



D1.2 - Report on Requirements and Specifications of the Overall Concept (V2)



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Summary

This document provides an extended definition of the RESTORE overall concept, providing additional details of the main innovative components of RESTORE. This document uses as starting point the previous version of the deliverable, D1.1 - Report on Requirements and Specifications of the Overall Concept (V1), now updating it with the outcomes and conclusion obtained during the project execution. Particularly, this deliverable receives relevant information from the conclusions of the following tasks:

Task 3.2 - Design for upscaling the HP/ORC solution for small Districts

Task 3.3 - Design for upscaling the HP/ORC solution for large Districts

Task 2.6 - Upscaling and industrialization of the TCES system for the RESTORE application

This information has been used in order to update the overall concept, which is summarized in this deliverable. First, to set the context, the deliverable describes the RESTORE overall concept and its objectives in related to the storage and delivery of energy in both forms (heat and electricity). Then, the deliverable is focused on the definition of the systems that born from the RESTORE concept which are related to the adaptation to the two main fields of applications, one dedicated to large scale applications, while the other focus on small scale applications. For each one, the deliverable provides an extend description, through the definition of the systems main components and its tables for specifications and requirements. However, as the deliverable objective is to focus on the overall concept, the values of the specifications should be adapted, as ad-hoc solutions, considering the boundary conditions imposed by each specific application. In that context, the document provides the general bases of the concept that will be considered as a guide for potential future RESTORE system implementation at higher TRLs.

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1. Introduction

The RESTORE concept implies an innovative solution for decarbonising heating and cooling networks, based on the combination of two key innovative technologies. The concept through, energy storage, aims to cover the gap and match the needs of the producers (energy sources) and the consumers (users) in order to ease the integration of clean energy technologies for the decarbonization.

The first technology the project aims to develop is an innovative thermal energy storage system based on the storage of heat through the use of reversible thermochemical reactions, the Thermochemical Energy Storage (TCES). In this system part of the energy is stored in the form of enthalpy of reaction which is quite suitable for seasonal energy storage proposes, while other part of the energy remain as sensible heat, which can be used for daily energy storage. The system represents a key development due to the fact that it allows harnessing the enormous amount of energy that is normally wasted due to the mismatch between energy demand (loads) and energy generation (related to the availability of the renewable resource or waste heat), occurring between hours, days or even seasons.

In addition, the project aims to develop a second technology, namely a reversible Heat Pump (HP) /Organic Rankine Cycle (ORC) and to combine it with the TCES system. This second technology, when working as heat pump, is able to adapt the energy from different Renewable Energy Sources to feed the thermochemical reactor. In addition, when discharging as ORC, the system adapts the energy received from the reactor to the conditions demanded by different potential users, and mainly to a District Heating network for its decarbonization. From the overall concept, two different systems can be clearly differentiated.

The first system, focus on small scale applications. This system is based on the use of a fully reversible machine, able to work in two different modes:

- As a Heat Pump, when there is excess of energy, adapting the energy conditions of the energy sources to the requirements of the thermochemical reactor, where heat is finally supplied for charging the energy storage system.
- As Organic Rankine Cycle, when there is a demand of energy by the users, receiving the energy from the discharge of the reactor (inverse reaction) and adapting it to the conditions demanded by a District Heating Network.

The key component of this is the reversible screw machine that is able to work as compressor during the charge mode, and as an expander during the discharging mode.

The second system, focus on large scale applications. This system is based on the use of a mid-reversible machine, which means that some components are used for both charging and discharging cycles, while others are used just for one of these processes. For example, a compressor is needs for its use only during the charge mode, while a turbine is used only during the discharge process.

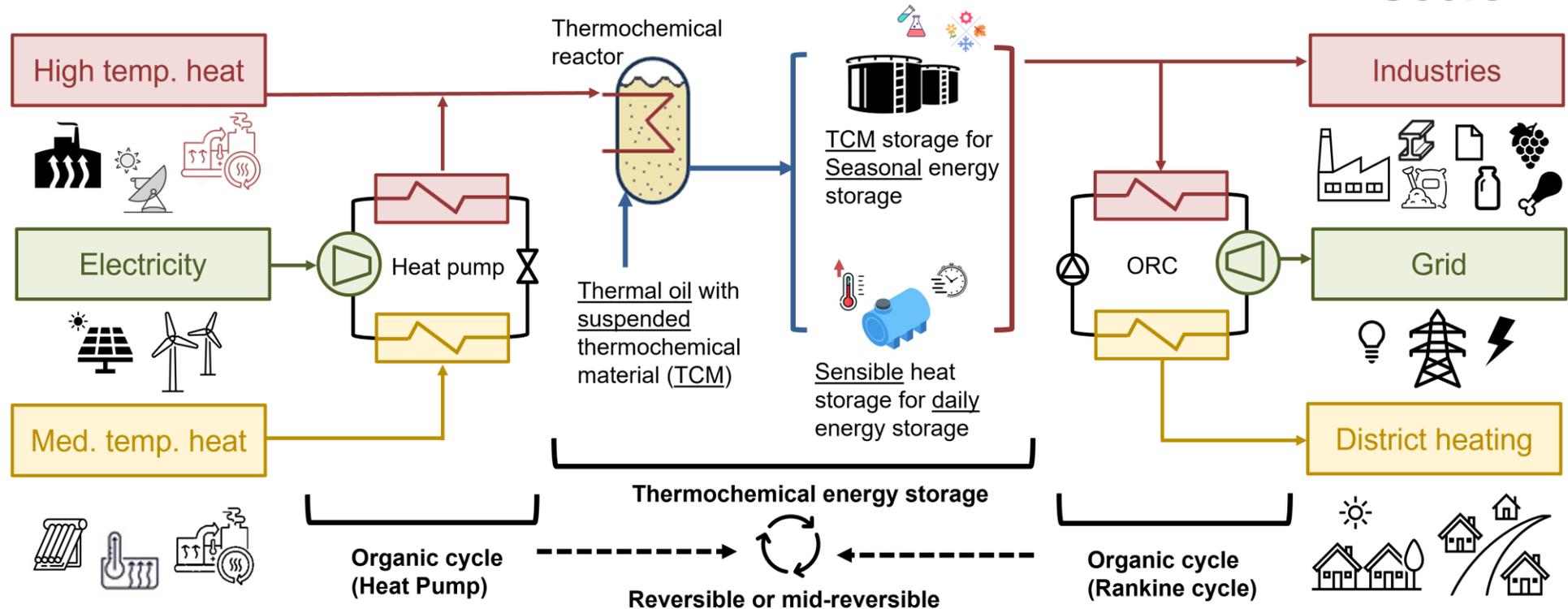
In the following sections, both systems are described, including in each case the description of the main components. The information provided in this document applies to the RESTORE **overall** concept, thus it provides a general definition, commenting in some component the different suitable options, which must be selected, adapted, and designed as an ad-hoc

solution considering the boundary conditions imposed by each specific application. In that context, the document sets the general bases of the concept which can be used in the future as a started point for the design of a facility based on this concept, thus providing a template of the datasheet which must be fulfilled as starting point of the engineering phase for the construction of a real plant in the future.

Energy Sources

RESTORE technology

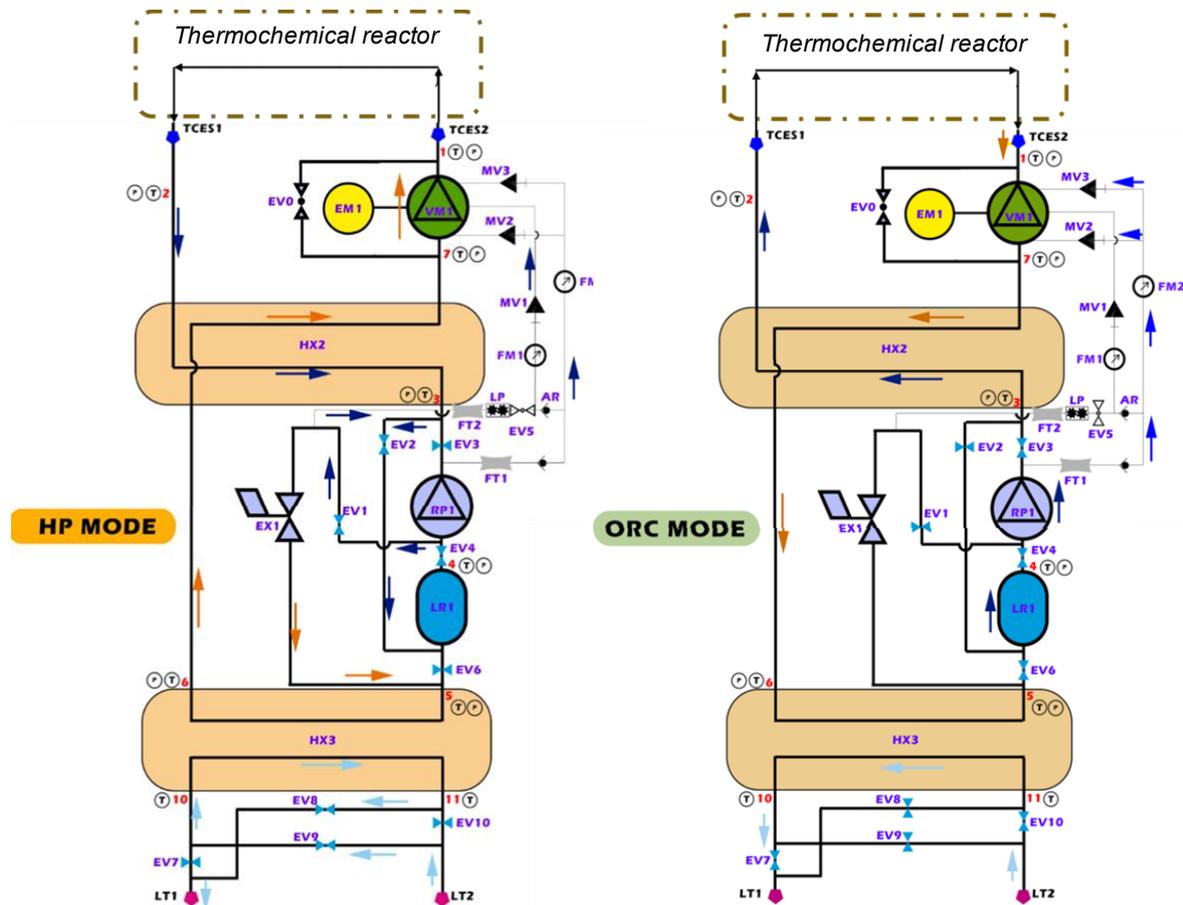
Users



2. The small-scale RESTORE system.

The small-scale RESTORE system is designed to applications where the demanded energy is relatively smaller, specifically this system is able to be scaled up to 300 kW of electric power when considering the size of the organic cycles. This includes applications such as low-emission buildings, small RES plants for distributed generation or facilities with reduced waste heat (Data centres, University Campuses).

Specifically, the main characteristic of this this system lies on the organic cycles, which considers a fully reversible machine which is able to operate in two different modes, as a heat pump during the charging process and as Organic Rankine cycle during the discharging process. Figure below shows a general scheme and flows directions for the organic machine operated in both modes.



As show in the figure, in the upper zone, this system is coupled to the thermochemical reactor where it transfers or receives the required thermal energy. Therefore, the components of this system can be easily divided into different groups, or subsystems: One dealing with all the main components of the organic machine while the other one dealing with all the main

components of the Thermochemical Energy Storage system. In the following sections, these two subsystems are described in detail, including the definition of their main components.

2.1. The reversible organic machine (rORC)

The reversible organic machine oversees adapting the temperature levels to requirements of the system which receives it. Specifically, the system in heat pump mode, adapts the energy received by the source to the conditions demanded by the thermochemical reactor, while during the Organic Rankine Cycle mode, adapts the conditions from the reactor discharge to the requirements of the District Heating and Cooling network.

In more detail, during the charging process, the system operates in Heat pump mode. During this process the main objective of the system is to upgrade heat from the lower-temperature source (which can be a thermal renewable energy source or waste heat) to a high-temperature sink, the thermochemical reactor. Heat is absorbed in the lower temperature heat exchanger, which works as evaporator in this mode. There the fluid evaporates into a low-pressure vapor. This vapor then enters the regenerator, where it gains additional heat from a higher-temperature vapor stream exiting the higher temperature heat exchanger, which in this mode works as condenser, increasing its enthalpy before compression. The preheated vapor is then compressed in the screw machine to a high pressure and temperature. After compression, it releases heat at high temperature in the high temperature heat exchanger integrated inside the thermochemical reactor, supplying useful heat to the industrial process. The condensed high-pressure liquid may partially vaporize due to subcooling recovery in the regenerator, transferring sensible heat to the colder stream. Afterward, the fluid passes through an expansion valve, reducing its pressure and temperature, and then re-enters the evaporator to repeat the cycle. The regenerator thus improves system efficiency by internally exchanging heat between the cold vapor from the evaporator and the warm liquid or vapor from the condenser.

During the discharge, the system working now as an Organic Rankine Cycle, operates by adapting thermal energy from the high-temperature source, the thermochemical reactor, to the conditions demanded by the District Heating Network while transforming part in mechanical work. In this mode, the system receives high-temperature heat from the thermochemical reactor in the high temperature heat exchanger, which now works as evaporator, where the working fluid is vaporized at high pressure. The high-pressure vapor then expands through the screw machine, generating mechanical power converted to electricity. After expansion, the low-pressure vapor enters the regenerator, where it transfers part of its residual heat to the compressed liquid exiting the pump. This internal heat exchange improves the cycle's efficiency by preheating the working fluid before it enters the evaporator. The partially cooled vapor then passes through the condenser, where it releases its remaining heat at a lower temperature to a District Heating network. The condensed fluid is subsequently pumped to high pressure and further heated in the regenerator, completing the cycle. This integration of regeneration and low-grade heat recovery maximizes the energy utilization and efficiency.

The selection of the working fluid will determine the design and sizing of the remaining components of the rORC system. The selection of the working fluid will be primarily conditioned by the thermal requirements of the TCES and, secondly, by the boundary conditions, which are mainly determined by the enthalpy level of the available thermal energy sources and the temperature/s requirements of the district heating system.

The methodology for selecting the working fluid must take into account thermodynamic factors (critical temperature, density, heat transfer coefficients, etc.), environmental factors (low GWP, zero ozone depletion potential, etc.), and techno-economic considerations.

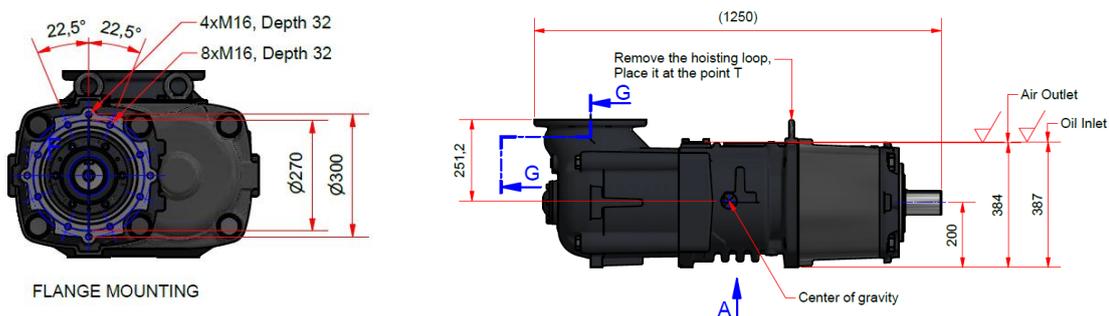
In the following sections, the components of this subsystem are described in detail.

2.1.1. The volumetric machine

The screw machine is a positive displacement device capable of operating in two modes: as an expander for an Organic Rankine Cycle and as a compressor for the heat pump. In turbine (expander) mode, the machine receives high-pressure vapor from the ORC evaporator and allows it to expand through helical rotors, converting thermal energy into mechanical work. Through adaptation of the shaft, a magnetic coupling can be included, allowing coupling to a synchronous machine, which work as generator to produce electricity in the discharge. The expansion process occurs progressively along the rotor profile, ensuring efficient energy conversion with the chosen working fluid.

In compressor mode, the same screw machine operates in reverse: it receives low-pressure vapor and compresses it to a higher pressure and temperature suitable for the thermochemical reactor. The synchronous machine works now as a motor consuming electricity. The rotors mesh to reduce the working volume, increasing both pressure and enthalpy of the refrigerant vapor. The internal built-in ratio can be modified depending on the final conditions required.

Additionally, the machine must consider an adaptable lubrication, sealing and bearing systems, allowing reversible flow operation and maintaining high efficiency in both modes.



The specifications for the volumetric machine are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution. The parameters indicated (either fixed values or ranges) are independent of the machine size and, therefore, applicable to all ad-hoc solutions.

Volumetric reversible machine		
Parameter	Value	Unit

Heat Pump mode		
Inlet pressure		bar
Outlet pressure		bar
Inlet Temperature		°C
Outlet Temperature		°C
Mass flow		Kg/h
Oil charge	3-7	%
Volume ratio	4,1 – 7,4	-
ORC mode		
Inlet pressure		bar
Outlet pressure		bar
Inlet Temperature		°C
Outlet Temperature		°C
Mass flow		Kg/h
Volume ratio	4,1 – 7,4	-
Electric connection		
Power consumption in motor mode		kW
Power generation in expander mode		kW
Voltage range		V
Frequency		Hz

2.1.2. The Heat exchangers

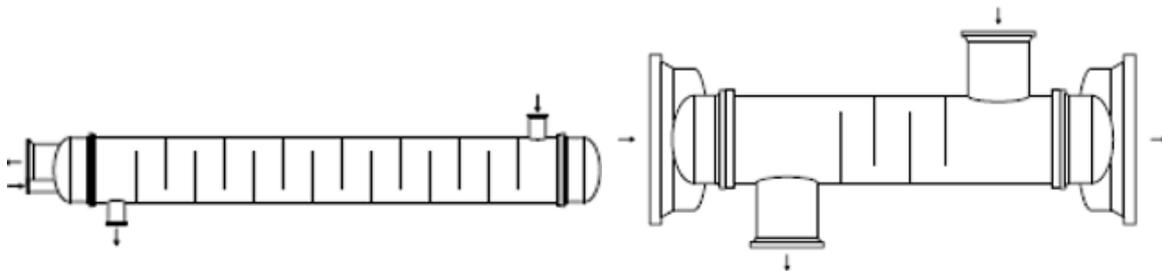
The heat exchangers of the reversible machine should be designed the most restrictive conditions (normally those of the Heat Pump Mode). The Shell and Tube types are quite recommended in those applications where the room restriction is not mandatory. This type of heat exchanger eases the maintenance effort related to dirt in the circuit, water hardness, etc, presenting simplicity of its maintenance and cleaning. However, in those applications where the room restriction is severe, plate heat exchangers can be used, reducing the final volume of the machine and maximizing the compactness of the final system. Connections of the heat exchangers with the piping are recommended to be welded to avoid any potential refrigerant leakages. The shell-and-tube configuration allows safe and efficient heat exchange and unlocks the possibility of installing baffles on the shell side to enhance turbulence and promote uniform temperature distribution.

Specifically, the regenerator operates as an internal heat recovery unit in both modes: Heat Pump and Organic Rankine Cycle. It enables thermal energy exchange between two streams of the same organic working fluid within each cycle. In the ORC, the regenerator transfers sensible heat from the low-pressure vapor exiting the turbine (on the shell side) to the high-

pressure liquid exiting the pump (on the tube side), thereby preheating the fluid before it enters the evaporator. In the Heat Pump mode, the regenerator performs a similar function: it transfers heat from the hot refrigerant vapor leaving the condenser to the cold fluid exiting the expansion valve, increasing the temperature of the suction stream entering the evaporator. This dual-function regenerator improves the thermal efficiency of both systems by reducing the external heat input required for evaporation and minimizing exergy losses. The regenerator should be designed for bidirectional or switchable operation, depending on the system mode, and is constructed from high-conductivity, corrosion-resistant materials suitable for the chosen organic fluid and operating temperatures.

The other heat exchanger to be remarked is the lower temperature heat exchanger, operating alternately as the evaporator in HP mode and the condenser for ORC mode. In both operational modes, the organic working fluid flows through the tube side, while water circulates through the shell side.

When functioning as the evaporator in the heat pump, the organic fluid enters the tubes at low pressure and absorbs thermal energy from hot water flowing on the shell side. This heat input causes the fluid to vaporize, producing a high-temperature, low-pressure vapor that is directed to the compressor. In ORC mode, the same unit acts as the condenser, where high-pressure vapor exiting the turbine flows through the tubes and releases latent heat to the cooler water on the shell side, condensing into a liquid. The counter-flow or crossflow configuration enhances the thermal gradient across the exchanger, improving phase change efficiency in both directions. The shell side can be equipped with baffles to increase water-side turbulence and optimize heat transfer. The unit should consider cyclic and switchable operation, with materials selected to withstand the thermal and chemical properties of the organic fluid under both evaporating and condensing conditions.



Specifications and Requirements

The datasheet applicable to this type of component is shown below (a similar datasheet can be used for both low temperature Hx and regenerator), as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Low temperature heat exchanger and regenerator		
Parameter	Value	Unit
Low Temperature Heat exchanger		
Pressure inside tubes at nominal conditions		bar

Pressure outside tubes at nominal conditions		bar
Liquid phase inlet temperature (vector fluid)		°C
Vapor phase outlet temperature (vector fluid)		°C
Inlet temperature (water)		°C
Outlet temperature (water)		°C
Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
Regenerator		
Pressure inside tubes at nominal conditions		bar
Pressure outside tubes at nominal conditions		bar
Liquid phase inlet temperature		°C
Liquid phase outlet temperature		°C
Vapor phase inlet temperature		°C
Vapor phase outlet temperature		°C
Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
Constructive parameters Low Temperature Heat exchanger		
Heat exchanger typology	Shell & Tubes/Plates	
Heat transfer area internal		m ²
Heat transfer area external		m ²
Diameter of tubes		cm
Tubes thickness		cm
Constructive parameters Regenerator		
Heat exchanger typology	Shell & Tubes/Plates	
Heat transfer area internal		m ²
Heat transfer area external		m ²
Diameter of tubes		cm
Tubes thickness		cm

2.1.3. Expansion valve

The expansion valve is a critical component of the system. While it regulates the flow of refrigerant into the lower temperature heat exchanger, it reduces the high-pressure liquid refrigerant from the condenser to a lower pressure, enabling it to evaporate and absorb heat efficiently. This pressure drop also results in a temperature drop, facilitating effective heat exchange. The valve is able to modulate the flow based on system load, a motor operated valve is a good choice as it allows to respond to the cycle requirements in HP mode. Proper function ensures system efficiency, prevents compressor damage, and maintains stable temperatures in the heat exchangers. The valve must be chosen considering the mass flow of the final plant which is set by the boundary conditions of the case of application.



Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Expansion valve		
Parameter	Value	Unit
Material	Steel	
Flow		m ³ /h
Inlet pressure		Barg
Outlet pressure		Barg

2.1.4. The organic fluid pump

The fluid pump plays a vital role in the operation of the system in discharge mode. Located between the condenser and the regenerator, the pump pressurizes the low-pressure working fluid exiting the condenser and sends it through the regenerator before it enters the evaporator. This high-pressure liquid absorbs residual heat from the hot, low-pressure vapor exiting the turbine via the regenerator, preheating the fluid and reducing the heat input needed from the external source. The pump must ensure a stable, continuous flow under high pressure to optimize heat recovery and maintain system performance. It typically handles organic fluids and must be designed to withstand thermal and chemical stresses. Its operation is tightly integrated with system controls to match flow rates and pressure with varying thermal loads which is crucial to control the behaviour of the cycle in the discharging mode to fulfil the requirements of the District Heating Network.



Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Organic Fluid Pump		
Parameter	Value<	Unit
Material	Steel	
Flow		Kg/h
Inlet pressure		Barg
Outlet pressure		Barg
Inlet temperature		°C
Inlet temperature		°C

2.2. The thermochemical energy storage (TCES)

Thermochemical energy storage deals with the energy storage functionality of the RESTORE system. This system is thermally charged through the energy provided by the condenser of the heat pump and can be charged directly by energy sources with a temperature compatible with the thermochemical charge reaction. The heat is provided in the reactor which is filled with the solid thermochemical material (A) suspended in oil. Within the reactor an endothermic reaction takes place, releasing products (commonly water/steam and a thermochemical solid material (B) suspended in oil) that are then circulated through a preheater, transferring its heat to the inlet of the reactor, improving in that way the efficiency. After the preheater, the cooled products are introduced through a separator where the thermal oil is recirculated while the other flow

rich in B (and a reduced amount of thermal oil) is stored. The recirculated thermal oil receives in a mixer the material A and the cycle starts again.

During the discharge, the process is reversed. The products of the charging process are now reactants (solids (B) + water) that are merged in the reactor, undergoing an exothermic reaction. The heat released is transferred to the evaporator of the reversible machine, now working in Organic Rankine Cycle mode. The products of the discharging process (thermochemical solid material (A)) are then circulated through the preheater, transferring its energy to the flow entering in the reactor. Then the flow (rich in A) is separated, the oil recirculated and the thermochemical material stored.

In this system, the following main components (or group of components) can be identified:

The thermochemical reactor(s): where the heat is supplied or released during the thermochemical reaction.

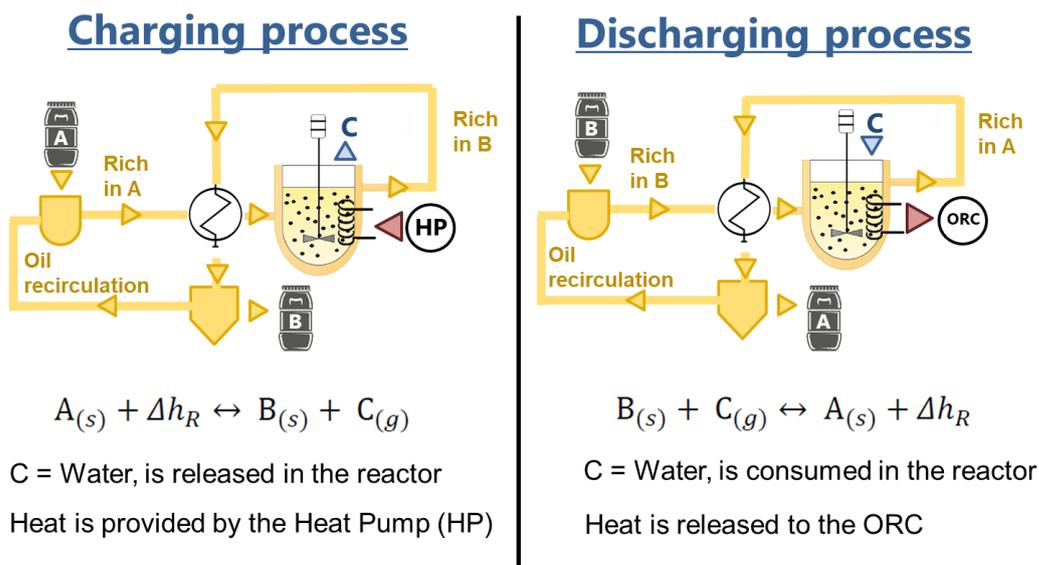
The product/reactant system: related to the storage and supply of the substances involved in the thermochemical reaction. Two groups can be considered:

The solids storage: composed of the tanks where the thermochemical material is stored.

The water system: in charge of providing/receiving the water required/released in the thermochemical reaction. Water could be provided in an open loop or stored.

The transport system: in order to circulate the materials involved in the system, including product/reactants and the thermal oil, from the storage to the reactor and vice versa.

In the following sections, these components are described. The image below illustrated the TCES subsystem for both charge and discharge.

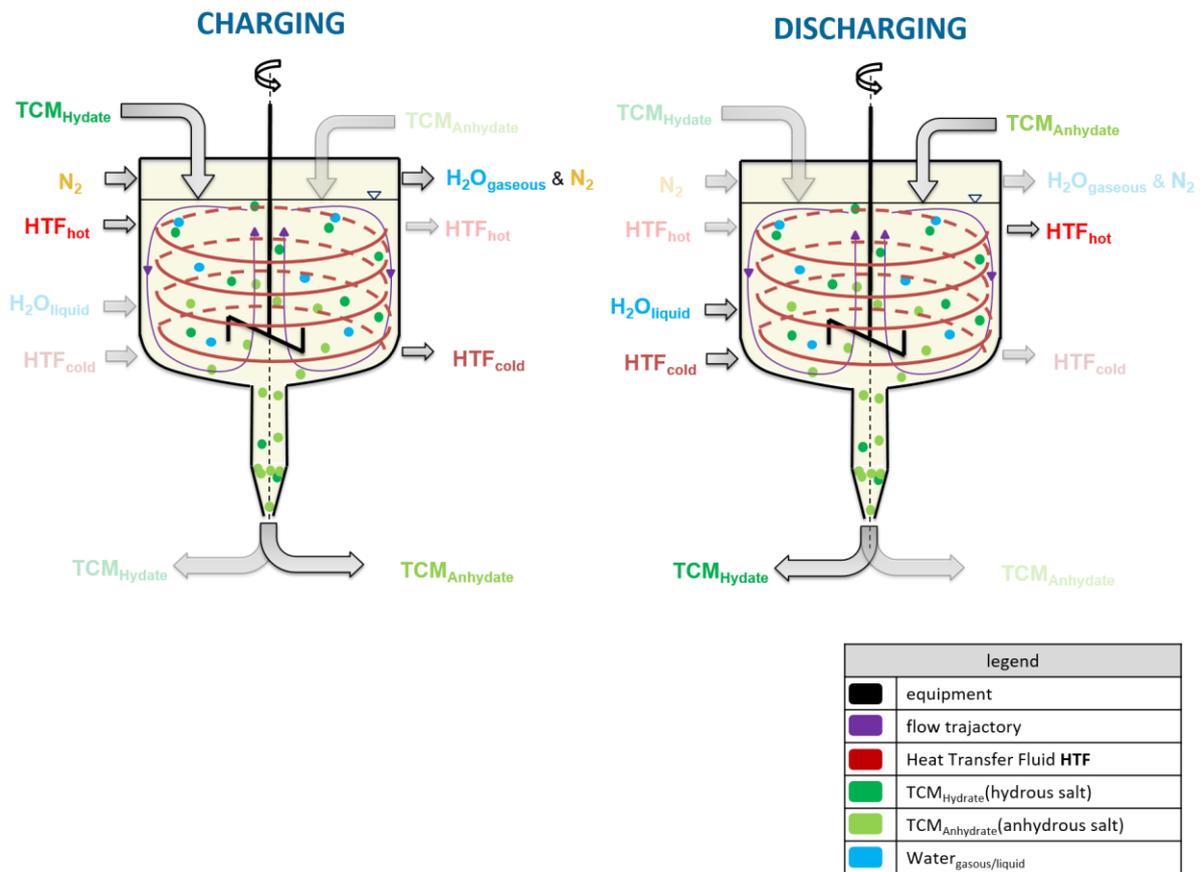


2.2.1. The reactor

The reactor is the subsystem where the thermochemical reaction takes place. It is a stirred tank that works as a suspension reactor where the thermochemical solid material is suspended in a thermal oil. Integrated into the reactor are one or more coils that work as the high temperature heat exchanger for transferring heat from or to the organic cycle. During charging, the suspended solid material (A) receives heat from the coil producing the solid material (B) and water. During the discharge the solid material (B) is recombined with water. This reaction forms the solid (A) and releases heat that is transferred to the coil. The reactor must guarantee a continuous operation which means that the flow of reactants that reach the reactor and the product that leaves it as well as the heat transferred must be uninterrupted during the operation. The tank also includes a mechanical stirrer which helps to produce homogenous conditions within the reactor, improving the mixing, the heat exchange and in general facilitating the reaction.

The operating temperature inside the reactor depends mainly on the thermochemical reaction finally chosen but also on other operational parameters such as the working pressure inside the tank. Depending on the boundary conditions set by the case of application, the thermochemical energy storage system can use different thermochemical materials.

The reactor considers a double purpose reactor which is based on the use of a unique reactor that can work in both charging and discharging modes. The reactor can include one or several coil(s) inside the tank. This unique heat exchanger can work as a condenser of the heat pump during the charging process or as an evaporator of the Organic Rankine Cycle during the discharge. The reactor must be adapted to receive thermochemical solid material (A) and release water and material (B) during the charging process and be able to mix water and thermochemical solid material (B) for producing material (A) during the discharge. The figure below shows a schematic of the concept:



The use of a unique reactor allows for reducing equipment and cost associated with the TCES subsystem.

Specifications and Requirements

The specifications for the unique reactor subsystem are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

Dual purpose reactor datasheet		
Parameter	Value	Unit
Tank		
Material	Steel	
Tank diameter		m
Tank height		m
Capacity		m ³
Design pressure		barg
Design temperature		°C
Corrosion allowance		mm
Heat exchanger coil		

Heat transferred at operating conditions in charge		kW _{th}
Heat transferred at operating conditions in discharge		kW _{th}
Mean temperature difference		K
Minimum free space between surfaces		mm
Fouling factor (in and out)		
Thermochemical reaction parameters		
Thermochemical reaction	Charge: Discharge:	
Thermochemical solid material		
Operating pressure in charge		barg
Operating pressure in discharge		barg
Concentration of solids suspended in oil during charge		%wt
Concentration of solids suspended in oil during discharge		%wt
Temperature of operation in charge		°C
Temperature of operation in discharge		°C
Stirrer type		
Stirring nominal speed		rpm

The unique tank solutions must fulfil the following requirements:

- Continuous operation is mandatory
- Tanks materials compatible with the chosen oil and reaction products/reactants
- Temperatures of operations compatible with the thermodynamic cycle:
- Security Issues:
 - o Low toxicity of materials in the reaction
 - o Non-flammability or similar issues.
 - o Not exceeding pressures

Other relevant characteristics:

- Compactness is of special interest in small district applications.

2.2.2. The product/reactant system

The objective of this subsystem is to guarantee the availability of the substances that participate in the thermochemical reactor as well as their correct storage. These substances can be generalized for the hydration and dehydration reactors to: the thermochemical solid material (A), the thermochemical solid material (B) and water. Thus this subsystem can be

subdivided into blocks. On the one hand the part in charge of supplying water and on the other hand the part in charge of the solid materials.

2.2.2.1. The solids storage

The solids material that participates in the thermochemical reaction is provided during the construction of the whole system. The amount of material is directly related to the capacity for storing energy of the overall system. In seasonal storage, enough material must be supplied to guarantee one year of operation (the same material is reused in the following years of the plant). Due to the separation process is not perfect (around 20% of oil may be present in the mix sent to the storage tank), the tanks must ensure no leakages are present.

As the solids are stored at ambient temperatures, the most convenient solution is the one based on the use of high-density polyethylene (HDPE), which is ideal for storing the thermochemical materials as do not present inconveniences in relation to abrasive or viscous materials that require both chemical resistance and moderate thermal tolerance.

However, the maximum volume of these tank is limited, around 5m³, so in the case of higher volumes required, several tanks are stacked in parallel until cover the total amount of thermochemical material.

This solution allows to present a cost competitive solution while storing a huge amount of thermochemical material to increase the storage capacity. Considering UV-stabilized, chemically resistant HDPE, the tank ensures compatibility with most synthetic and mineral-based thermal oils while withstanding continuous temperatures up to 90°C.

The vertical cylindrical structure includes a slightly conical bottom, with reinforced walls to manage the combined mechanical load of the solid-liquid mixture. Key features include a top manway for inspection and a bottom discharge outlet suitable for solids. While stored, the remaining thermal oil forms a film in the upper part, improving the protection of the thermochemical material stored. To ensure safety and longevity, it includes pressure relief. The tanks can be easily transported and must be located on stable concrete base to support the weight of several tanks in parallel. The design must comply with the industry standards for thermoplastic tank construction.

Specifications and Requirements

The specifications for the solids storage are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

Solids Storage units datasheet		
Parameter	Value	Unit
Thermochemical solids material (A) Storage Unit		
Number of tanks		
Material of the tanks		
Tank capacity		m ³

Stored mass		kg
Design pressure		barg
Design temperature		°C
Operating pressure		barg
Operating temperature		°C
Corrosion allowance		mm
Thermochemical solids material (B) Storage Unit		
Number of tanks		
Material of the tanks		
Tank capacity		m ³
Stored mass		kg
Design pressure		barg
Design temperature		°C
Operating pressure		barg
Operating temperature		°C
Corrosion allowance		mm

2.2.2.2. The water/steam system

The thermochemical reactions considered in the project are based on hydration/dehydration processes which means water is essential in the process. During the charging process (dehydration reaction) water is released meanwhile in the discharge (dehydration reaction) water is demanded. The quality of water provided to the system must be adequate for the thermochemical reaction. Two solutions could be differentiated for the water supply system:

On the other one, the close loop configuration, where the water is stored in tanks. This tanks are refilled or empty depending on the reactor process (charging or discharging). On the one hand, the open loop configuration, where the water released during the charging process leaves the reactor (commonly in the form of steam) and is integrated for its use in the configuration or consume by surrounding applications demanding steam. On discharging process, water in the form of liquid can be directly introduced in the reactor if it fulfill the quality specifications.

2.2.2.2.1. Close loop

The close loop configuration implies the use of water storage units in order to guarantee the supply of water at any time. The CAPEX of this system is tentatively higher due to the use of tanks for storing water. However, it presents some advantages like independency of potential water scarcities or does not require water treatment in those cases where the water quality is

quite low (the water supplied at the beginning must fulfill the requirements associated with the quality of water). The tanks must be sized in order to guarantee the required operational hours of storage defined for the whole thermochemical energy storage system (in line with the solids storage). The close loop configuration can use different storage methodologies depending on the overall system integration. If the steam released can be thermally integrated and cooled before it storage, water can be stored for longer periods at low temperature, in this case, non-pressurized steel tanks are suitable. If the steam released must be directly stored, an steam accumulator is required which is suitable for shorter periods of storage.



Specifications and Requirements

The specifications for the close-loop water supply system are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

Close loop water supply subsystem datasheet		
Parameter	Value	Unit
Tank		
Number of tanks		
Material of the tanks		
Tank capacity		m ³
Stored mass		kg
Design pressure		barg
Design temperature		°C
Operating pressure		barg
Operating temperature		°C
Corrosion allowance		mm
Pump		
Number of pumps		
Type		

Material		
Nominal/Max flow rate		M3/h
Total differential head		m
Water specifications		
Dissolved Oxygen		Mg/L
Conductivity (EC)		μS/cm
TDS		ppm
Salinity		mg/L
pH		pH

The requirements to be fulfilled are the following:

- The tanks' material must be stainless and compatible with water.
- In case of steam accumulators, it must integrate relievers for security reasons.
- The experimental activities carried out in WP2 have demonstrated that tap water is suitable for the reactions meanwhile salt water is not suitable. Thus, the following requirements associated with the quality of water (required for tap water) can be also demanded in the TCES:
 - o Dissolved Oxygen < 8 mg/L
 - o Conductivity (EC) < 800 μS/cm
 - o TDS < 500 ppm
 - o Salinity < 900 mg/L
 - o pH in the range of: 6.5 - 8

2.2.2.2.2. Open loop

A continuous flow of treated water is provided to the reactor during the discharge process. During the charge, the released water could be provided for any demand. This solution is tentatively cheaper than the close loop and more adequate in regions that do not present water scarcity during winter (when the system is charged). In those regions, the open loop could be an advantage due to the subsystem being charged, thus releasing water, during summer when the water demand and scarcity are commonly higher. This configuration is suitable for those cases where the facility can be easily connected to a water supply point, thus delivering or consuming water when charging or discharging.

Specifications and Requirements

The specifications are only related to the quality of the water provided.

Open loop water supply subsystem datasheet		
Parameter	Value	Unit
Pump		

Number of pumps		
Type		
Material		
Nominal/Max flow rate		m ³ /h
Total differential head		m
Water specifications		
Dissolved Oxygen		Mg/L
Conductivity (EC)		μS/cm
Total dissolved solids (TDS)		ppm
Salinity		mg/L
pH		pH

In this subsystem only requirements associated with the quality of water are identified, and are similar to the shown in the close loop system:

- Dissolved Oxygen < 8 mg/L
- Conductivity (EC) < 800 μS/cm
- TDS < 500 ppm
- Salinity < 900 mg/L
- pH in the range of: 6.5 - 8

2.2.3. The transport system

Due to the fact that the main reacting components are solids, oil is used as a carrier substance to enhance transportability. The thermochemical solids material are suspended in the oil which transports them from the storage units to the reactor and vice versa. In addition, the oil has additional functions as improving the mixing and the heat transfer behavior.

Within this group, two key components can be easily differentiated: the circulating pumps for impulsing the mix of solids and thermal oil through the circuit, the separator, in charge of divide the solids from the oil, in order to maximize the concentration of solids in the solids storage, avoiding therefore higher volumes of storage and reducing the final CAPEX cost of the plant. Different thermal oils are compatible with the RESTORE application. However, depending on the thermal oil chosen. Therefore, it is important previous to the desing of the facility fulfill a datasheet similar to the presented below once the thermal oil has been chosen.

Transport system		
Parameter	Value	Unit
Thermal oil specifications		
Type of Oil		

Viscosity (high and low temp. of operation)		Pa s
Density (high and low temp. of operation)		Kg/m ³
Atmospheric Boiling Point		°C
Flash point		°C
Fire point		°C
Auto-ignition temperature		°C
Pour point		°C
Coefficient of thermal expansion		mm ³ / °C

Some key requirements to be considered:

- The thermal oil must have a crystallizing point below the minimum operating temperatures expected.
- The thermal oil must have an auto-ignition temperature above the maximum operating temperatures expected.
- If the maximum operating temperature is above the flash point, the design must consider the security standards applied in these cases.

2.2.3.1. The circulating system

The circulation system is key for the mixture (solids and thermal oil) transportation from the storage tanks to the reactor and from reactor to separator. The system must be designed to handle a mixture of oil and solid that can show high concentrations in some points of the facility. Therefore, a progressive cavity pump is quite suitable for this application. This type of pump is particularly well-suited for high-viscosity fluids containing abrasive or shear-sensitive solids, providing a continuous, non-pulsating flow that minimizes the risk of sedimentation. The whole system must consider thermally insulated piping, temperature and pressure sensors. The pump should operate efficiently not only at ambient temperatures but also at elevated temperatures (>140°C and can transfer solids without degradation or clogging). Key advantages include its ability to handle abrasive mixtures, high volumetric efficiency, and the capability to operate at low speeds, significantly reducing wear and maintenance requirements.

Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Transport system		
Parameter	Value	Unit
Circulating subsystem		
In charge, mass flow from solids unit storage (A) to the reactor		Kg/h

In charge, mass flow from the reactor to solids unit storage (B)		Kg/h
In discharge, mass flow from solids unit storage (B) to reactor		Kg/h
In discharge, mass flow from the reactor to solids unit storage (A)		Kg/h

2.2.3.1. The separator

A cyclone separator is proposed for concentrating a mixture composed of thermal oil and suspended solids, aiming to achieve a final composition quite high on solids and reduced thermal oil, reducing the size of the solid's storage. The cyclone operates based on centrifugal separation principles: the incoming mixture is introduced tangentially at high velocity into the cylindrical body of the cyclone, generating a strong vortex. Due to differences in density and inertia, the heavier solid particles are forced outward and spiral downward along the cyclone walls, collecting at the bottom underflow outlet, while the lighter thermal oil, along with fine entrained particles, exits through the top overflow. The cyclone must be constructed with materials capable of withstanding potential abrasion from solid particles, such as high-grade stainless steel or ceramic-lined steel. Critical design features include a robust vortex finder, wear-resistant cone geometry, and the ability to adjust flow rates to optimize separation efficiency. Advantages of this system include continuous operation, lower maintenance, compact footprint, and efficient separation. It is especially well-suited for high solid-loading, ensuring consistent concentration without mechanical degradation of particles. This technology is particularly convenient for this process because it allows effective bulk separation of solids from oil, reducing downstream load on pumps and facilitating the recovery or reuse of both phases in process.



Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Transport system		
Parameter	Value	Unit
Separator		
Type of separator	Cyclonic	
Inlet mass flow		kg/h
Mass flow of recirculated oil		kg/h
Solids concentration before the separator		%wt
Solids concentration after the separator (to solids storage)		%wt
Solids concentration after the separator (recirculated oil)		%wt

3. The large scale RESTORE system

The large-scale RESTORE system is designed to applications where the demanded energy is higher than the previous case, specifically this system is able to be scaled in the order of megawatts of electric power when considering the size of the organic cycles. This includes applications such as: Large non-dispatchable power plants or energy-intensive industrial sectors with significant waste heat availability. Meanwhile the thermochemical energy storage keeps some similarities with the previous one (just adapting it to bigger sizes), the main difference lies on, if possible, the use of a mid-reversible organic cycle. In this case, both organic cycles adopt the same working fluid and share some components but not all of them. In addition, the compressor and the expander are different machines both based on turbomachinery while some heat exchangers can be used in both modes. If the boundary conditions do not allow the mid-reversible configuration, two different cycles must be adopted. Therefore, this system is easily differentiated between the cycle which aims to adapt the energy input to the conditions demanded by the reactor (Large Heat Pump) and the other cycle which deals with the adaptation of the inputs from the reactor during discharge to the conditions required by the district heating.

The innovative combination of a TCES and the LHP/ORC technology makes possible to overcome the intermittency among the supply of thermal energy and the fluctuating demand for heat or cold present in DHC networks, thus increasing the availability and reliability of energy distribution on the grid.

As in the previous case, the components of this system can be easily divided into different groups, or subsystems:

First group, considering with the components that are unique for the heat pump.

Second, involving components only used in the ORC.

Thirds, including components used in both organic cycles

Forth, including the components grouped in the Thermochemical Energy Storage.

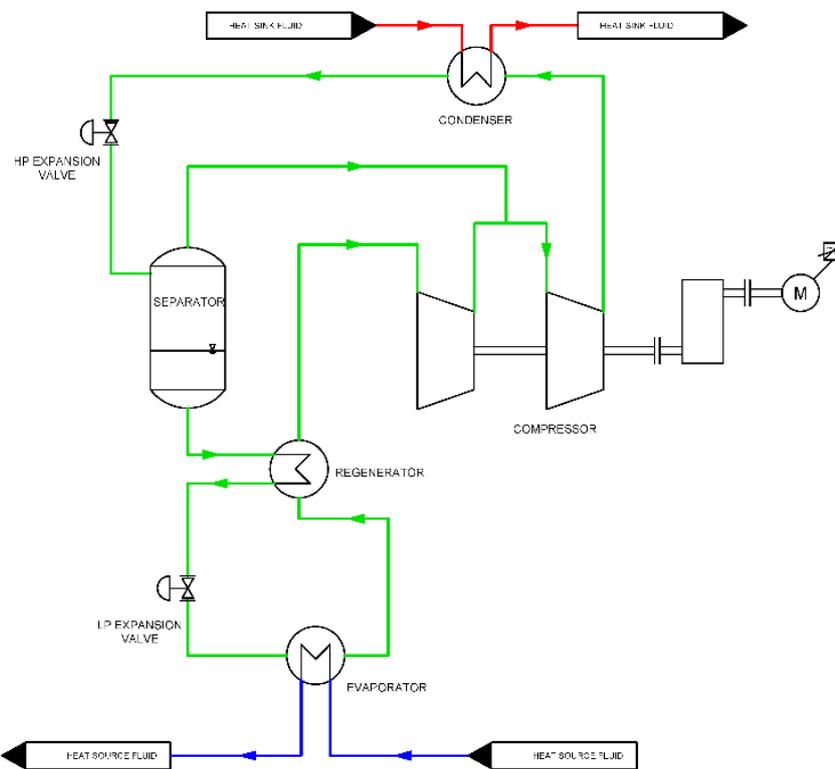
In the following sections, these two subsystems are described in detail, including the definition of their main components.

3.1. The large heat pump (LHP)

The purpose of the Large Heat Pump is to upgrade the heat received from the energy source and adapt it to supply heat at the conditions demanded by the thermochemical reactor which is connected through a heat exchanger. The purpose is to transfer thermal power when there is an excess of energy in order to store it for higher demand periods.

In this configuration, the system operates exclusively in heat pump mode to deliver high-temperature thermal energy to a thermochemical reactor. Its main function is to extract heat from a low-temperature thermal source—such as industrial waste heat or renewable heat—and upgrade it to meet the reactor's thermal requirements. The working fluid absorbs heat in the low-temperature heat exchanger, functioning as an evaporator, where it evaporates into low-pressure vapor. This vapor passes through a regenerative heat exchanger, where it gains additional sensible heat from a warmer stream exiting the high-temperature heat exchanger,

thereby increasing its enthalpy prior to compression. The preheated vapor then enters a centrifugal compressor, which raises its pressure and temperature efficiently through dynamic compression. The high-temperature, high-pressure vapor is directed into the high-temperature heat exchanger integrated within the thermochemical reactor, where it releases heat to drive the endothermic reactions. The vapor condenses during this process, and the resulting high-pressure liquid partially recovers residual heat in the regenerator, transferring it to the incoming cold vapor. The fluid then expands through an expansion valve, reducing its pressure and temperature, and returns to the evaporator to complete the cycle. The regenerator enhances overall system efficiency by internally exchanging heat, and the centrifugal compressor allows for high flow rates and reliable operation under steady-state conditions, making the system particularly suited for continuous industrial heat supply.

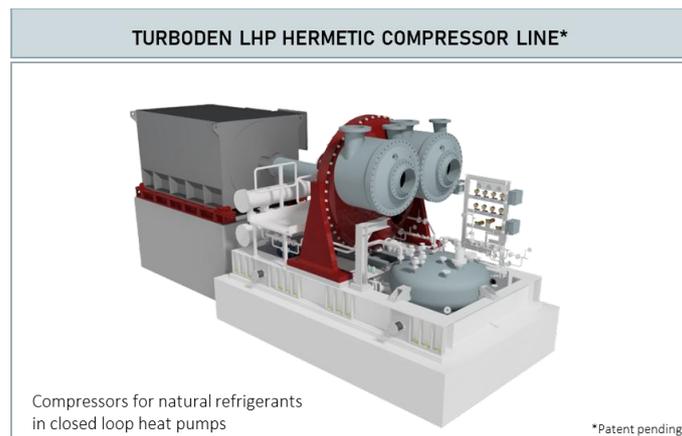


3.1.1. Centrifugal compressor

In this heat pump system, the centrifugal compressor plays a critical role in upgrading the enthalpy of the working fluid to deliver high-temperature heat to the thermochemical reactor. Unlike positive displacement compressors, the centrifugal compressor operates based on dynamic compression principles, using high-speed impellers to impart kinetic energy to the vapor. This kinetic energy is then converted into pressure through a series of stationary diffusers. In this application, the vapor entering the compressor has been preheated in a regenerator, which improves overall compression efficiency and reduces the required work input. The compressor is designed to handle moderate to high volumetric flow rates and is particularly well-suited for continuous, steady-state operation. Its ability to deliver high-

pressure, high-temperature vapor with relatively low mechanical wear makes it an optimal choice for systems with long operating cycles and demanding thermal output requirements. The compressor housing and internal components are constructed from materials capable of withstanding elevated temperatures and possible chemical interactions with the working fluid. Advanced sealing technologies and precision balancing are relevant to minimize leakage and vibration, ensuring operational stability. In addition, integrated control systems manage rotational speed and pressure ratios to adapt to variations in load and optimize the coefficient of performance (COP) of the heat pump. The centrifugal compressor’s compact design, high efficiency at design point, and minimal maintenance needs offer significant advantages in large-scale systems, particularly where reliability and thermal consistency are critical for reactor performance.

The centrifugal compressor is driven by a high-speed electric motor, designed for continuous operation under industrial conditions. The motor must deliver sufficient torque at high rotational speeds, typically above 10,000 RPM, to ensure efficient vapor compression. It is equipped with active cooling—either air or liquid—to manage thermal loads. The motor’s construction must be compatible with high ambient temperatures and integrated control systems allow precise speed regulation for optimal compressor performance.



Specifications and Requirements

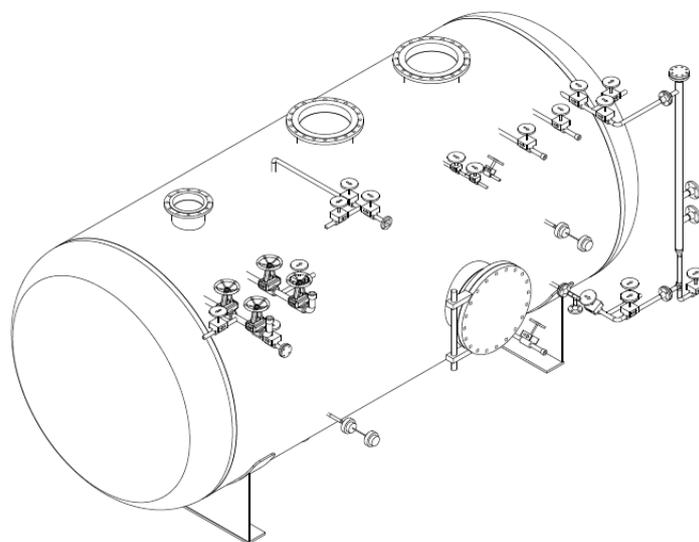
The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Compressor		
Parameter	Value	Unit
Type of compressor	<i>Centrifugal</i>	
Inlet pressure		bar
Outlet pressure		bar
Inlet Temperature		°C
Outlet Temperature		°C

Specific volume at the suction		m ³ /kg
Mass flow		kg/h
Electric connection		
Power consumption		kW
Voltage range		V
Frequency		Hz

3.1.2. Vessel

In this heat pump system, the vessel serves as a high-pressure liquid-vapor separator, installed immediately downstream of the condenser. Its primary function is to ensure complete separation of the condensed liquid working fluid from any remaining vapor before the fluid enters the regenerator or expansion device. The vessel operates under high-pressure, high-temperature conditions, receiving a two-phase mixture from the condenser. Due to gravity and internal flow control features, the denser liquid settles at the bottom, while any residual vapor is directed to the top and either recirculated or vented, depending on the system configuration. To enhance separation efficiency, the vessel may incorporate internal elements such as demister pads, baffles, or coalescing filters, which aid in removing entrained droplets from the vapor stream. Constructed from high-grade stainless steel or carbon steel with suitable pressure ratings, the vessel is thermally insulated to minimize heat losses and maintain fluid stability. Liquid level is monitored via sensors and/or sight glasses, and control valves regulate the outflow to downstream components. The vessel also acts as a buffer or reservoir, ensuring steady liquid supply during transient load conditions. Designed in accordance with pressure vessel codes, it ensures mechanical integrity, operational safety, and reliable phase separation—key to maintaining the thermodynamic performance and protecting the integrity of the heat pump cycle.



Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Expansion vessel		
Parameter	Value	Unit
Material	Carbon Steel	
Flow		m ³ /h
Inlet pressure		Barg
Outlet pressure		Barg

3.1.3. Heat Pump Regenerator

The regenerator is implemented as a shell-and-tube heat exchanger, designed to recover internal energy within the heat pump cycle and improve overall thermal efficiency. Its main role is to transfer heat from the high-pressure, saturated liquid existing from the condenser to the low-pressure vapor stream coming from the evaporator. The saturated liquid flows through the shell side, while the vapor stream passes through the tube side in a counterflow arrangement. As heat is exchanged, the liquid is subcooled, which reduces flash vaporization during expansion and ensures a more stable liquid supply to the evaporator. Concurrently, the vapor is superheated before entering the centrifugal compressor, minimizing the risk of condensation during compression and improving compressor reliability. The shell-and-tube configuration allows for robust mechanical construction, efficient heat transfer, and ease of maintenance under high-temperature and high-pressure operating conditions. The regenerator is built using thermally conductive, corrosion-resistant materials and is designed to minimize pressure drop while ensuring effective thermal coupling. Its integration into the cycle significantly increases the coefficient of performance (COP) and contributes to the safe and efficient operation of the entire system.

Specifications and Requirements

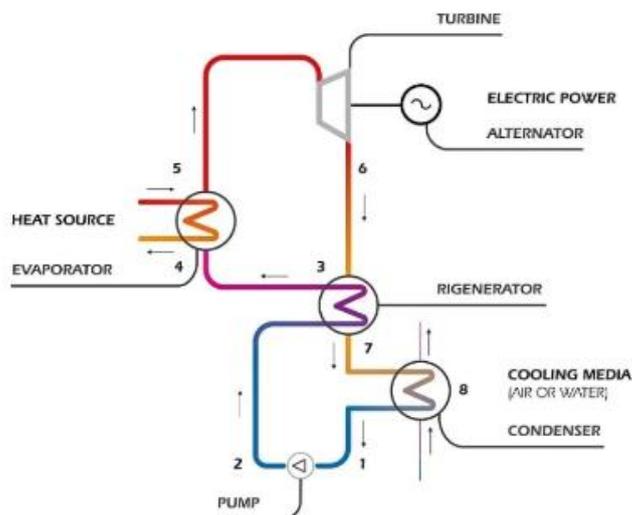
The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications. The parameters indicated (either fixed values or ranges) are independent of the machine size and, therefore, applicable to all ad-hoc solutions.

Heat Pump Regenerator		
Parameter	Value	Unit
Heat Pump mode		
Pressure inside tubes at nominal conditions		bar
Pressure outside tubes at nominal conditions		bar

Liquid phase inlet temperature		°C
Liquid phase outlet temperature		°C
Vapor phase inlet temperature		°C
Vapor phase outlet temperature		°C
Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
Constructive parameters		
Heat transfer area internal		m ²
Heat transfer area external		m ²
Diameter of tubes	19.05	cm
Tubes thickness	1-4	cm

3.2. The Organic Rankine Cycle (ORC)

The Organic Rankine Cycle (ORC) is configured to recover thermal energy from a thermochemical reactor and convert it into useful heat for a district heating network. In this system, the organic working fluid is first pressurized by a feed pump and then enters the evaporator, where it absorbs high-temperature heat from the reactor. This causes the fluid to vaporize and expand through a turbine or expander, generating mechanical work that can be used directly or converted to electricity. After expansion, the partially condensed vapor passes through a regenerator, where it preheats the pressurized liquid returning from the pump, thereby reducing the heat demand on the reactor and increasing cycle efficiency. The working fluid then flows into the condenser, where it transfers residual thermal energy to a district heating network at a lower temperature. This heat delivery supports residential or industrial heating demands while ensuring full condensation of the fluid. The regenerated and condensed working fluid is finally recirculated by the pump to complete the cycle. The inclusion of the regenerator enhances system performance by recovering internal heat, while the overall configuration allows for efficient integration between high-grade heat from the reactor and low-grade heat delivery to end users.



3.2.1. Turbine

The turbine in the ORC system is a crucial component that converts the thermal energy of the high-pressure organic vapor into mechanical power. It is an axial-flow turbine, specifically designed to handle the moderate mass flow rates and enthalpy drops typical of organic working fluids. The vapor enters the turbine at high pressure and temperature, expanding along the axial direction through multiple stages of rotor and stator blades, which extract energy efficiently. The resulting shaft power can be used to drive a generator or mechanical load. The axial design offers advantages in terms of compactness, smooth flow, and high efficiency over a wide operating range. The turbine materials are selected to be compatible with the organic fluid and to withstand moderate thermal and mechanical stresses. Careful sealing and lubrication systems are incorporated to maintain operational reliability. This turbine is integrated with the regenerator and condenser to optimize the overall cycle efficiency by maximizing energy extraction from the vapor before condensation.



Specifications and Requirements

The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Turbine		
Parameter	Value	Unit
Inlet pressure		bar
Outlet pressure		bar
Inlet Temperature		°C
Outlet Temperature		°C
Mass flow		Kg/h
Electric connection		
Power generation		kW
Voltage range		V
Frequency		Hz

3.2.2. Pump

The pump in the Organic Rankine Cycle (ORC) is a centrifugal pump responsible for pressurizing the condensed working fluid before it enters the evaporator. Designed to handle the moderate pressures and relatively low viscosity of organic fluids, the centrifugal pump provides a continuous, steady flow essential for stable cycle operation. It operates efficiently to minimize parasitic power consumption, contributing to the overall system performance. The pump is constructed with materials compatible with the organic working fluid and designed to withstand moderate temperature conditions typical of the ORC. Precision sealing systems prevent leakage, ensuring system integrity and safety. Often paired with variable speed drives, the pump can adjust flow rates dynamically to match load variations, optimizing cycle efficiency. Its smooth hydraulic operation reduces the risk of cavitation and mechanical wear, thereby protecting downstream components such as the evaporator and regenerator.

Specifications and Requirements

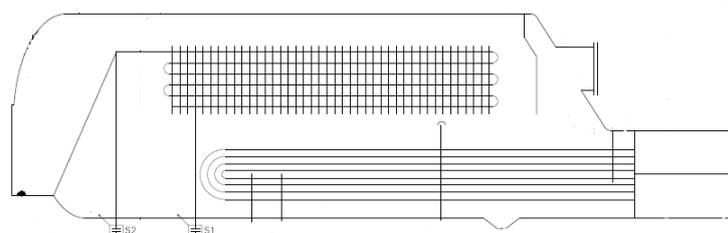
The datasheet applicable to this component is shown below, as mentioned previously the value of these parameters must be defined in an ad-hoc solution, so this datasheet must be considered as a template of specifications.

Organic fluid pump and motor
Pumps

Inlet pressure		bar
Outlet pressure		bar
Mass flow		Kg/h
Pumps electric connection		
Power		kW
Voltage range		V
Frequency		Hz

3.2.3. ORC Regenerator

The regenerator in the ORC is a key component designed to improve overall cycle efficiency by recovering heat that would otherwise be lost. It functions as a heat exchanger, transferring thermal energy from the exhaust vapor exiting the turbine to the liquid working fluid coming from the pump before it enters the evaporator. By preheating the liquid, the regenerator reduces the external heat input needed to vaporize the working fluid, thereby increasing the system’s coefficient of performance. The device typically consists of finned coils, where fins made of high-conductivity metals like aluminum or copper are attached to the pipes. These fins substantially increase the heat transfer surface area, enhancing the effectiveness of thermal exchange between the two streams. The compact design of the regenerator enables it to be integrated efficiently within the ORC loop, maintaining minimal pressure drop and ensuring reliable operation under varying load conditions.



ORC Regenerator		
Parameter	Value	Unit
Pressure inside tubes at nominal conditions		bar
Pressure outside tubes at nominal conditions		bar
Liquid phase inlet temperature		°C
Liquid phase outlet temperature		°C
Vapor phase inlet temperature		°C
Vapor phase outlet temperature		°C

Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
Constructive parameters		
Heat transfer area internal		m ²
Heat transfer area external		m ²
Diameter of tubes		cm
Tubes thickness		cm

3.3. Common components of ORC and HP

3.3.1. The High pressure heat exchanger

The high pressure heat exchanger is in charge of transferring/receiving heat to/from the thermochemical reactor. We can refer to the condenser when the machine is operated in Heat pump mode and we can refer to the evaporator when the machine works as ORC. There are two options depending on the boundary conditions: Hx integrated in the reactor or external Hx. In the first case, the same coiled heat exchanger can work as a condenser in the heat pump charging reactor and as an evaporator in the ORC discharging the reactor.

The specifications for the high pressure heat exchanger are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

High pressure heat exchanger		
Parameter	Value	Unit
Heat Pump mode		
Pressure of the working fluid at nominal conditions		bar
Phase change temperature at nominal conditions		°C
Organic fluid inlet temperature		°C
Organic fluid outlet temperature		°C
Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at operating conditions		kW _{th}
ORC mode		
Pressure inside tubes at nominal conditions		bar
Phase change temperature at nominal conditions		°C
Organic fluid inlet temperature		°C
Organic fluid outlet temperature		°C

Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at operating conditions		kW _{th}
Constructive parameters – ORC mode		
Heat exchanger typology	Shell & Tube	
Heat transfer area		m ²
Diameter of tubes		cm
Tubes thickness		cm

The list of requirements of the high pressure heat exchanger is the following:

- The definition of the heat exchanger must be compatible with the thermochemical reactor specifications.
- The heat exchanger must include a drum/phase separator in order to guarantee single phase fluid at the outlet avoiding vapor fraction at throttling valve inlet (Heat Pump mode) and liquid fraction at turbine inlet (ORC mode).

3.3.2. The low pressure heat exchanger

The low pressure heat exchanger works as an evaporator in the Heat Pump mode, harnessing the medium-temperature heat provided by the RES or the waste heat recovery. During the discharge, it operates in ORC mode providing heat to the district heating.

The specifications for the low temperature heat exchanger are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

Low pressure heat exchanger		
Parameter	Value	Unit
Heat Pump mode		
Pressure inside tubes at nominal conditions		bar
Phase change temperature at nominal conditions		°C
Organic fluid inlet temperature		°C
Organic fluid outlet temperature		°C
Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
ORC mode		
Pressure inside tubes at nominal conditions		bar
Phase change temperature at nominal conditions		°C
Organic fluid inlet temperature		°C
Organic fluid outlet temperature		°C

Heat transfer coefficient at nominal conditions		W/m ² K
Heat transferred at nominal conditions		kW _{th}
Constructive parameters – ORC mode		
Heat exchanger typology	Shell & Tube	
Heat transfer area		m ²
Diameter of tubes		cm
Tubes thickness		cm

In some cases, a double low pressure heat exchanger could be included, depending on the requirements of the specific case. This double configuration allows a double evaporator in the Heat Pump mode, each evaporator will work at a different temperature level providing thus increasing the capacity of integrating different heat sources (for instance, integrating RES and WHR sources that provide heat at different temperature levels).

The list of requirements of the low pressure heat exchanger is the following:

- The heat exchanger must be able to receive heat at the temperate provided by the RES and WHR.
- The heat exchanger must be able to deliver heat at the temperature required by the District Heating.

3.4. The thermochemical energy storage (TCES)

The thermochemical energy storage is quite similar to the described for the small-scale system, however, the equipment must increment their size and capacity for its adaptation to bigger plants. However, their working principle and their main characteristic (qualitative speaking) are similar as well as the general scheme. Therefore, in order to avoid redundancy of information this section will be focused on the differences between both systems (TCES for small scale vs TCES larger scales).

3.4.1. The reactor

Similar to the small scale case, the reactor considered is a stirred tank that works as a suspension reactor where the thermochemical solid material is suspended in a thermal oil. Due to the higher sizes of the tank the stirrer should include blades at different height in order to guarantee a correct mixing and flow of the suspension. Additionally, buffers can be added to the configuration in order to improve mixing but mainly the heat transfer.

The system could reach sizes in the order of few megawatts of thermal input. If additional thermal input is required, several reactors can be placed working in parallel, this configuration can support also partial loads operation activating some reactors while other are not working.

The heat exchanger that interacts directly with the organic cycles can be internal or external depending on the conditions applicable to the Heat Pump and the Organic Rankine Cycle.

Specifications and Requirements

The specifications for the unique reactor subsystem are stated in the following template datasheet which summarizes the main parameters. The value of these parameters must be defined in an ad-hoc solution.

Dual purpose reactor datasheet		
Parameter	Value	Unit
Tank		
Tank diameter		m
Tank height		m
Capacity		m ³
Design pressure		barg
Design temperature		°C
Corrosion allowance		mm
Heat exchanger coil		
Heat transferred at operating conditions in charge		kW _{th}
Heat transferred at operating conditions in discharge		kW _{th}
Mean temperature difference		K
Minimum free space between surfaces		mm
Fouling factor (in and out)		
Thermochemical reaction parameters		
Thermochemical reaction	Charge: Discharge:	
Thermochemical solid material		
Operating pressure in charge		barg
Operating pressure in discharge		barg
Concentration of solids suspended in oil during charge		%wt
Concentration of solids suspended in oil during discharge		%wt
Temperature of operation in charge		°C
Temperature of operation in discharge		°C
Stirrer type		
Stirring nominal speed		rpm

In cases of application where the boundary conditions are quite restrictive, a double reactor configuration could be considered, including a reactor connected to the Heat Pump, and other

different reactor connected to the Organic Rankine Cycle. This double configuration allows an optimization of the reactor separately allowing higher flexibility. However, the investment cost of this solution is higher, thus this configuration is only recommended in those cases where the dual-purpose reactor solution is not compatible.

3.4.2. The transport system

There are not relevant differences between the transport system of the small scale system and the bigger one. Mainly, the circulating system, will be based on the use of proper pumps suitable for high concentration mixtures (of solids and thermal oil). As higher flows are required for large scale applications, a pumping system involving several pumps working in parallel is required in order to reach high flows of suspension. In a similar way, for the separation process, industrial cyclonic separators must be considered in order to reach a high level of separation, allowing to store the solids with a minimum percentage of thermal oil. Several cyclonic separators can be stacked in order to process higher flows of mixture.

3.4.3. The reactant/product system

In relation to the solid's storage, there are now remarkable differences in comparison with the small-scale case. For large applications, the number of tanks in parallel will be increased due to the higher amount of material to be stored, thus it is recommended a dedicated building (as a warehouse) to ensure the protection the high number of tanks that will be filled with thermochemical material.

In relation to the water storage, in the scenario of large-scale applications where the energy balances and flows are quite high, the amount of water to be produced is quite considerable. Therefore, the most recommended solution is the open loop configuration, allowing not include tanks for its storage and reducing considerably the CAPEX.

4. Conclusion

This document provides an extended definition of the RESTORE overall concept, providing additional details of the main innovative components of RESTORE. This document updates the overall concept described at the beginning of the project, after the knowledge obtained during the project execution.

The document introduces the overall concept and detail the two different systems that can be developed based on this concept. One for small-scale applications, considering a reversible organic machine couple to the thermochemical energy storage, and the other one focused on large scale applications, where a mid-reversible solution is considered which means some components are used during charging and discharging process while others are only used in one of these processes.

For each system (small and large scale), the deliverable provides an extend description, through the definition of the systems main components and its tables for specifications and requirements. However, as the deliverable objective is to focus on the overall concept, the values of the specifications should be adapted, as ad-hoc solutions, considering the boundary conditions imposed by each specific application, so this tables must be considered as templates that are fulfilled as starting point for the design of a real facility based on the outcomes of this research project. In that context, the document provides the general bases of the concept that will be considered as a guide for potential future RESTORE system implementation at higher TRLs.