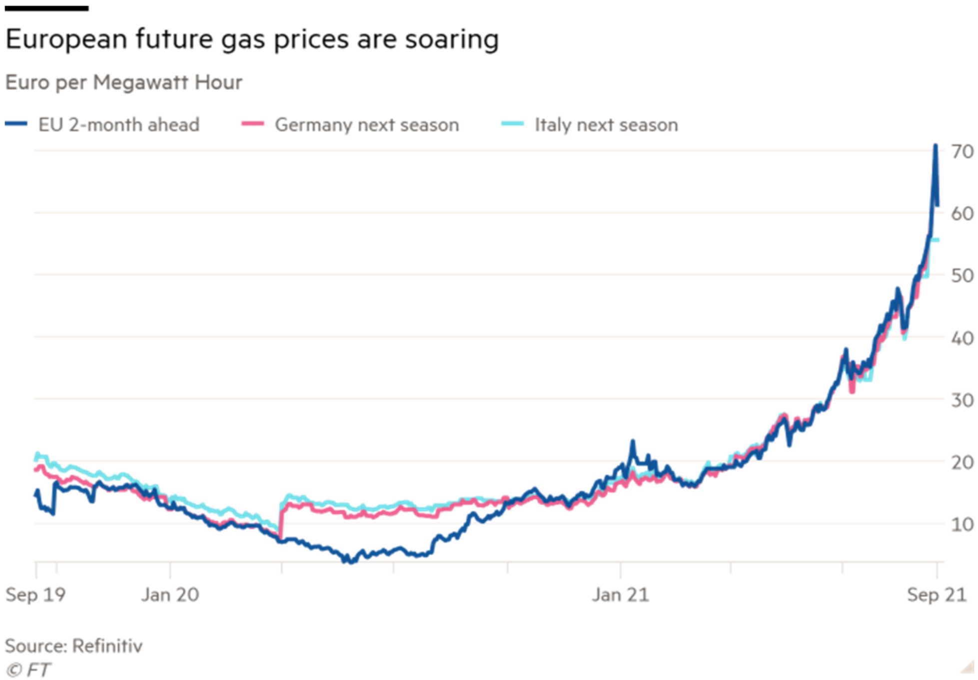
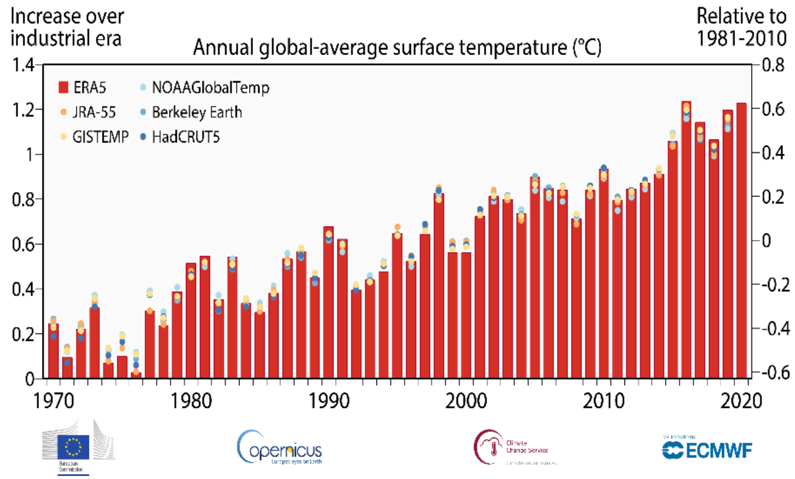
# Casos prácticos de producción de energía eléctrica a través del uso de energías renovables y calor residual con la tecnología ORC

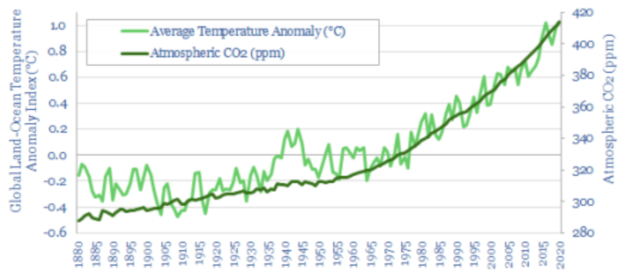
J. Navarro-Esbrí – *Grupo de investigación* *ISTENER (UJI)*

# 1. INTRODUCTION

We are currently facing a problem of global average temperature rising and also energy price increase

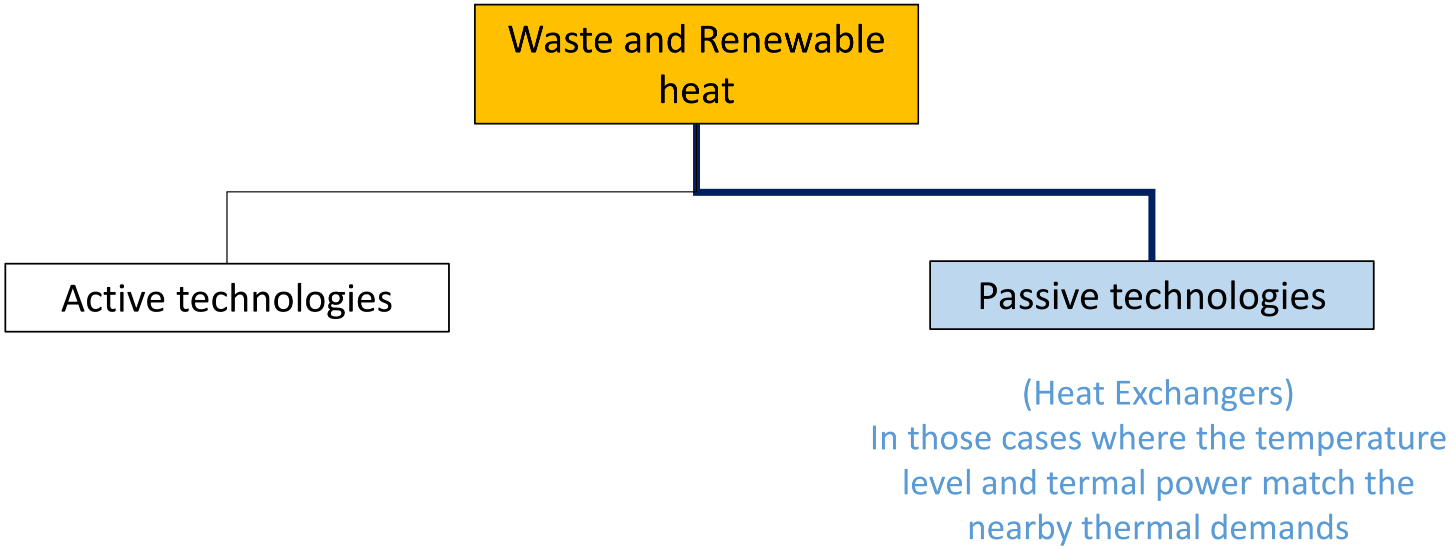


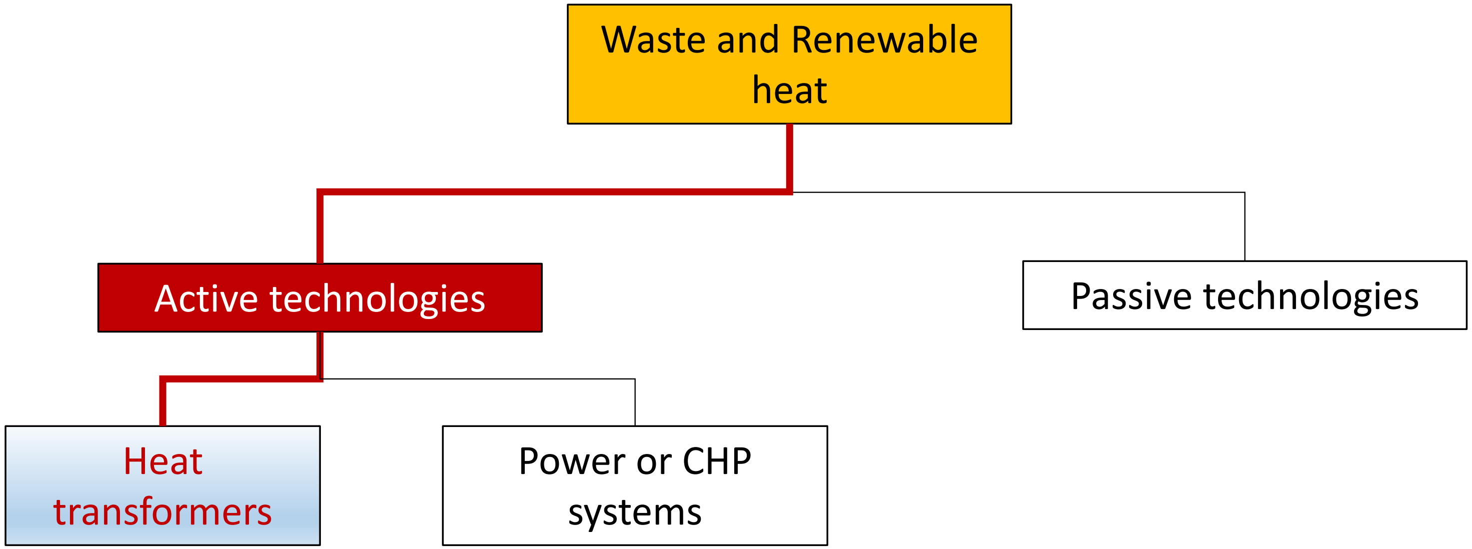

*J. Navarro-Esbrí*

Technologies dedicated to the use of waste and renewable heat can improve energy efficiency, reducing energy consumption and, therefore, GHG emissions



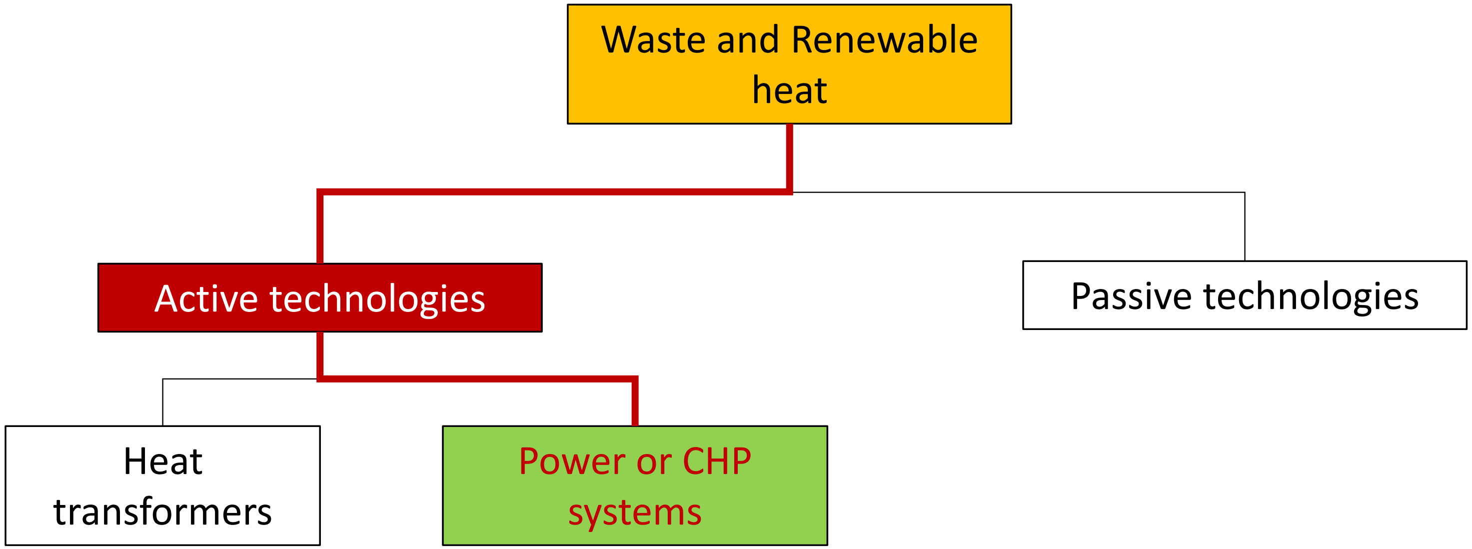
# 1. INTRODUCTION

Technologies dedicated to the use of waste and renewable heat can improve energy efficiency, reducing energy consumption and, therefore, GHG emissions




Adapt the thermal level of the heat source to those close thermal demands (rising through heat pump systems or taking profit through cold production systems)

Technologies dedicated to the use of waste and renewable heat can improve energy efficiency, reducing energy consumption and, therefore, GHG emissions




Turning heat into electricity or electricity and profitable heat

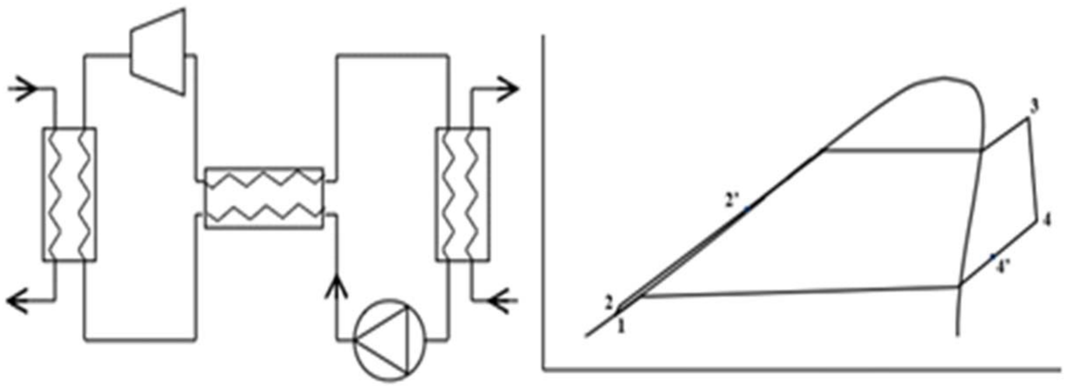
## 1. INTRODUCTION

Focusing on Power or CHP technologies for low temperature heat recovery, ORC technology stands out due to its simple structure, reliability and easy maintenance.

Waste and Renewable heat

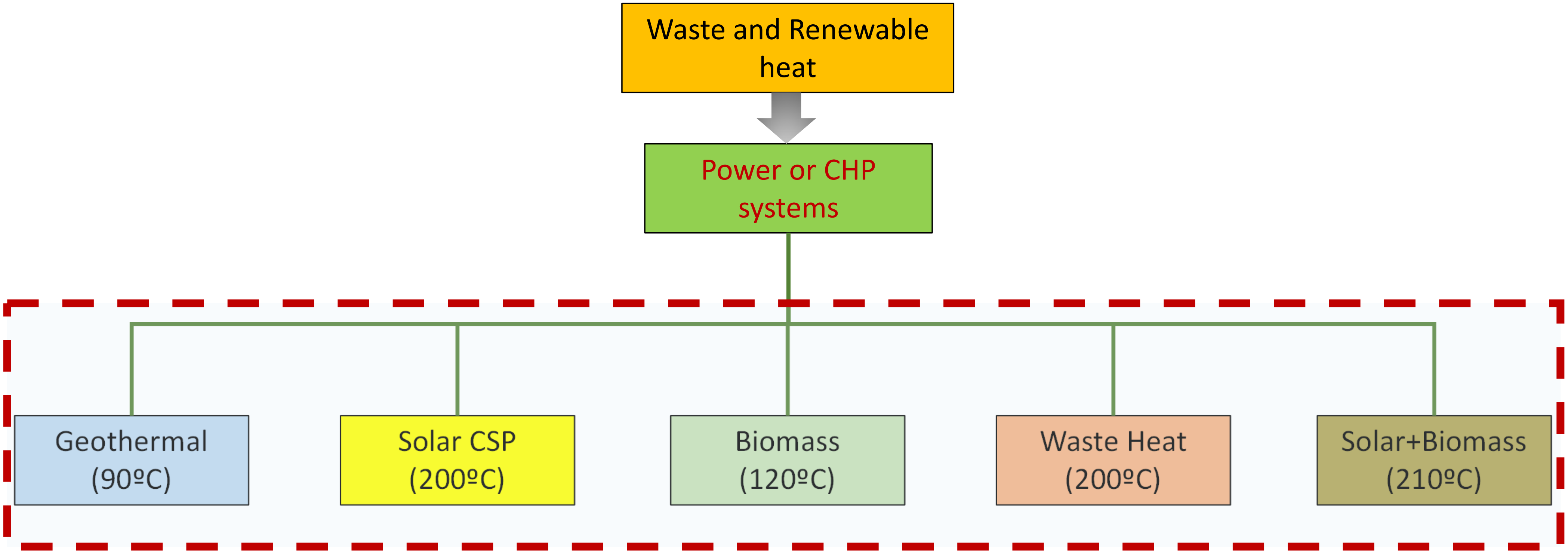
↓

Power or CHP systems




J. Navarro-Esbrí

Here, the attention is focused on low temperature waste and renewable heat sources (from 90ºC up to 210ºC) and microgeneration (< 100 kWe), analyzing various real applications of ORC technology.



# 2. CASE STUDY (GEOTHERMAL)

The first case consists of an ORC machine used for electricity generation with geothermal water as a co-product from and Oil&Gas extraction.

## 2. CASE STUDY (GEOTHERMAL)

The first case consists of an ORC machine used for electricity generation with geothermal water as a subproduct from and Oil&Gas extraction.

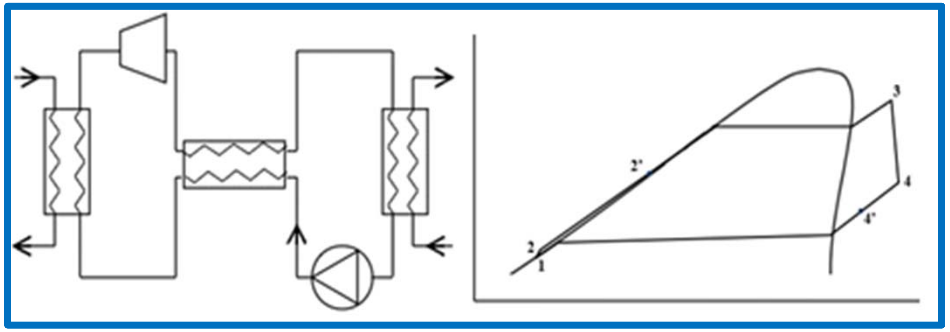
During oil production, the Oil&Gas company encountered high temperature gradients, permeable rocks, and water which could be brought to the surface without additional cost as a co-product of oil extraction

Oil

Geothermal water

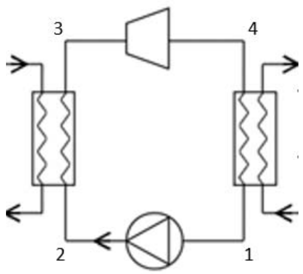
T > 80ºC

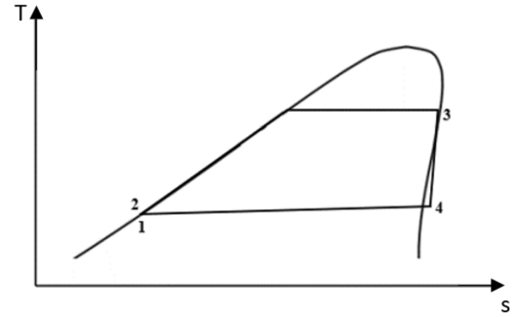
An ORC is installed to take profit of the geothermal water to produce electricity.



# 2. CASE STUDY (GEOTHERMAL)

## Geothermal energy ORC main characteristics




| | |
|---|---|
| **Working fluid** | HFO-1234ze(E) |
| **Cycle configuration** | Basic cycle |
| **Expander type** | Volumetric |
| **Heat source fluid** | Geothermal water |
| **Heat sink fluid** | Air (ambient) |

## Geothermal energy ORC operating data

| | |
|---|---|
| Heat source inlet temperature (ºC) | 93 |
| Heat source outlet temperature (ºC) | 83 |
| Heat source volumetric flow rate ($m^3/h$) | 129 |
| Heat source thermal power (kWt) | 1300 |
| Ambient temperature (ºC) | 30 |
| Gross power output (kWe) | 82 |
| Gross efficiency (%) | 6,3 |
| Net efficiency (%) | 5,2 |

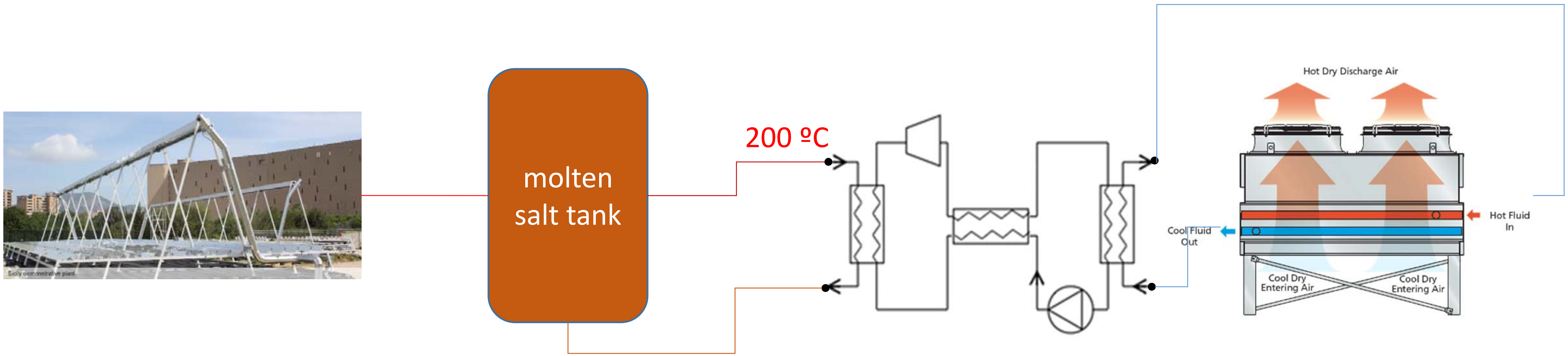
Economic feasibility for this case depends mainly on the electricity price and investment cost, since geothermal energy is a co-product (zero cost). In this specific case, the facility is in the field, separated from the primary electricity grid, and electricity cost is higher than in a typical industrial facility. So, despite the low efficiency of the ORC machine, caused by the low heat source temperature, economic feasibility is high enough to be replicated.

# 3. CASE STUDY (SOLAR)

This ORC machine is integrated into a trigeneration installation developed in the framework of the European project STS-Med (Small scale Thermal Solar units for Mediterranean communities), in the Italian pilot plant of the project, in which they also included a concentrated solar power (CSP) plant, biomass boiler, thermal storage tank, and absorption chiller.

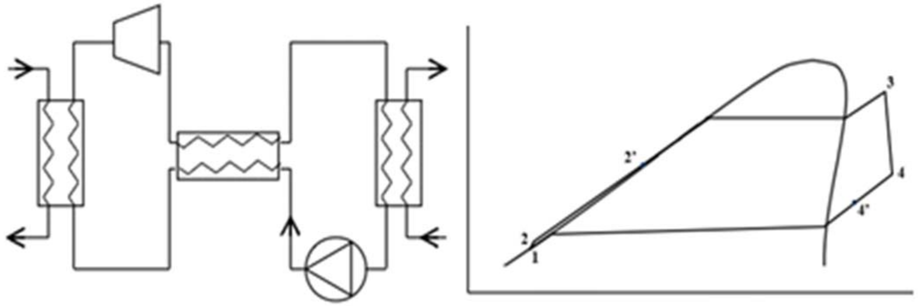
# 3. CASE STUDY (SOLAR)

The installation consists of Fresnel linear concentrators modules with a surface of 470 m$^2$. (producing a maximum thermal power of 220 kW) and a high-performance energy storage tank, consisting of an 8 m$^3$ molten salt tank with a thermal capacity of 400 kWh that operates between 160 and 260 °C.



# 3. CASE STUDY (SOLAR)

## Solar energy ORC main characteristics


| | |
|---|---|
| **Working fluid** | HFC-245fa |
| **Cycle configuration** | Regenerative cycle |
| **Expander type** | Volumetric |
| **Heat source fluid** | Thermal oil |
| **Heat sink fluid** | Water (dry cooler) |

## Solar energy ORC operating data

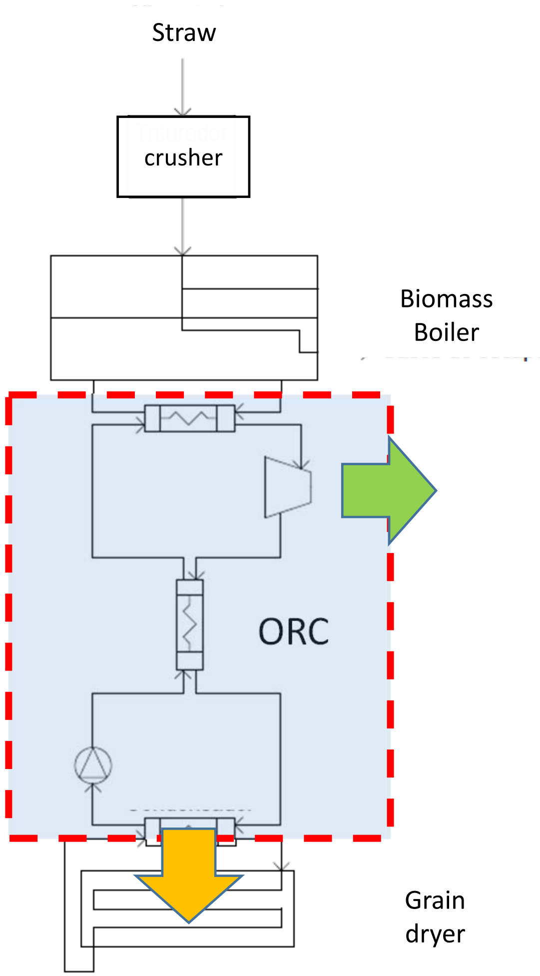

| | |
|---|---|
| Heat source inlet temperature (ºC) | 200 |
| Heat source outlet temperature (ºC) | 165 |
| Heat source volumetric flow rate ($m^3/h$) | 3,5 |
| Heat source thermal power (kWt) | 63 |
| Heat sink inlet temperature (ºC) | 25,8 |
| Gross power output (kWe) | 8,5 |
| Gross efficiency (%) | 13,4 |
| Net efficiency (%) | 11,4 |

About economic feasibility, it is not the main key of the project, as the main objective is to show different possibilities of integrating renewable technologies for trigeneration installations.

This case presents an ORC machine that is integrated into the biomass cogeneration system of farm exploitation located in the UK. Activities related to the agricultural process produce large amounts of residues, in the form of straw, used as biomass for drying the grain.

# 4. CASE STUDY (BIOMASS)

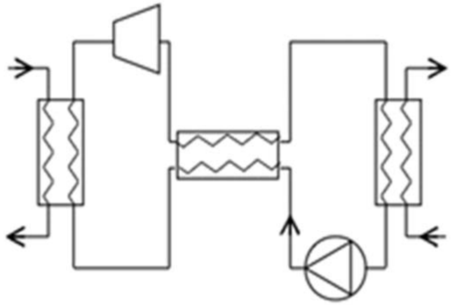
The ORC equipment is designed to use low temperature heat sources, between 90 °C and 120 °C, with simple integration with conventional biomass boilers. The useful heat produced by the ORC is used to meet the grain dryer demand (in the form of hot water 50ºC).

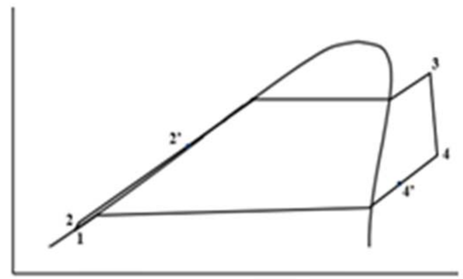




J. Navarro-Esbrí

# 4. CASE STUDY (BIOMASS)

## Biomass energy ORC main characteristics



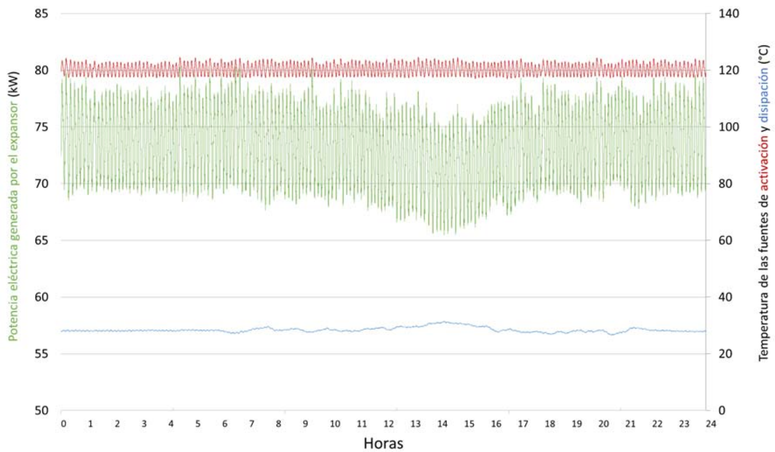

| Working fluid | HFC-245fa |
|---|---|
| Cycle configuration | Regenerative cycle |
| Expander type | Volumetric |
| Heat source fluid | Water (biomass boiler) |
| Heat sink fluid | Water (dryer) |

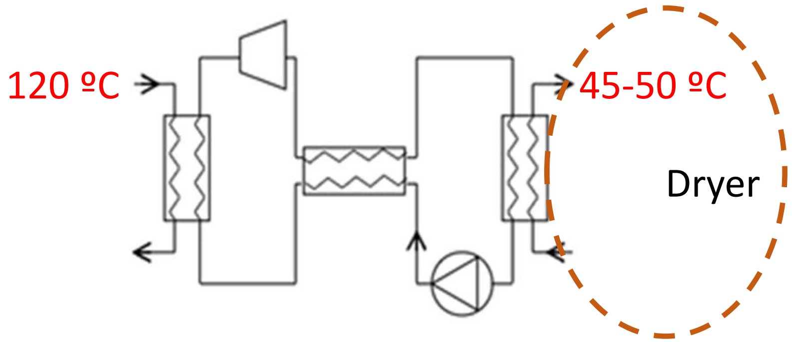
# 4. CASE STUDY (BIOMASS)

ISTENER UJI

## Solar energy ORC operating data


| Heat source inlet temperature (ºC) | 120 |
| --- | --- |
| Heat source outlet temperature (ºC) | 107 |
| Heat source volumetric flow rate ($m^3/h$) | 61,5 |
| Heat source thermal power (kWt) | 895 |
| Heat sink temperature (ºC) | 35-46 (750 kWt) |
| Gross power output (kWe) | 73,5 |
| Gross efficiency (%) | 8,2 |
| Net efficiency (%) | 7,5 |



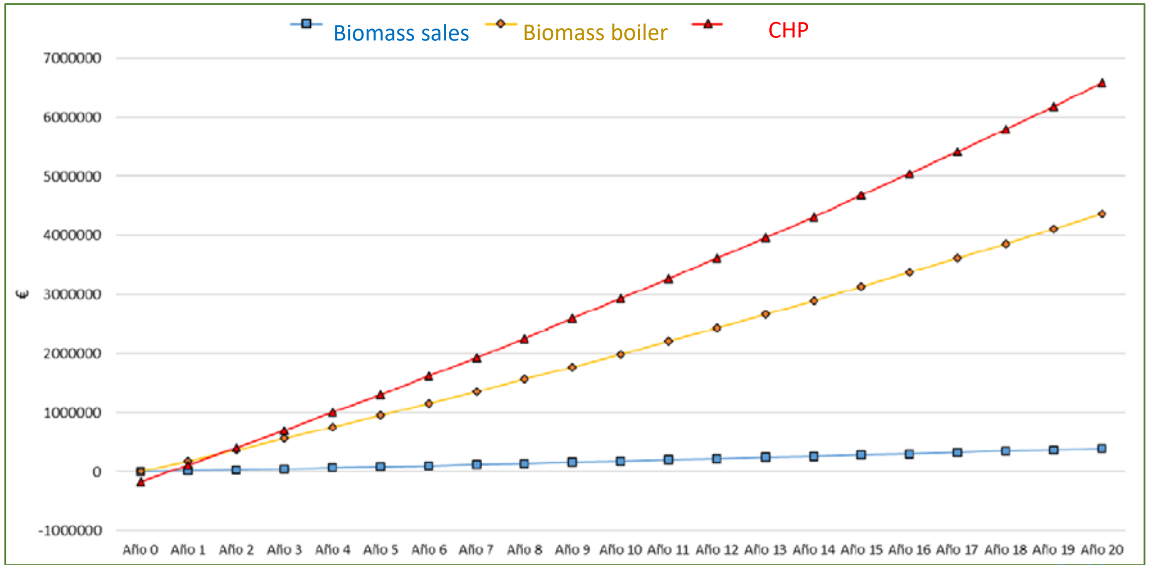

*J. Navarro-Esbrí*

# 4. CASE STUDY (BIOMASS)

## Solar energy ORC operating data


Economic feasibility, in this case, is increased by the Combined Heat and Power (CHP) production, thanks the Renewable Heat Incentive (RHI) of the government.

Cash flow of the facility during 20 years

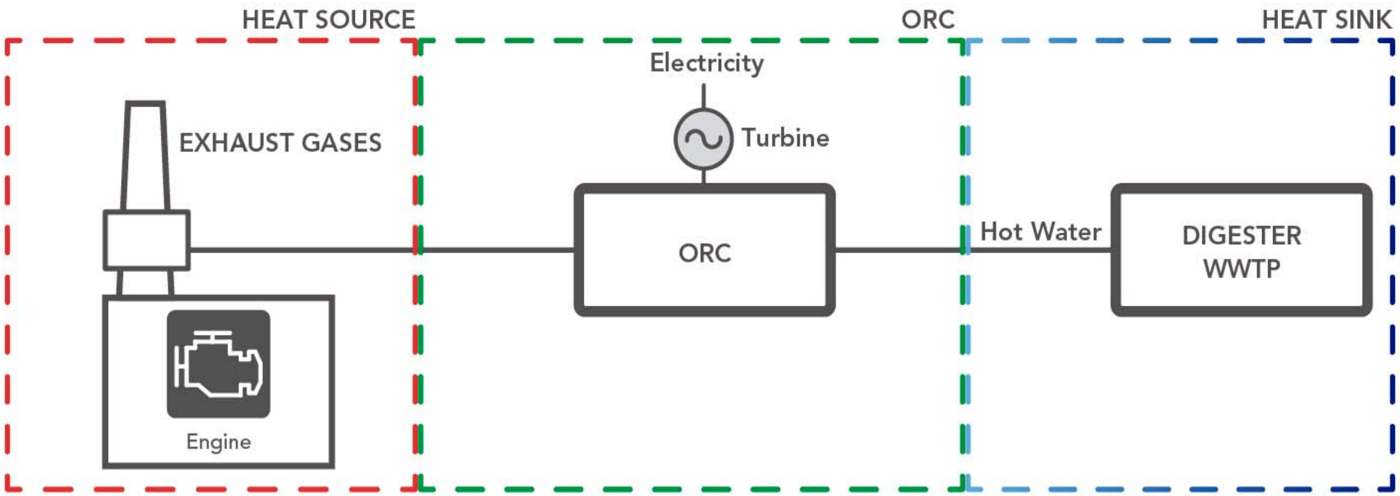



*J. Navarro-Esbrí*

This case consists of an ORC equipment installed in the wastewater treatment plant of Alcoy (Spain).

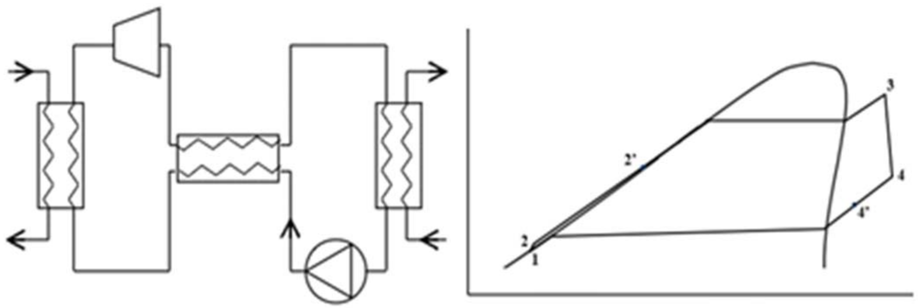
# 5. CASE STUDY (WHR - GAS ENGINE)

This case consists of an ORC equipment installed in the wastewater treatment plant of Alcoy (Spain). The machine uses the waste heat from the cogeneration engine to produce electricity and heat to assist the anaerobic digester.



# 5. CASE STUDY (WHR - GAS ENGINE)

## WHR CHP ORC main characteristics

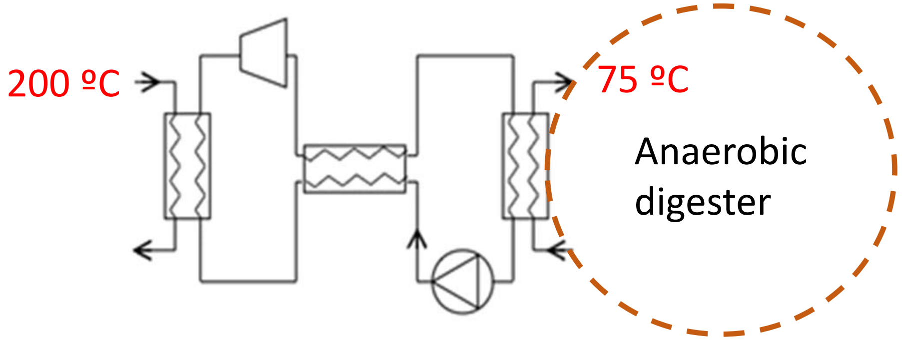

| Working fluid | HFC-245fa |
|---|---|
| Cycle configuration | Regenerative cycle |
| Expander type | Volumetric |
| Heat source fluid | Thermal oil (engine WH) |
| Heat sink fluid | Water (digester) |

# 5. CASE STUDY (WHR - GAS ENGINE)

## Energy ORC operating data


| Heat source inlet temperature (ºC) | 200 |
|---|---|
| Heat source outlet temperature (ºC) | 140 |
| Heat source volumetric flow rate ($m^3/h$) | 12,5 |
| Heat source thermal power (kWt) | 400 |
| Heat sink temperature (ºC) | 60-75 (300 kWt) |
| Gross power output (kWe) | 35 |
| Gross efficiency (%) | 8,8 |
| Net efficiency (%) | 6,9 |

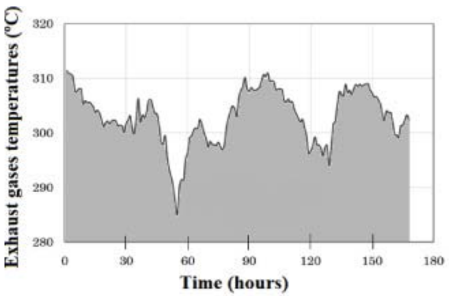
Economic feasibility, in this case, is imposed by energy efficiency of the global WWTP. It depends on the energy price (electricity and heat) and $CO_2$ emissions reduction.

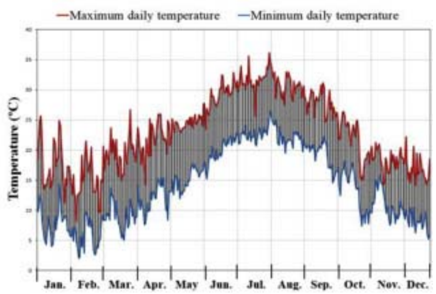


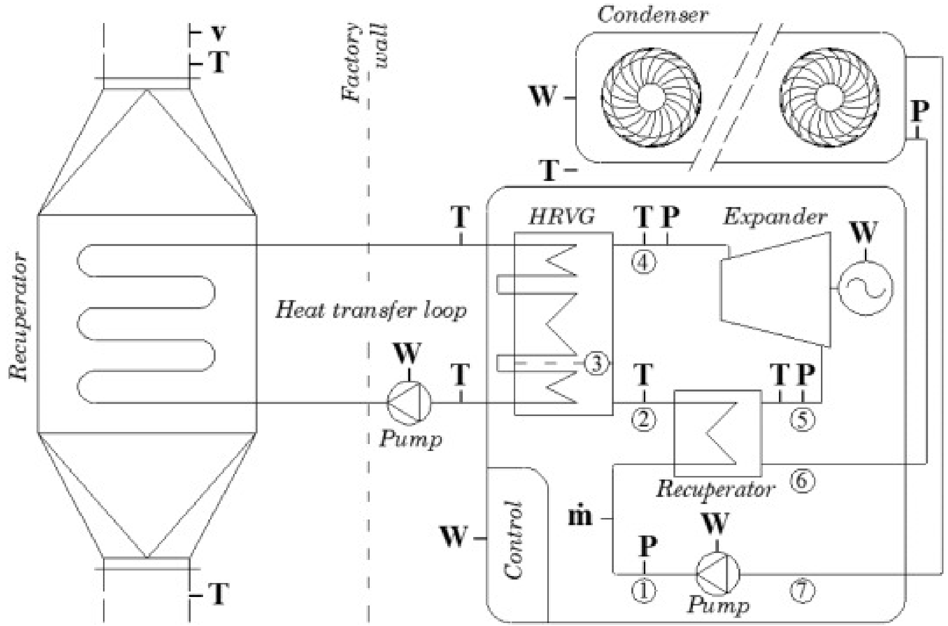

*J. Navarro-Esbrí*

This case deals about an experimental application of an ORC (organic Rankine cycle) in a ceramic kiln in Nules (Spain).

## ORC main characteristics



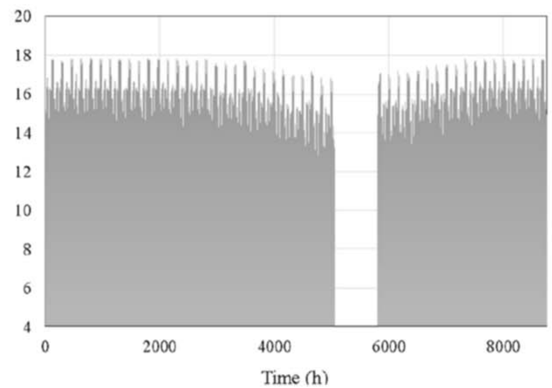

| | |
|---|---|
| **Working fluid** | HFC-245fa |
| **Cycle configuration** | Regenerative cycle |
| **Expander type** | Volumetric |
| **Heat source fluid** | Thermal oil |
| **Heat sink fluid** | Ambient air |

# 5. CASE STUDY (WHR – CERAMIC KILN)

## ORC main characteristics

Feasibility study.

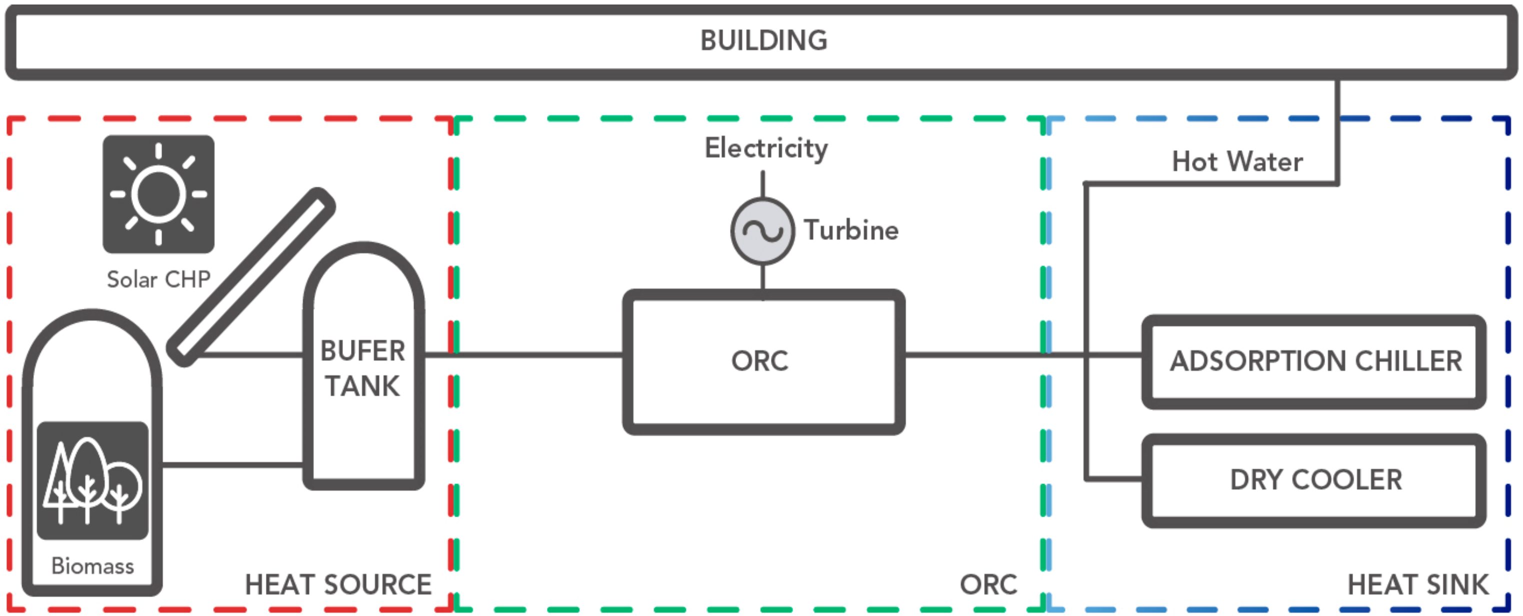
| Simulation results | |
|---|---|
| Electrical production (kWh) | 120,886 |
| Thermal oil pump consumption (kWh) | 5611 |
| Final energy (kWh) | 115,274 |
| Operating time (h) | 8016 |
| *Annual cash flow* | |
| Electricity cost (€/kWh) | 0.1246 |
| Electricity saving (€) | 14,363 |
| Annual maintenance (€) | 1200 |
| First year cash flow (€) | 13,163 |
| *Capital expenditure indications* | |
| ORC and dissipation system (€) | 60,000 |
| *Economic results* | |
| Net present value, 15 years, 2% (€) | 138,286 |
| Internal rate of return (%) | 22.88 |
| Payback time (y) | 4.63 |




Regarding to experimental data, the thermal power input ranged from 128,19 kW to 179,87 kW. The maximum gross and net electrical powers achieved are 21,79 kW and 18,51 kW, respectively. The maximum cycle efficiencies reached are a gross electrical efficiency of 12,47% and a net electrical efficiency of 10,94%.

*J. Navarro-Esbrí*

This case consists of an ORC suitable for a combined Cold, Heat and Power (CCHP) application for buildings that use solar biomass supported renewable energy as heat source. The cogeneration unit is planned to work in two different operating modes: generation mode and cogeneration/trigeneration mode.



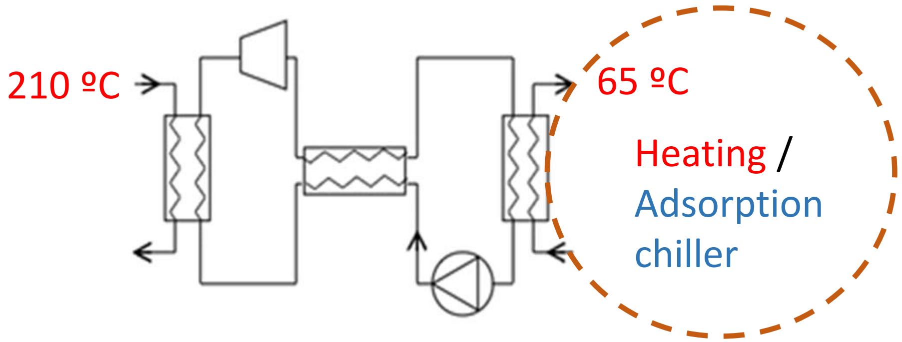

*J. Navarro-Esbrí*

# 6. CASE STUDY (SOLAR+BIOMASS)

## CCHP ORC operating data

| Heat source inlet temperature (ºC) | 210 |
|---|---|
| Heat source outlet temperature (ºC) | 143 |
| Heat source volumetric flow rate ($m^3/h$) | 10 |
| Heat source thermal power (kWt) | 368 |
| Heat sink temperature (ºC) | 55-65 (340 kWt) |
| Gross power output (kWe) | 52 |
| Gross efficiency (%) | 14 |
| Net efficiency (%) | 12 |

Economic feasibility, in this case, depends on the electricity costs and the use of the heat produced by the ORC. The adsorption machine allows to extend the use of the heat produced by the ORC during summer mode, with the corresponding energy saving increase. The solar facility and biomass costs are limiting the feasibility.



## 7. CONCLUSIONS

The practical cases presented in this paper show the flexibility and possibilities of the ORC technology using low temperature heat sources (from 90ºC) in small scale facilities (from 10 kWe up to 75 kWe).

The gross efficiencies of the ORC is varying from 6,3% (activation temperature of 93ºC and ambient temperature of 30ºC) up to 14% (activation temperature of 210ºC and producing 75ºC hot water).

The ORC technology is demonstrated to be technically feasible in small scale (<100 kWe) and economically feasible depending on the energy costs and the incentives.

# REFERENCES


- **Practical cases of electricity production through different renewable energy and waste heat sources with Organic Rankine Cycle technology**. International Conference on Polygeneration 2021. 4-6 Ocober 2021.

- **Heat Energy Recovery for Industrial Processes and Wastes. Green Energy and Technology** (2023).
  ISSN 1865-3529- ISSN 1865-3537 (electronic)
  ISBN 978-3-031-24373-8 - ISBN 978-3-031-24374-5 (eBook).
  https://doi.org/10.1007/978-3-031-24374-5

# Thank you so much for your attention

*Grupo de investigación* ***ISTENER (UJI)***

www.istener.uji.es

navarroj@uji.es