



# Innovative Energy Storage Solutions for Sustainable District Heating and Cooling



[www.restore-dhc.eu](http://www.restore-dhc.eu)





*"The groundbreaking RESTORE concept represents an extraordinarily innovative solution for delivering both clean electricity and heat while matching production and demand."*

**Francisco Cabello Nuñez**

Project coordinator, Centro Nacional de Energías Renovables (CENER)



*"With the RESTORE technology it is possible to store the excess heat in summer for the winter season."*

**Prof. Franz Winter**

TCES expert, Technische Universität Wien



*"Energy storage is the keystone technology for the transition towards a fully renewable energy market and rORC can play a disruptive role in distributed energy networks and industrial energy efficiency"*

**Prof. Marco Astolfi**

ORC expert, Politecnico di Milano

# RESTORE CONCEPT

## A SOLUTION FOR THE INTEGRATION OF CLEAN ENERGY SOURCES

The increased deployment of clean energy sources within the heating and cooling sector is of paramount importance in reducing its dependence on fossil fuels and the significant environmental impacts associated with their use. However, a major challenge arises from the non-dispatchability of most clean energy sources, which leads to a fundamental mismatch between energy production and demand.

The RESTORE project presents a radically innovative concept that enables the integration of a wide range of sustainable energy sources, including not only renewable energy sources (RES)

but also waste excess heat (WEH), within residential and industrial district heating and cooling (DHC) networks.

By combining clean energy sources with the energy storage capabilities proposed by RESTORE, it is possible to address the misalignment between energy supply and demand, thus paving the way for a reduction in fossil fuel dependence and enhancing environmental sustainability.

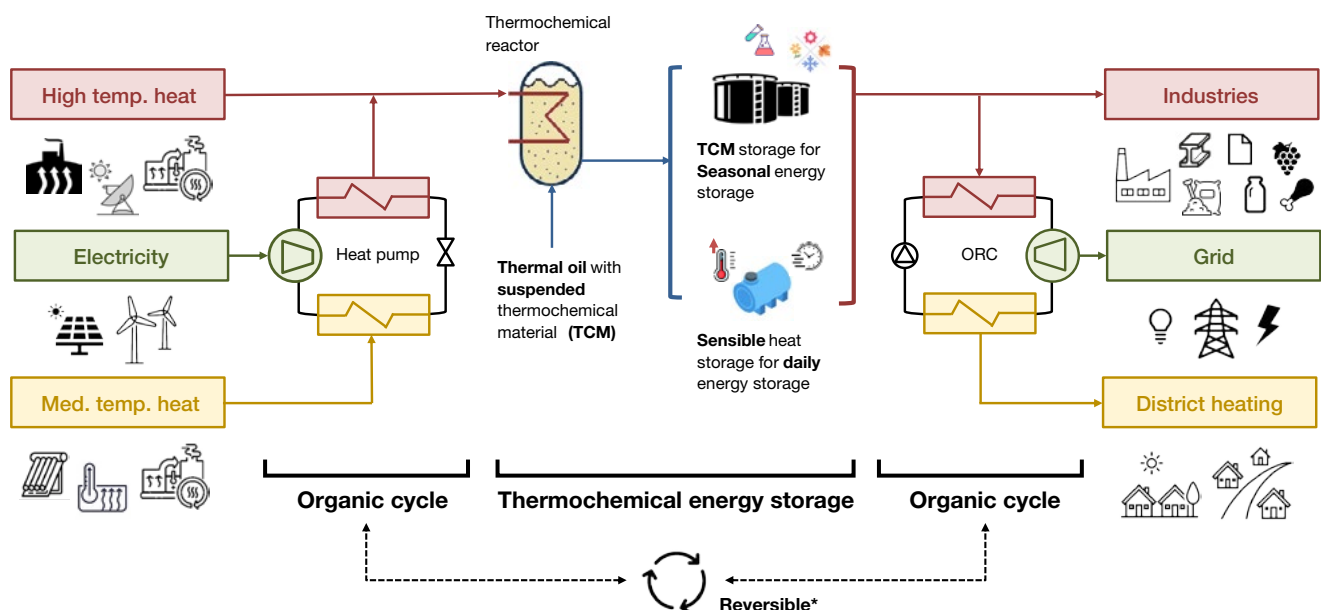
The RESTORE solution is built upon the integration of two key technologies: reversible Organic Rankine Cycle (rORC) and thermochemical energy storage (TCES). In heat pump mode, the organic

cycle first captures energy from various clean sources and delivers heat in the required conditions for a thermochemical reactor. The energy supplied to the reactor is stored both as reaction enthalpy and sensible heat. Upon demand, the system discharges the stored energy, providing heat directly to local industries or operating an ORC to generate electricity, while simultaneously adjusting the conditions to meet the heating requirements of a residential district.

### ENERGY SOURCES

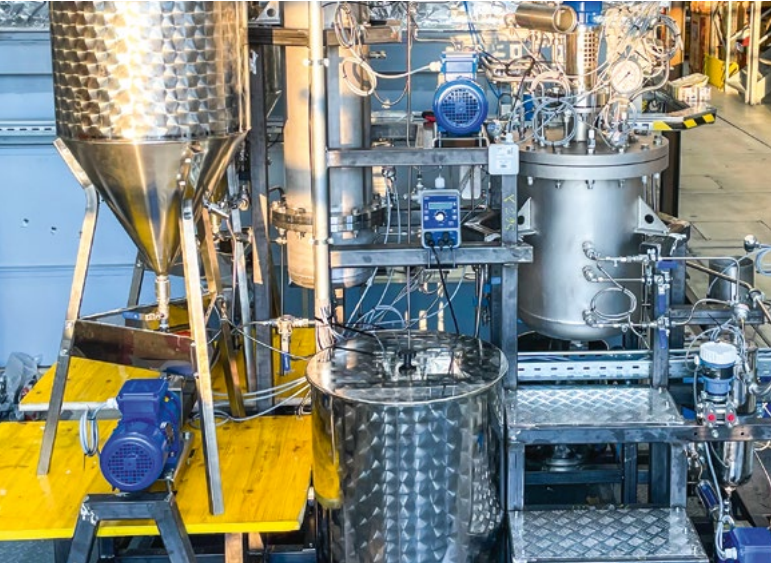
### RESTORE TECHNOLOGY

### USERS



# HIGH ENERGY DENSITY – NO HEAT LOSSES

## THERMOCHEMICAL ENERGY STORAGE (TCES)



5 kW<sub>th</sub> TCES continuous reactor system: Material testing device for different TCES pairs, p<sub>max</sub> = 10 bars, θ<sub>max</sub> = 200 °C.

By storing energy in chemical reactions, also known as thermochemical energy storage (TCES), it is possible to deposit energy without losses over long periods of time. In comparison to other technologies, the energy density is significantly higher. Moreover, the temperature level can be adapted to the requirements by choosing a suitable thermochemical material and by adjusting the pressure level. For the RESTORE concept, TCES is therefore the ideal solution for both short- and long-term energy storage. As part of the project, the

technology is being substantially advanced through the development of prototypes.

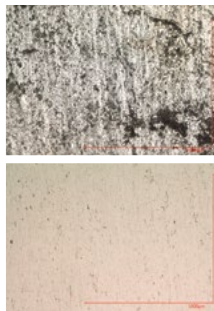
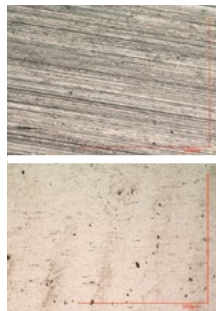
The TCES system on the left is a small-scale version of 30 kW<sub>th</sub> /150 kWh system to be installed in the laboratory of TU Wien. It can handle different TCES-materials like CuSO<sub>4</sub>·5H<sub>2</sub>O, CaCl<sub>2</sub>·2H<sub>2</sub>O or K<sub>2</sub>CO<sub>3</sub>·1,5H<sub>2</sub>O.

To adapt the reactor to the different TCES-pairs the system can be operated up to p<sub>max</sub> = 10 bars and θ<sub>max</sub> = 200 °C. The reactor can be operated in charge and discharge mode.

**Charge mode:** The thermochemical material inside the reactor is split up into a solid and gaseous compound. The gaseous compound (here H<sub>2</sub>O) is condensed and stored in a water container. The uncharged material is transported from the vessel for uncharged material, passing a preheater to the reactor where the decomposition takes place due to heating. After recooling and separating the solid material from the oil the charged material is stored.

**Discharge mode:** The solid material is recombined in the reactor with the gaseous/ liquid component and heat is released and extracted via an internal coil.

Mass flows, temperatures and pressures are measured to observe progress of reaction as well as for formulating the energy balance.



### Suspension properties

The behavior of the suspension is described concerning:

- density
- energy density
- viscosity

### Corrosion tests

Different types of steels were investigated according to their corrosion resistance

- Storage effects over 5 months and for 25 cycles were detected,
- Steels like 1.4301, 1.4404 and 1.4571 were analyzed

### Flow structure and heat transfer

Measurements concerning heat transfer, suspension distribution and flow structure were done

- Use of a glass reactor for observing flow structure by using PIV,
- Performing heat transfer measurements

*Stable continuous operation with heat charging and discharging cycles has been successfully proven with copper-sulfate and Potassium-carbonate. Further scale-up to 5 kW and 30 kW is ongoing.*

## RESULTS

### Optimized TCES materials

The chemical and thermophysical properties of numerous TCES materials were thoroughly analyzed, and the most optimal candidates were selected with energy densities up to 1.11 GJ/m<sup>3</sup> suspension (or 2.07 GJ/m<sup>3</sup> salt)

### Extensive material examination

Various types of mineral, silicon and vegetable oils, individually and in combination with each other or additives, were evaluated, and the optimal combinations for reaction were determined; thus, over 5–30 charging discharging cycles for 5 chemical systems was proven in lab-scale batch reactor

### Innovative sparger systems

were designed and applied to enhance mass transfer with the reactors.

### Optimized flow dynamics

Various impeller designs and agitation systems were evaluated through numerical simulations and experimental studies to optimize flow dynamics within certain reactor geometries and associated equipment.

### High heat transfer efficiency

leading to improved reaction kinetics and better control of TCES materials was successfully obtained.

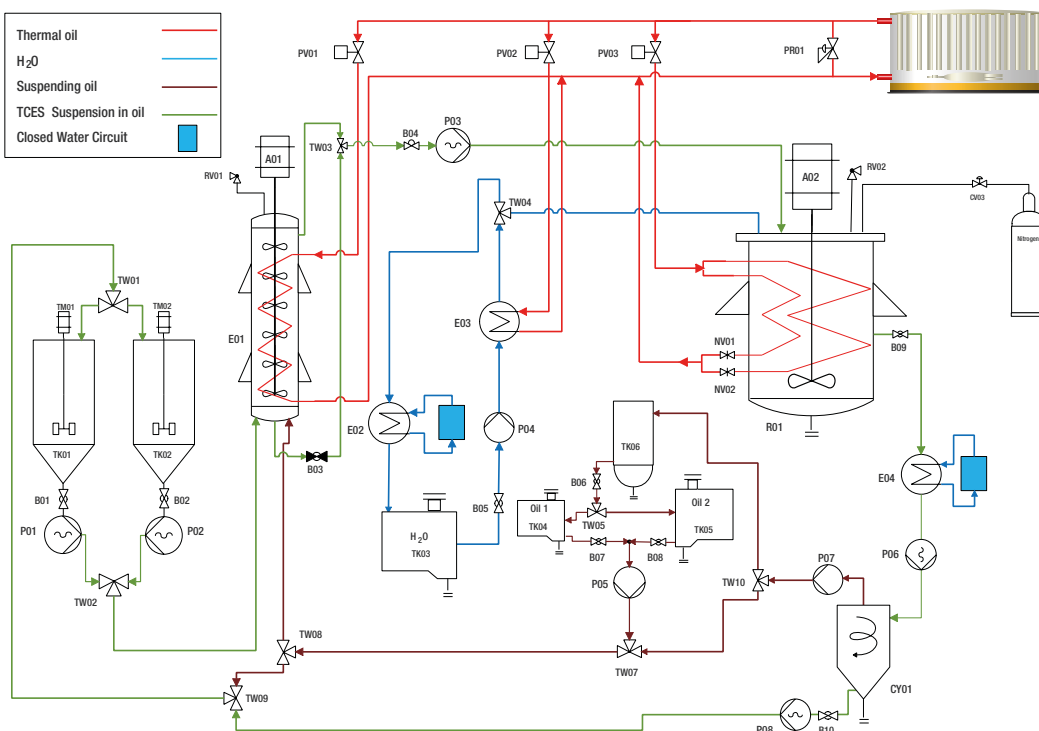
**Development of optimized preservation techniques** by the systematic examination of storage effects on TCES materials.

### Easy to scale-up system

An optimized process flow was engineered that allows for easy scale-up and further systems modularity.

### 5 kW<sub>th</sub> TCES pilot plant

Leveraging the insights from multi-disciplinary investigations and other low-scale test setups, a 5 kW<sub>th</sub> TCES pilot plant is manufactured as an intermediate step for the RESTORE 30 kW<sub>th</sub> scale-up plant to evaluate TCES materials under various operating conditions to further assess their potential for thermochemical energy storage.

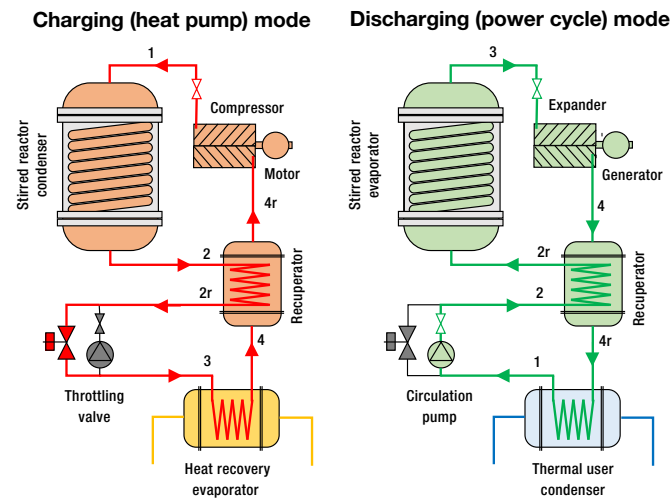


## Process flow diagram of the designed prototype reactor

Process flow diagram for the prototype reactor composed of storage tanks, water and oil circuits, CST Reactor, Heat Exchangers and other auxiliary equipment.

# INTEGRATE VARIOUS ENERGY SOURCES

## REVERSIBLE ORGANIC RANKINE CYCLE (rORC)



Thermally integrated Carnot Battery based on reversible ORC concept

### Reversible ORC Concept

Carnot Battery technology exploits heat and electricity by storing heat at high temperatures or chemical energy during charging and converts it back to electricity and mid-temperature heat during discharge. This reversible system functions as both a heat pump and a power cycle, using the same components. This dual functionality minimizes investment costs, maximizes operating hours, and enhances the overall economic viability of the system. Its core component, a volumetric machine, operates as both a compressor and an expander, depending on the operation mode and hence ensures high performance, minimal coupling issues, and flexible operation. This makes it ideal for small-to-medium application in distributed storage plants.

### Thermal integrated Carnot Battery Concept

The RESTORE project investigates and optimizes pumped thermal energy storage (PTES) systems based on Carnot batteries operating with ORC engines. This system seamlessly integrates heat from renewable energy sources and industrial processes, enabling the use of both surplus electricity from intermittent renewables and waste heat from various sources. As a result, this thermal integrated Carnot battery improves round-trip efficiency by minimizing thermal energy losses while offering a highly efficient solution for storing electricity from renewable sources.

An additional advantage of this system is the capability of ORC technology to absorb and release heat at nearly constant temperatures, making it ideal for medium-to-low temperature heat utilization and the controlled release of thermal energy for storage in the thermochemical reactor. Moreover, this system can be easily integrated within the district heating networks. The use of organic fluids also creates strong synergies with other industrial sectors, such as high-temperature heat pumps and industrial waste heat recovery, helping to explore and leverage economies of scale through large production volumes.

## RESULTS

### Efficiency

Exploitation of waste heat allows to boost the performance over 55 % for system not implementing additional sensible storage and approaching 100 % if more complex storage configurations are adopted.

### Flexibility

Capability to recover low-quality heat sources (< 80 °C), to upgrade them to TCES temperature (120–130 °C), to store them efficiently and then to use them when needed, either in thermal mode or in electrical mode.

### Scalability

It is possible to expand the range of applications, not limited exclusively to seasonal storage for large District Heating, but also for small towns and even for domestic and residential applications.

*Carnot Battery is the technology the energy storage market is waiting for.*

## rORC prototype

The rORC prototype was built by Enerbasque in collaboration with Politecnico di Milano. POLIMI optimized the system using numerical modeling and off-design performance analysis, selecting the working fluid, defining operating conditions, and addressing constraints. Meanwhile, Enerbasque handled the detailed design of the system, including component selection, layout definition, and modifications to the volumetric machine, which was initially designed as a compressor but later adapted to function as an expander as well.

The prototype is equipped with multiple temperature and pressure sensors for comprehensive monitoring and numerous automatically actuated valves, allowing a fast and reliable switching

between heat pump and power cycle operating modes. This prototype is currently being extensively tested in the laboratories of the Department of Energy of Politecnico di Milano, aiming to define the system's operational limits in terms of power and temperature and to analyze the transient conditions required for switching between different operating points.

Following this experimental campaign, it will be sent to the laboratories of TU Wien, where it will be connected to the continuous-loop thermochemical reactor. This final phase aims to test the effective integration of the two innovative systems developed within the RESTORE project.

## Carnot Battery upscale

The next step is to scale up the RESTORE rORC prototype for small-to-medium and large-scale applications, where Enerbasque and Turboden are working on the detailed mechanical design for the respective systems.

### Small scale

The solution for power outputs below 500 kW features a fully reversible configuration, minimizing installation costs and making it particularly attractive for small-scale residential or commercial markets. The design of this system builds on the experience gained from the prototype development and aims to provide guidelines for creating highly flexible machines with a broad operational range. A next generation olefin has been selected to ensure very high environmental sustainability and negligible fire hazard.

### Large scale

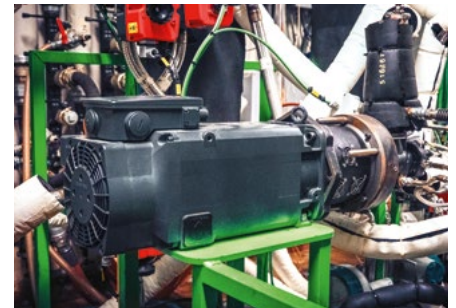
For power outputs above 1 MW, the system adopts a different approach, using two separate components – a compressor for the charging phase and a turbine for the discharging phase – to optimize efficiency. This configuration is designed to maximize performance while leveraging Turboden's expertise in turbomachinery for ORC engines and high-temperature heat pumps. Additionally, a natural working fluid has been selected for this machine to ensure high efficiency while maintaining full compliance with European regulations.



Commissioning and performance testing at POLIMI facilities.



Construction of rORC Prototype at Enerbasque Facility.



Twin Screw reversible volumetric machine – Compressor/ Expander

# VIRTUALLY SIMULATED INTELLIGENTLY INTEGRATED RESTORE USE-CASES

Based on six virtual case studies, potential applications of RESTORE technology at several locations in Europe are analyzed:

1

3

5

2

6

4



### Join the RESTORE virtual community!

To experience the disruptive potential of this innovation and interact with its capabilities, we invite you to join our community managed by Prospex Institute!

Register here!

### As a member, you'll receive:

- A comprehensive introduction to the project with a one-to-one meeting
- Access to a free webinar
- Membership in an active LinkedIn group
- Free trial access to the platform



**Use-Case 1**  
**Brønderslev plant**  
 Denmark

Residential/Industrial DH with Biomass and Solar Collectors and industrial waste excess heat (WEH).  
 Increased use of solar thermal energy and additional supply of electricity.



**Use-Case 2**  
**Gmunden cement factory**  
 Gmunden, Austria

Integration of different Cement Industry heat sources in DHC.  
 Integrating RESTORE technology into the Cement production plant to supply neighbouring heat consumers.



**Use-Case 3**  
**Mondi SCP Plant**  
 Ružomberok, Slovakia

Integration of different heat sources in DHC of Paper Mills Industry.  
 Maximization of RES integration and optimum WEH utilization from the factory for highly efficient seasonal storage of heat.



**Use-Case 4**  
**Alfa Acciai steel factory**  
 Brescia, Italy

Integration of different heat sources in DHC of Steel-working industry.  
 Improve HP utilization during summer season to increase its share on local DH.



**Use-Case 5**  
**Geothermie Holzkirchen Plant**  
 Holzkirchen, Germany

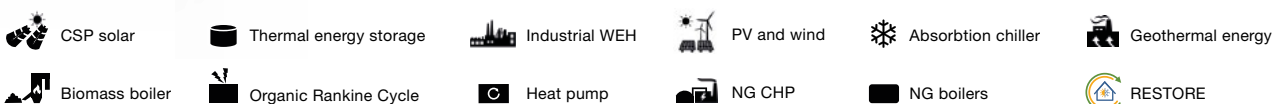
District heating with Geothermal Technology.  
 Maximization of the geothermal heat exploitation and optimum WEH utilization for highly efficient seasonal storage of heat.



**Use-Case 6**  
**POLIMI Campus**  
 Milan, Italy

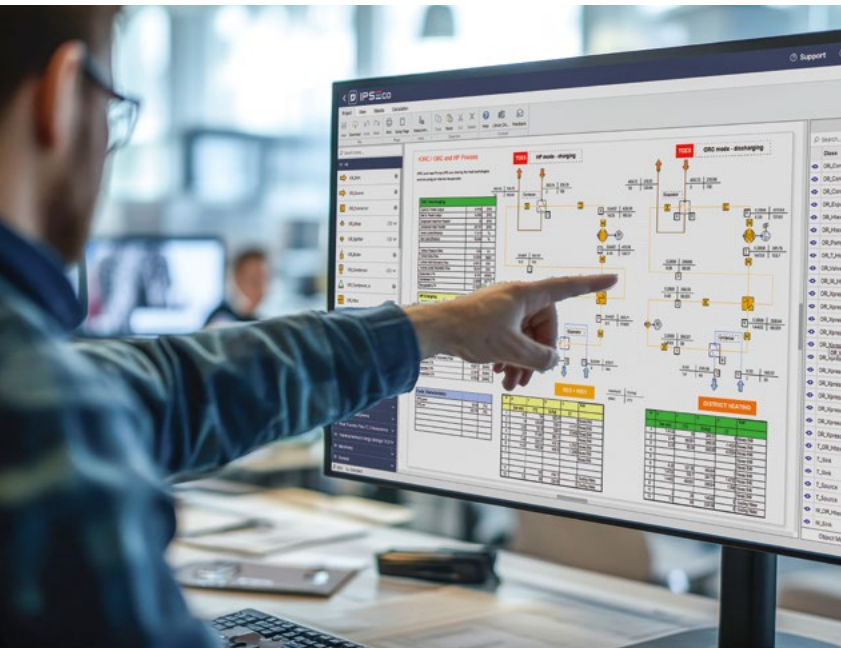
Small scale DHC network.  
 Apply the RESTORE concept for small size decentralized solutions and reduce natural gas consumption.

Legend:



# RESTORE IN SCALED-UP SCENARIOS

## PROCESS SIMULATION WITH VIRTUAL TOOL



### RESTORE Virtual Tool














To demonstrate the RESTORE concept and provide stakeholders and end-users with easy access to findings from the Use-Cases, the RESTORE virtual tool has been developed as an interactive web platform accessible via any web browser.

All Use-Cases are available through the virtual tool and can be explored in detail. Registered users can modify the existing Use-Cases process models and create own new test cases for the RESTORE technology.

The RESTORE virtual tool combines the capabilities of a generic process simulation framework with a library of components specifically developed to represent the RESTORE concept. Process models are constructed using the individual component models in the library.

The virtual tool includes a library of over 80 component models that can be graphically arranged to create process models for systems based on the RESTORE concept.

Excerpt from the RESTORE Model Library

-  **generator**  
gncrator
-  **G\_Sink**  
sink for a gas stream
-  **motor**  
motor
-  **OR\_Compressor**  
compressor for ORC fluids
-  **OR\_Connector**  
connector for ORC streams to be used in closed loops
-  **OR\_Htex**  
general purpose heat exchanger for ORC fluids
-  **OR\_Mixer**  
mixer for ORC streams
-  **OR\_Properties**  
calculation and display of physical properties of OR fluids
-  **OR\_Sink**  
sink for an ORC stream
-  **OR\_T\_Htex**  
heat exchanger for transfer from ORC fluid on hot side to thermofluid on cold side
-  **OR\_Xprescription**  
prescription/calculation of vapor quality of an ORC fluid
-  **TCM\_Connector**  
connector for TCM to be used in closed loops
-  **TCM\_Htex**  
heat exchanger for transfer from TCM fluid on hot side to TCM fluid on cold side

### Simulation Platform IPSE GO

The virtual tool is based on the process simulation platform IPSE GO, a generic and cloud-native process simulation framework. IPSE GO is adaptable to different applications through the use of application-specific model libraries. For the development of new model libraries, it relies on the Model Development Kit of the IPSEpro process simulation package.

IPSE GO features a graphic user interface for setting up process models graphically, solving them and displaying results. Additionally, it enables the integration of process models into websites, facilitating dissemination and broader accessibility. The platform also supports comprehensive project sharing and collaboration capabilities.

To customize it, IPSE GO exposes a scripting interface that allows to interface with other calculation modules such as Google Docs, a capability that is used for implementing the economic assessment of the RESTORE concept.

# COMBINING TECHNOLOGIES EFFICIENTLY

## BRØNDERSLEV FORSYNING A/S

### Use-Case 1: Brønderslev plant

Brønderslev hybrid plant is the world's first concentrated solar power (CSP)-biomass plant to utilize waste heat. The combined heat and power plant consists of a 16.6 MW parabolic trough collector field, two 10 MW biomass boilers, and an Organic Rankine Cycle (ORC) system with an electrical output of 4 MW. The solar collector field and biomass boilers are hydraulically connected and supply heat in parallel to the ORC system.

A multi-stage heat recovery process ensures that the waste heat is supplied to the local district heating grid. The solar field can also be operated independently of the biomass plant, supplying heat directly to the district heating grid. The hybrid plant performed reliably and successfully demonstrated the potential of CSP-biomass hybridization.

In the virtual Use-Case, the RESTORE solution is adapted to meet these specific requirements. It utilizes surplus solar

thermal energy from the existing parabolic trough solar collector field to directly charge the thermochemical reactor and produce dehydrated thermochemical storage material. Thereby, no heat pump is required for the charging operation, as the temperature of the thermal oil from the plant's solar circuit is sufficiently high.

During the discharging cycle, the thermochemical material is fed to the reactor at favorable periods to drive an ORC power turbine. Using the virtual tool, it is possible to adapt the process configuration of the RESTORE technology to these conditions and evaluate its performance in such a scenario.

#### Further info

Access to the results from the RESTORE virtual tool will be available under the following link: [about.ipsego.app/embed/RESTORE\\_Lib](https://about.ipsego.app/embed/RESTORE_Lib)



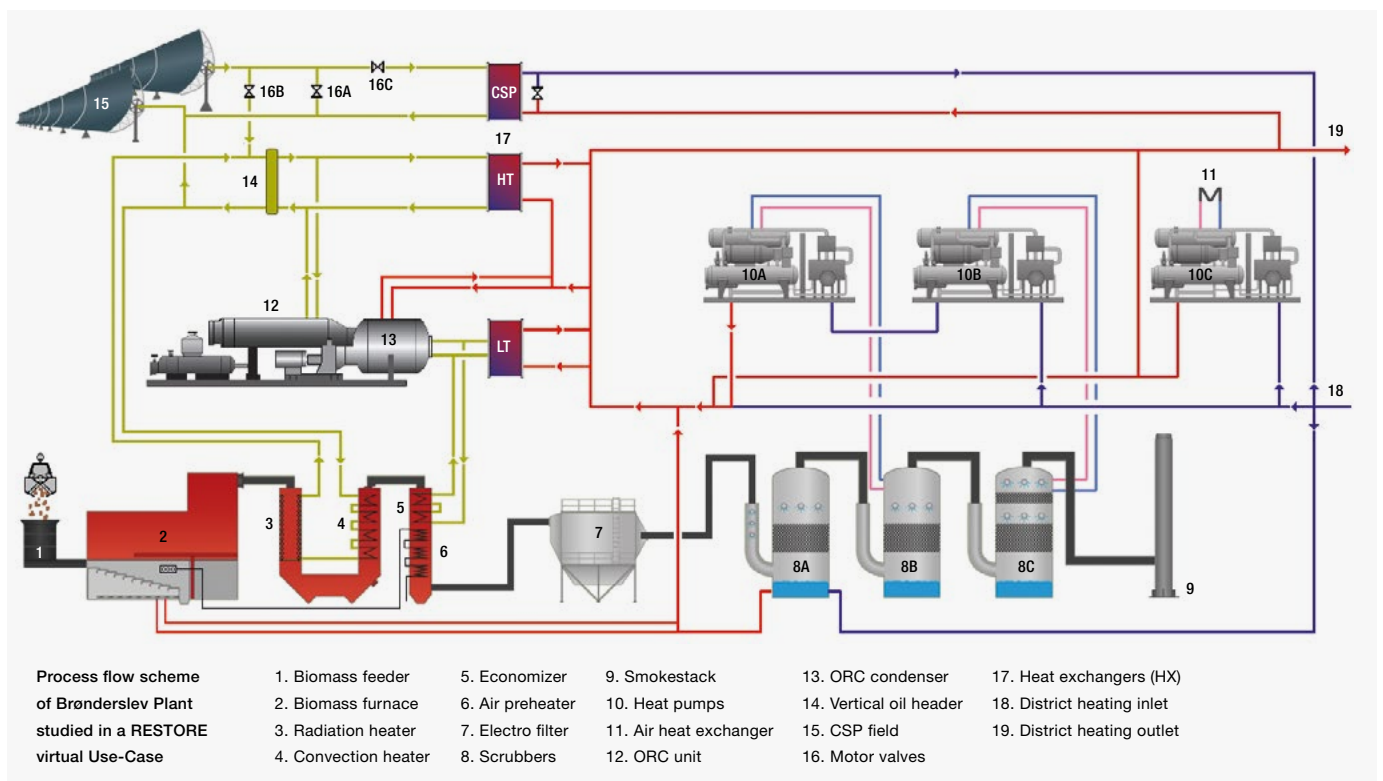
### RESULTS

#### Increased use of solar thermal energy

The virtual solution aims at the maximization of renewable energy integration in the district.

#### Additional supply of electricity

In periods with high electricity prices, the RESTORE solution can supply electrical power by running an ORC turbine via discharging the thermochemical material in the reactor.





## Renewable Energy based seasonal Storage Technology in Order to Raise Economic and environmental sustainability of DHC.

The RESTORE project that started in October 2021 and will be ending in 2025 involves 12 partners spread over 7 different countries in the EU. Fundación CENER, with large experience in the renewable and energy storage fields and in coordinating H2020 projects, leads the consortium, which encompasses an interdisciplinary group of entities. Universities with long experience in the proposed concepts assist companies specialized in the industrialization of the

developed technology. Additionally, SME specialized in simulation tools ensure the reliability of virtual Use-Cases analysis supported by industrial companies with large experience in sector coupling in DHC networks. Moreover, the consortium involves experienced entities, which carry out the assessment of the proposed technology in various areas as well as the dissemination and the exploitation of the project results.



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