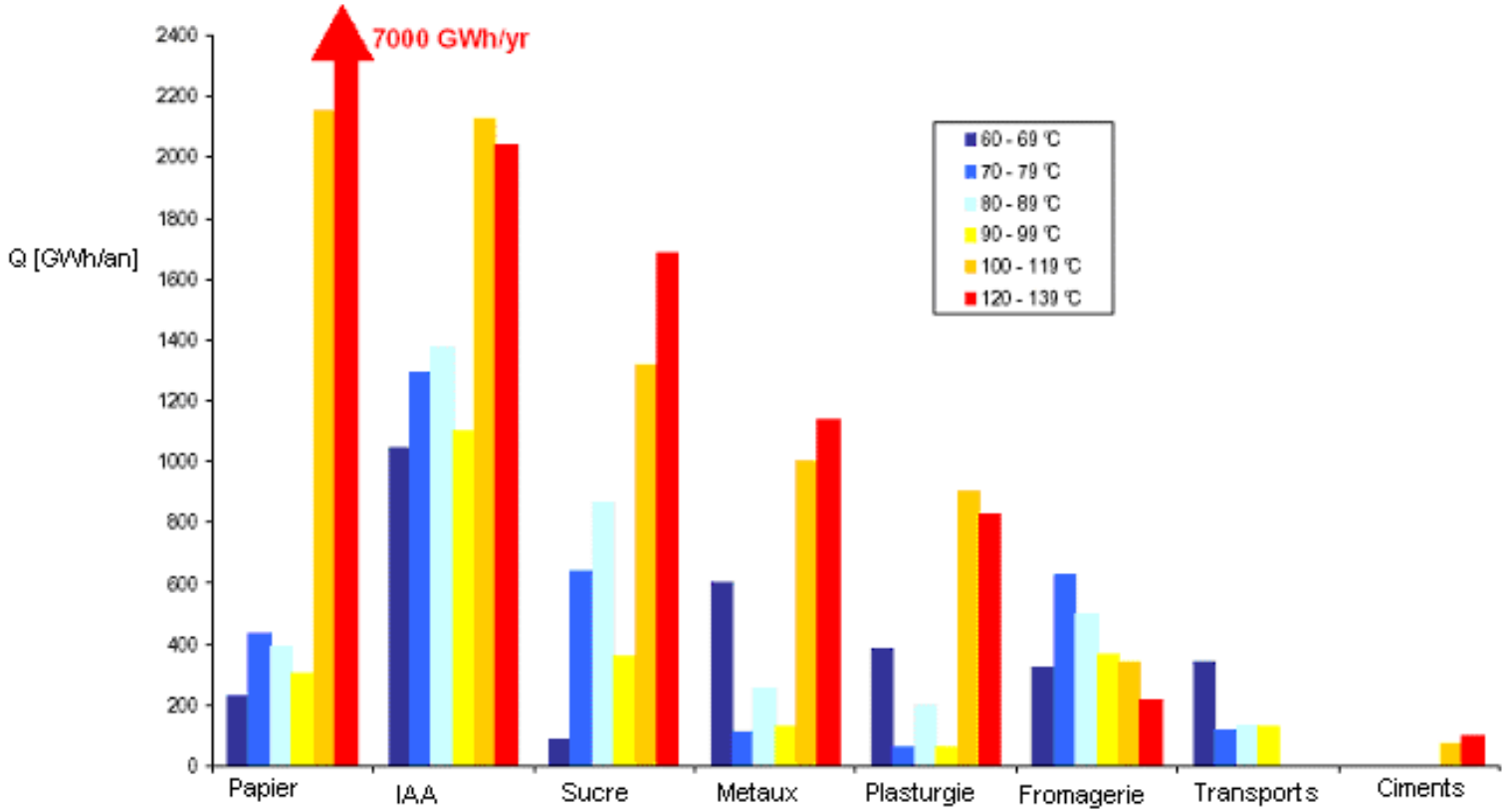


Heat market

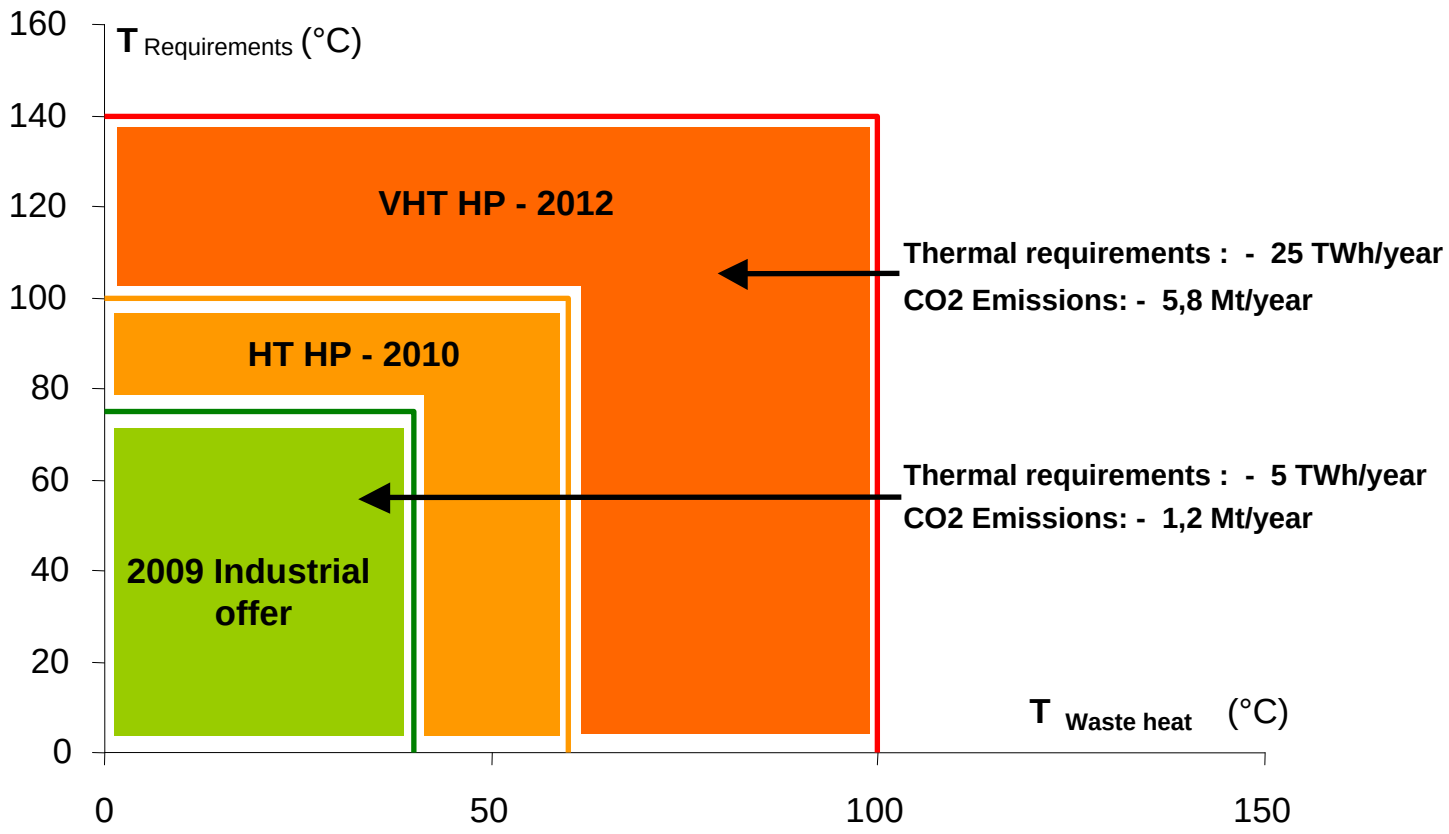
- 2007 Studies : Heat French market



High thermal requirements between 80 and 140°C

Temperature rise

HP operating range



Research program

EDF R&D : 3 main projects

Alter ECO Project

Partnership : Rhodia, Arkema, Danfoss, CIAT, GEA

HT/VHT HP
140°C – 250 kW

Integrator : CLAUGER

Technical Partnership

EDF /Johnson Controls

HT HP
100°C – 700 kW

Manufacturer : JCI

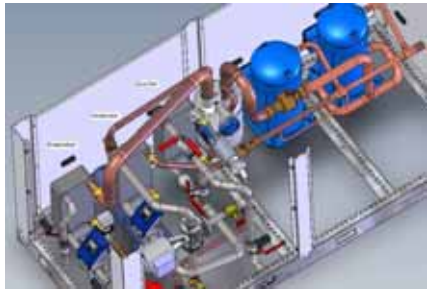
ANR PACO Project

Partnership : Johnson-Control, France Évaporation, CETHIL, AgroParistech, Matmeca …

VHT HP with water
140°C – 700 kW

Manufacturer: F-Évaporation

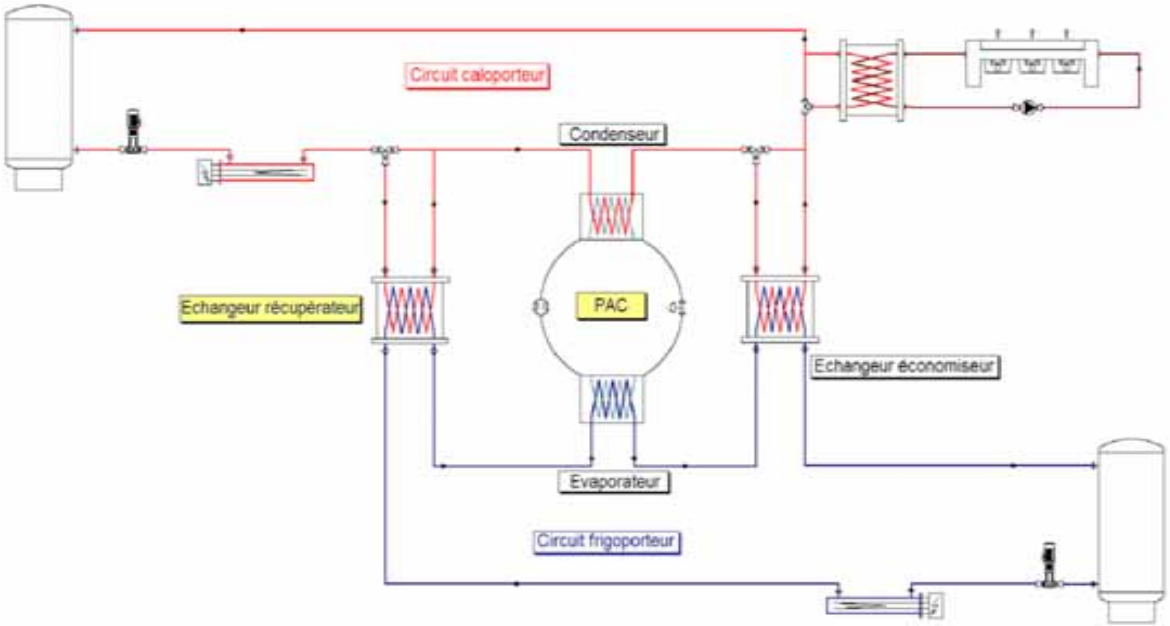
ALTER ECO project : Analysis Low Temperature Energy Recovering/ ECOnomy



- Funded by General Industry Direction
- Supported by the competitiveness pole AXELERA
- Aimed industrial sectors : chemistry, paper, plastics
- Partnership :

EDF R&D test bench in « Les Renardières »

- Large operating range
  - T evap mini : 5°C
  - Tcond Max : 150°C
  - Evaporator and condenser flow rate: 10 à 55 m3/h
  - Thermal power >700 kW
- Able to reproduce industrial conditions
- Supervisory control/measurements acquisition

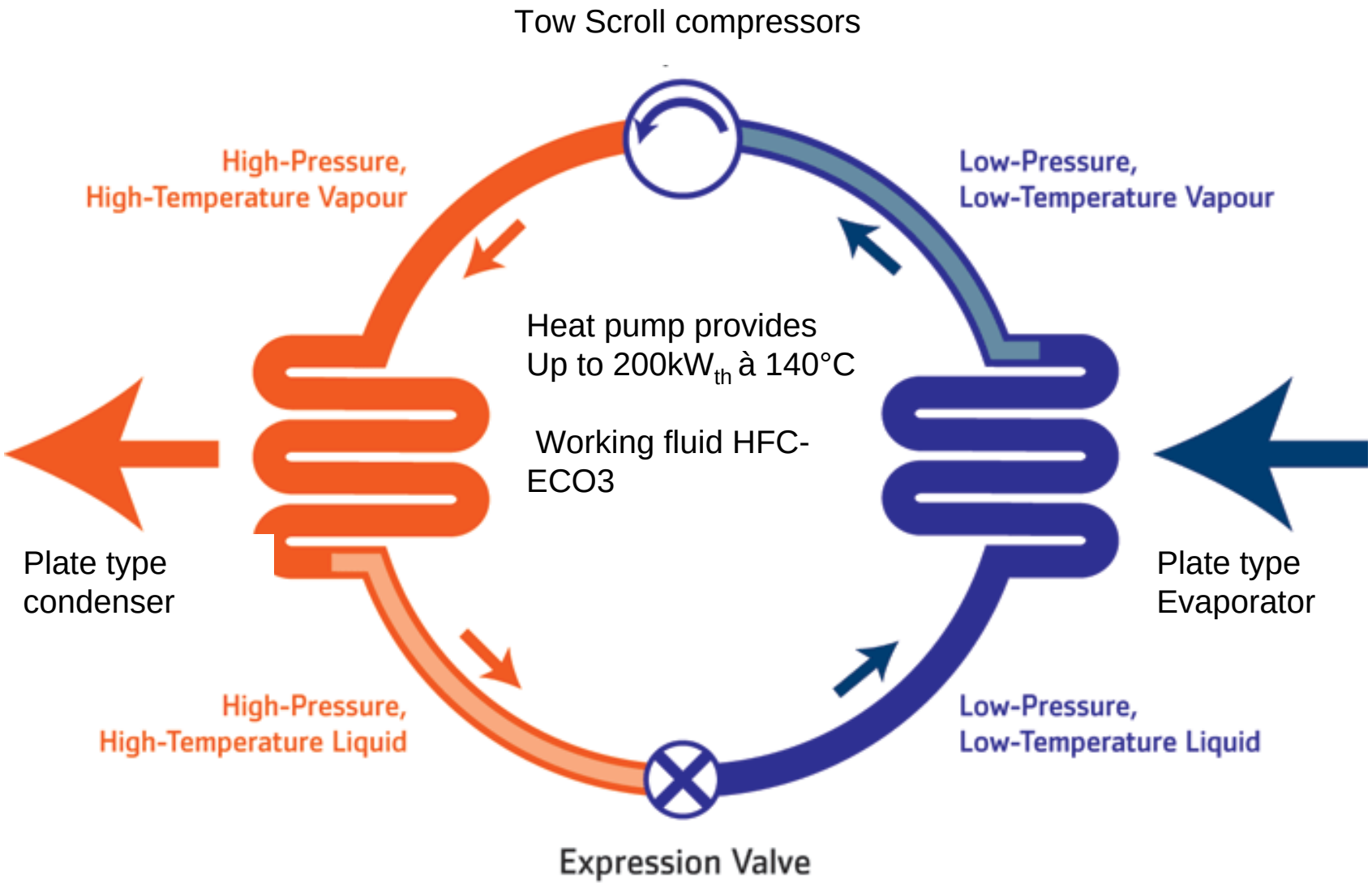


EDF R&D test bench in « Les Renardières »

High/Very high Temperature Heat pump

- HP HT/VHT Prototype
  - Working fluid (ARKEMA)
  - Compressor (DANFOSS)
  - Heat exchanger (CIAT)
  - Subcontractor integrator (CLAUGER)
  - Specifications and performance tests (EDF)

Industrial Heat pump prototype



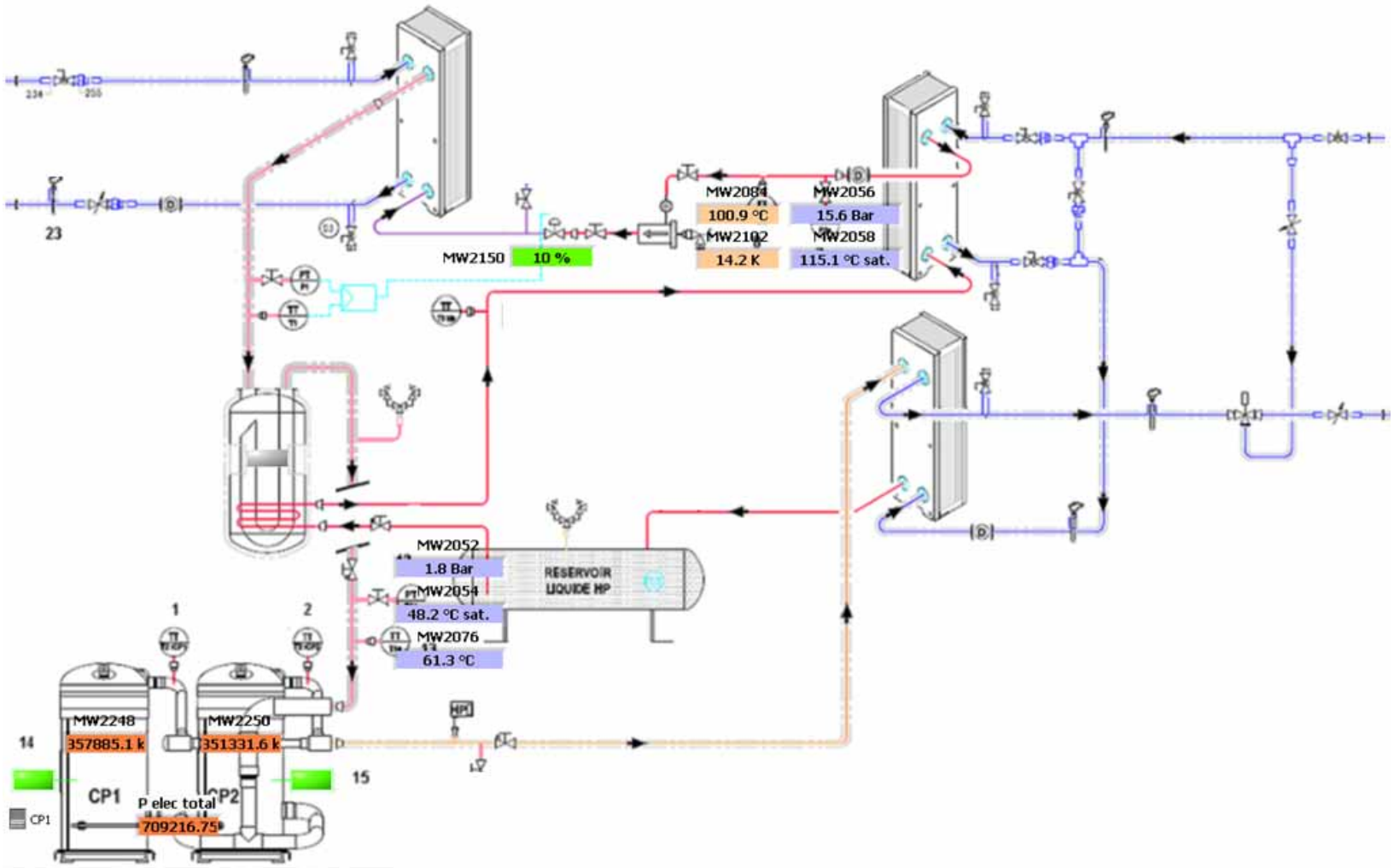
Heat pump presentation :

Technical specifications :

- Condensation temperature : 77 to 140 °C
- Evaporation temperature : 30 to 60 °C
- Compressors max power : 75 kWe
- Condenser max power : 200 kWt

Tests on EDF high temperature hydraulic bench

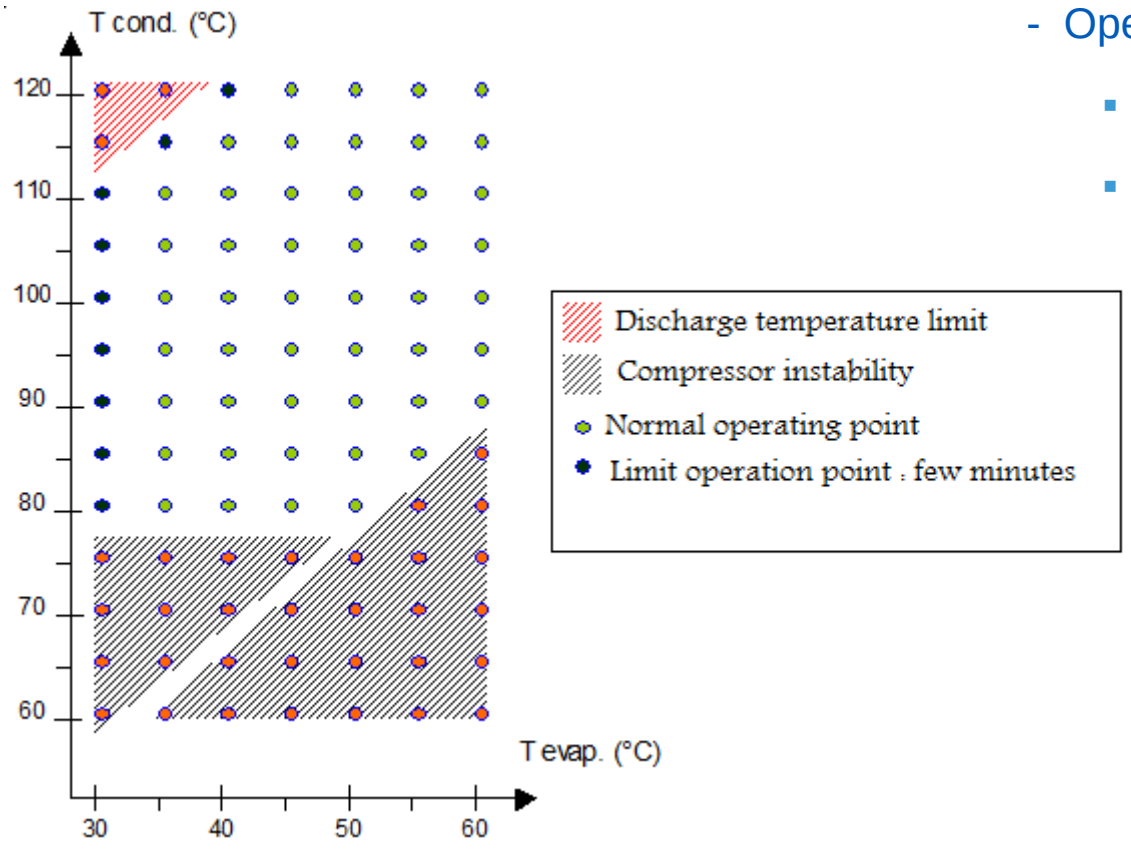
AlterECO heat pump design



Experimental test

Mapping

- Different operating points



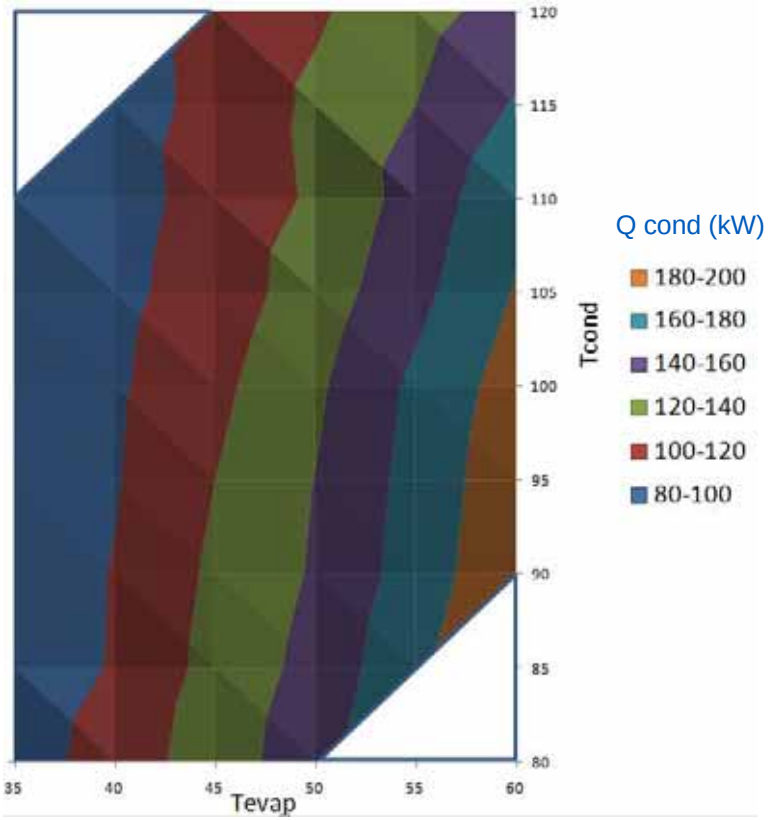
Aging test

- 1000 hours running test
- Operating point :
  - T evap : 60 °C
  - T cond : 120 °C

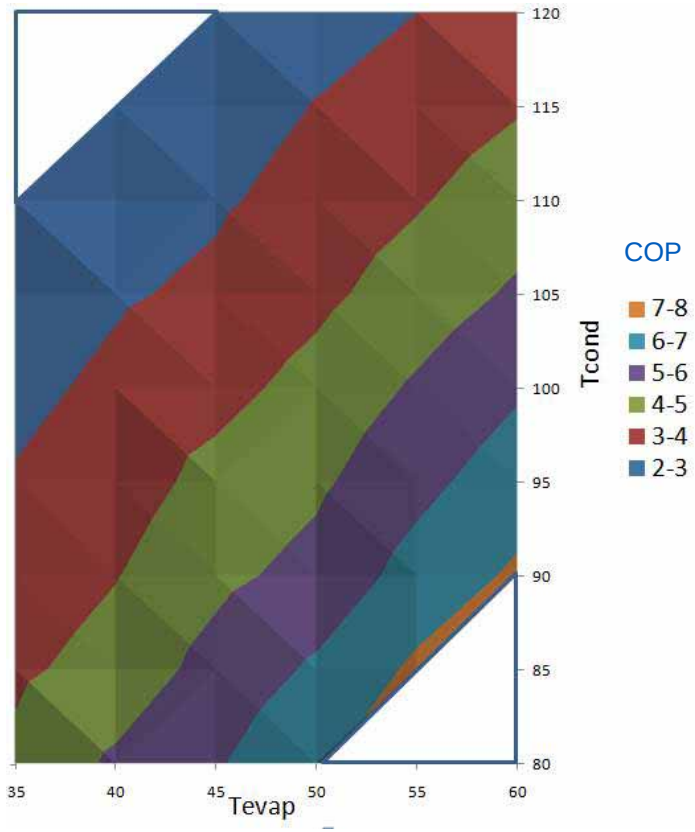
First test results

First test phase (120°C)
→Heat thermal power at the condenser
→COP

Q cond relative to Tevap and Tcond



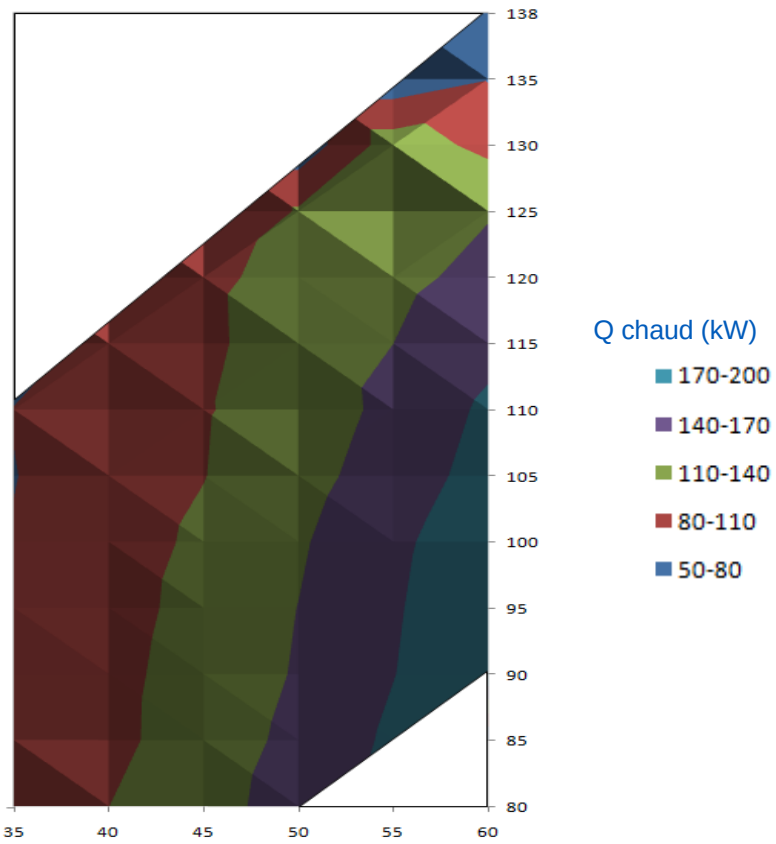
COP relative to Tevap and Tcond



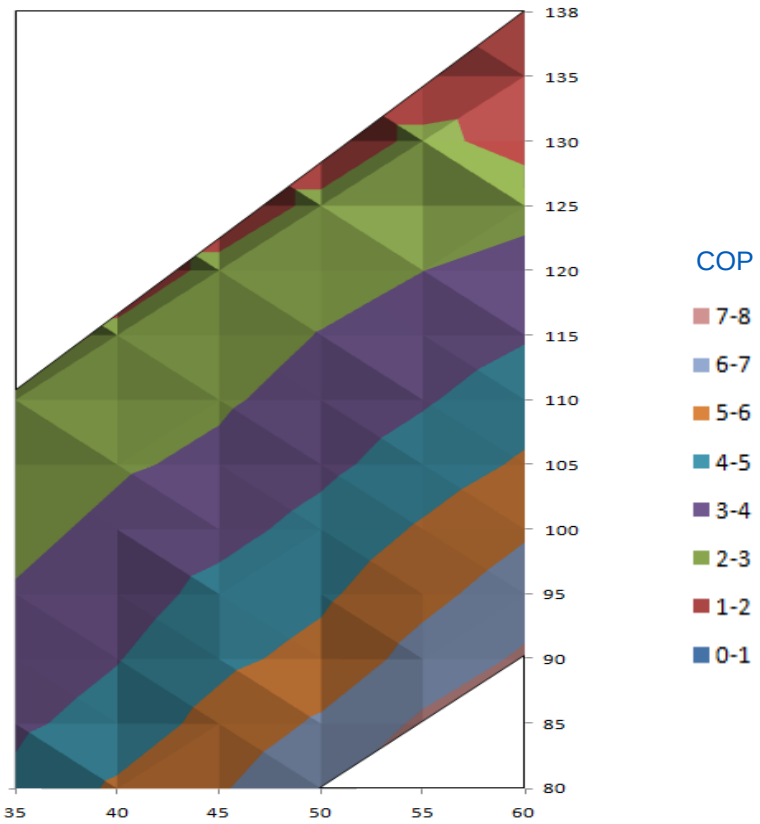
Second test results

Second test phase(140°C)
→Heat thermal power at the condenser
→ COP

Q cond relative to Tevap and Tcond



COP relative to Tevap and Tcond



Conclusions

- Performance mapping test are realized
- Aging test are realized : 1000 hours running test (T_{evap} = 60°C – T_{cond} = 120°C)
- HP up to 120°C → very high performance
- HP up to 140°C → feasibility is demonstrated but for high performances….
  - We need a too stage compressor for high temperature gap between evaporator and condenser
  - We need a special motor for high evaporating temperature.
- A industrial field test is actually on study.