FRIENDSHIP update

FRIENDSHIP
Forthcoming Research and Industry for European and National Development of SHIP

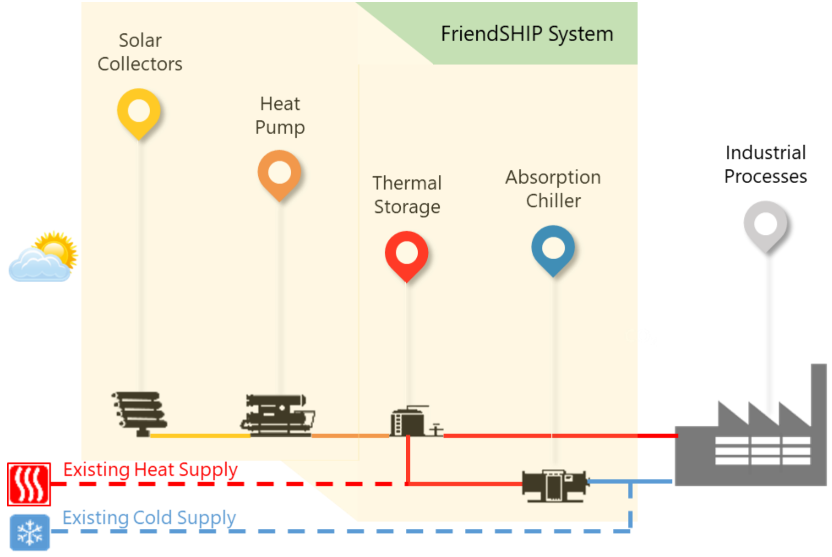
Grupo MT

24/10/2023

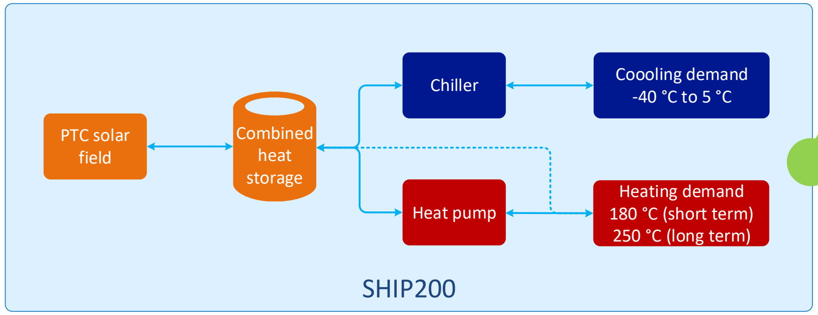
The FriendSHIP European project

Forthcoming Research and Industry for European and National Development of SHIP

Start: 01/05/2020
Duration: 48 months
Coord: CEA
Consortium: 10
Budget: 4,999,423.74 €
Type of action: RIA
Topic: LC-SC3-RES-7-2019 Solar Energy in Industrial Processes

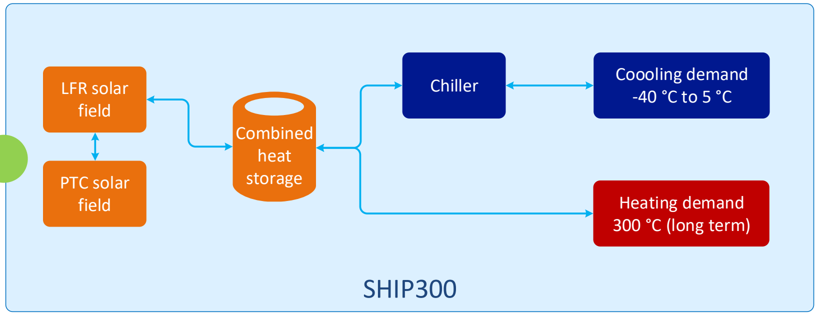


Main options



Validation of SHIP200 in relevant conditions
Demo site Grenoble (FR), Annual DNI 1,400 kWh/m²

Numerical validation of SHIP300 in relevant conditions *End-users sites (DE, PT, SP)*



The FriendSHIP European project

Forthcoming Research and Industry for European and National Development of SHIP

FRIEND SHIP
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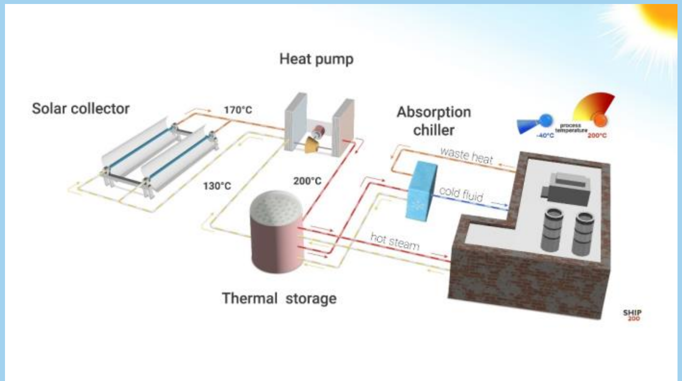

→ Project videos

→ Overall Concept

CLARIANT
AMIRES
ABSOLICON SOLAR COLLECTOR AB
cea
INDUSTRIAL SOLAR renewables onsite
RINA
SINTEF
SONAE
ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

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https://www.friendship-project.eu/

Technical WP

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Solar Collectors

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Status

- Finished – New selective coating to be used for the solar field of SHIP200 DEMO
- Deliverable: D2.1 Design engineering report for a solar thermal system with high availability
- 3 Papers :
- Review of the spectrally selective (CSP) absorber coatings, suitable for use in SHIP; Noč L.; Jerman I.; Solar Energy Materials and Solar Cells 2022, 238.
- A review of the use of nanofluids as heat-transfer fluids in parabolic-trough collectors; Chavez Panduro E.; Finotti F.; Largiller G.; Lervåg K.; Applied Thermal Engineering 2022, 118346.
- Environmentally sustainable electroplating of selective cobalt-chromium coating on stainless steel for efficient solar collectors; Zäll, E., Nordenström, A., Järn, M., Mossegård, J., Wågberg, T.; Solar Energy Materials and Solar Cells 2022, 111821.
- 1 video on Heat Production : https://vimeo.com/782532916

Solar Collectors

Nanofluids and selective coatings

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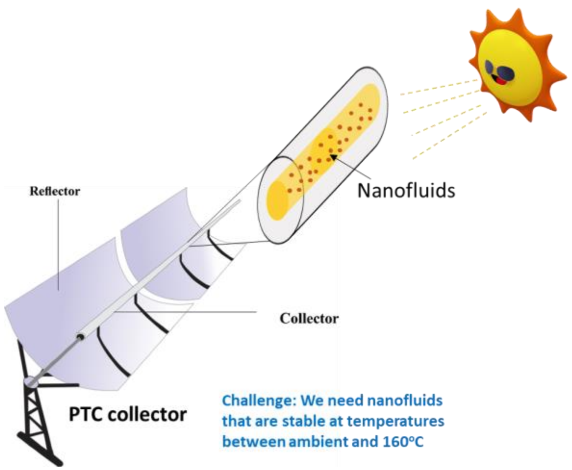
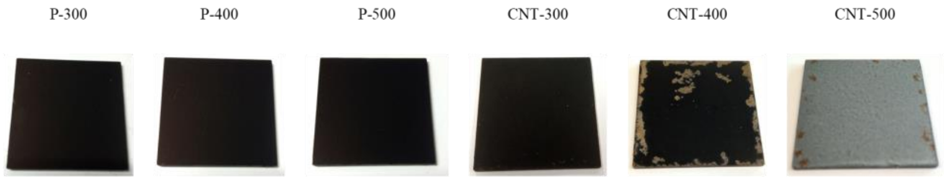
✓Literature study of nanofluids at high temperatures



Advantages	Drawbacks
• Good thermal properties • Inherently stable compared to e.g. microfluids (Brownian motions overcome gravitational settling)	• High cost of production • Stability can be broken by agglomeration – stabilization mechanisms are challenging at high temperatures • May lead to increased corrosion and erosion

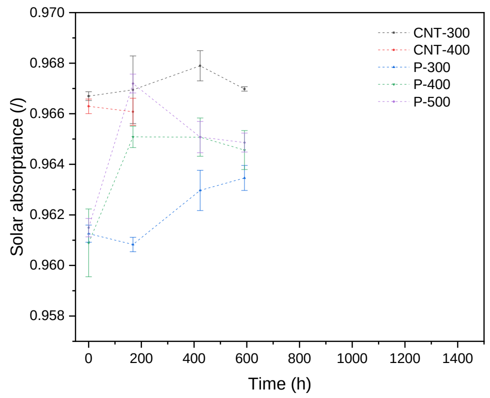
→ There is a need for **more experiments** with nanofluids at temperatures above 100 °C

✓Development and testing of Electroplating, Carbon nanotubes & Pigment based coatings



Characterization and ageing

→ DURASOL platform (CEA)



Very High Temperature Heat Pump

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Status

- Prototype commissioned and test campaign ongoing at SINTEF
- Public Deliverable 3.1: Initial heat pump concepts and integration principles for SHIP200 targeting heat delivery up to 200 °C (steam cycle) and 250 °C (e.g. CO_2 cycle)
- 1 video on Heat Production : https://vimeo.com/782532916

Very High Temperature Heat Pump

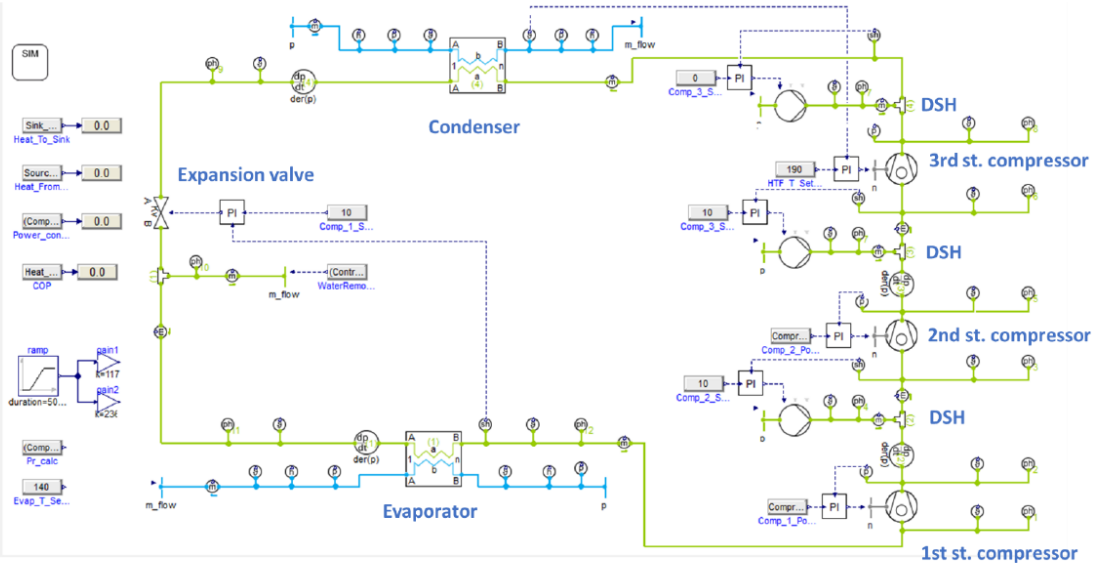
Dynamic simulation

Results from Modelica simulations:

- ✓ Dynamic models developed for best short-term and long-term HP concepts
- ✓ Simulated at design and off-design conditions (50-100% heat load) to assess operational performance, stability and integrability

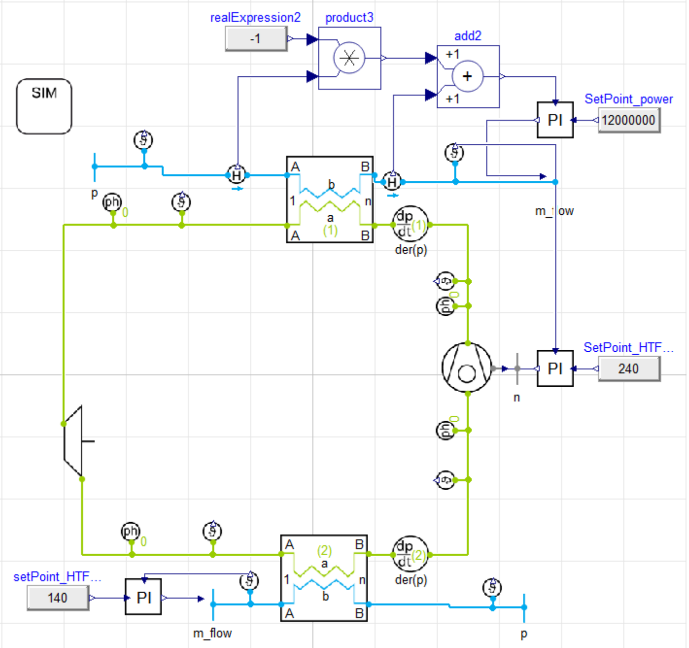
Closed loop steam HP cycle (SHIP 200)

- ✓ COP variations between 4.75 – 4.96
- ✓ Low variations due to improved HX performance at part loads



Reversed Brayton CO_2 HP cycle (SHIP 250)

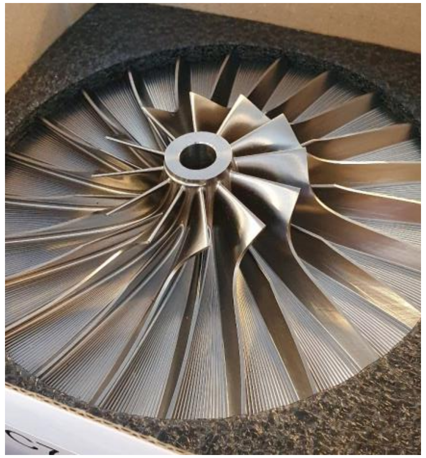
- ✓ COP at design point 2.44, 34% reduction at 50% load
- ✓ Improvement of control strategy may improve off-design performance

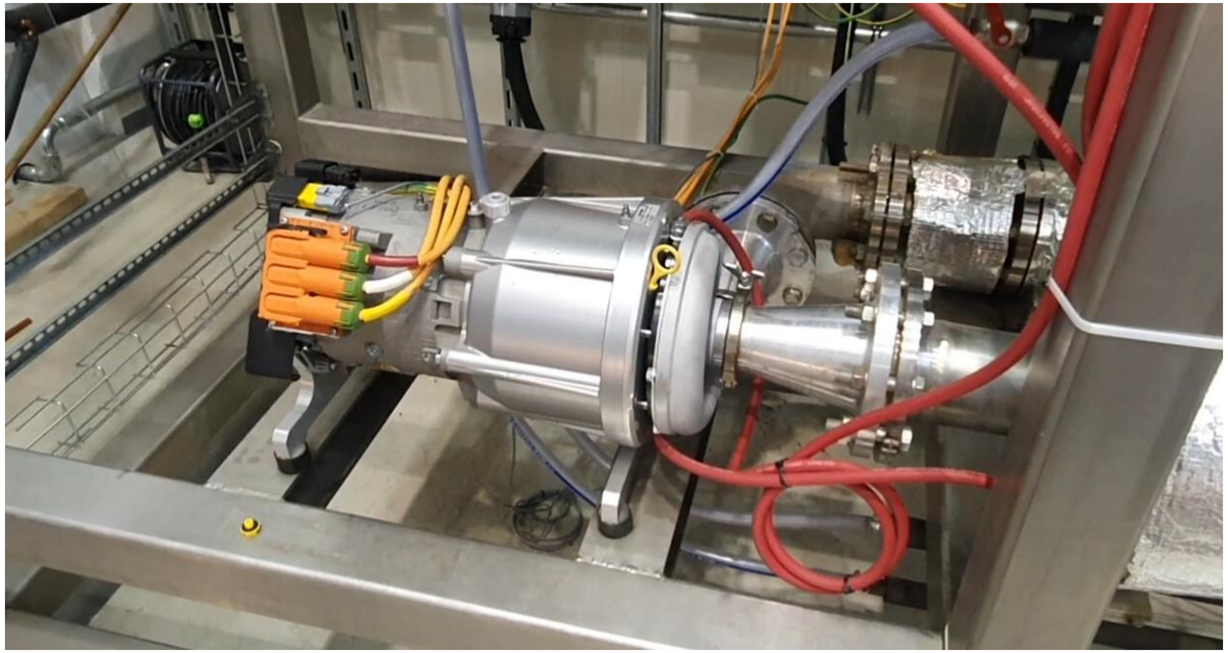


Very High Temperature Heat Pump

Turbo compressors

- Compressor: Rotrex - 2 x E-C38R-IX-PT52 (EA42 head unit)
- Two compressor stages
- Rotational speed: up to 90.000 rpm
- Improved labyrinth Lip seal
- Titanium impeller
- Purge chamber





Very High Temperature Heat Pump

Turbocompressors test rig

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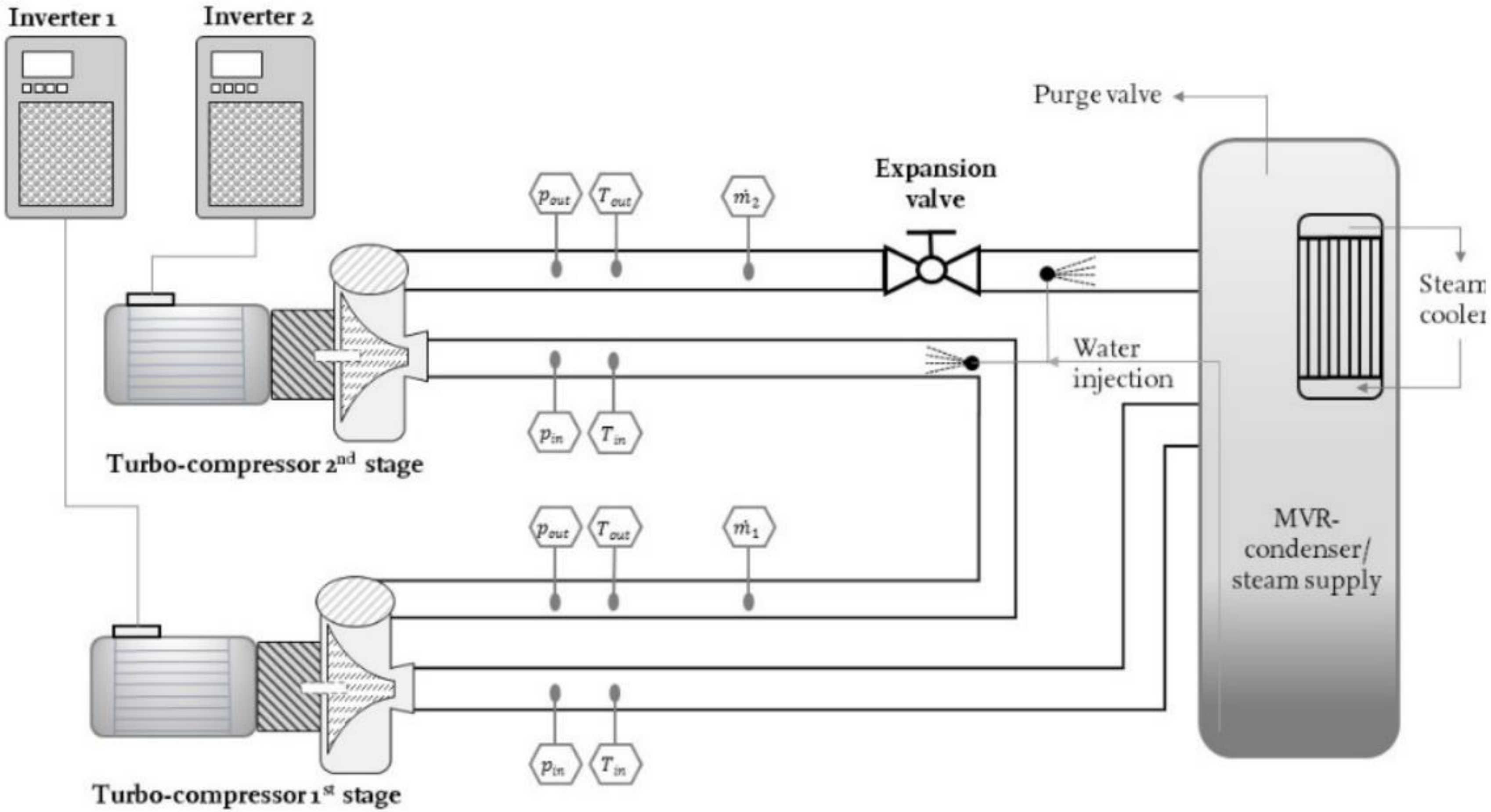
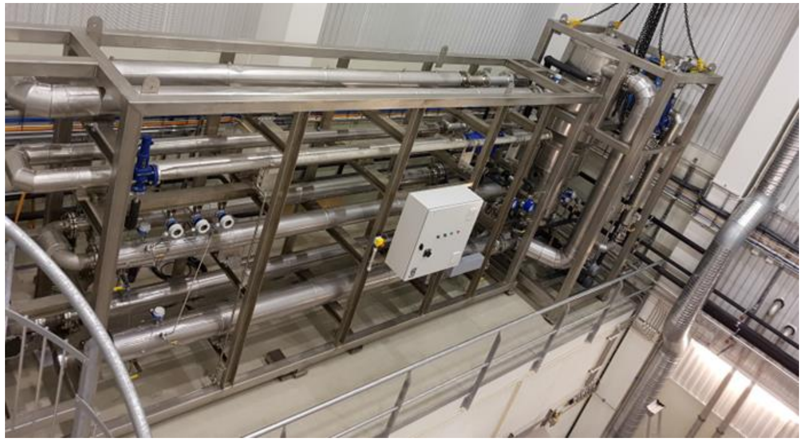


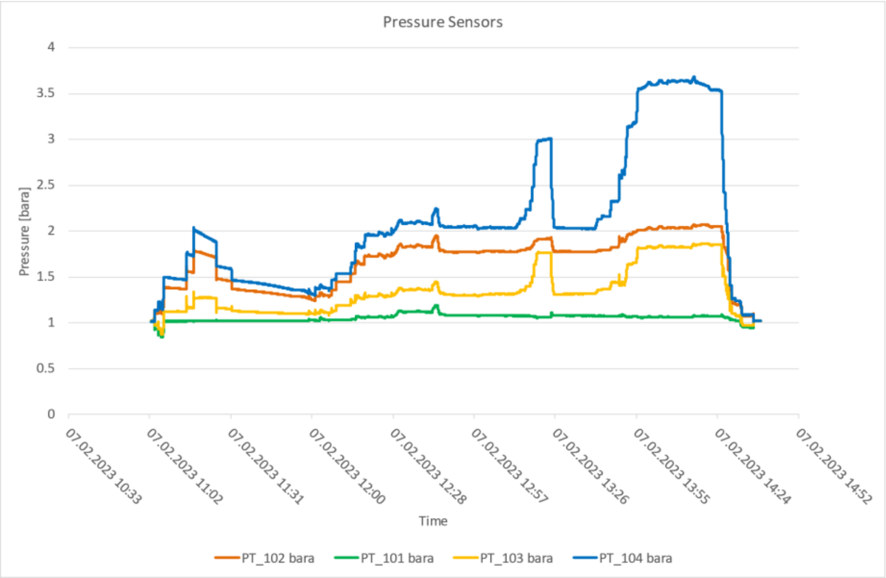


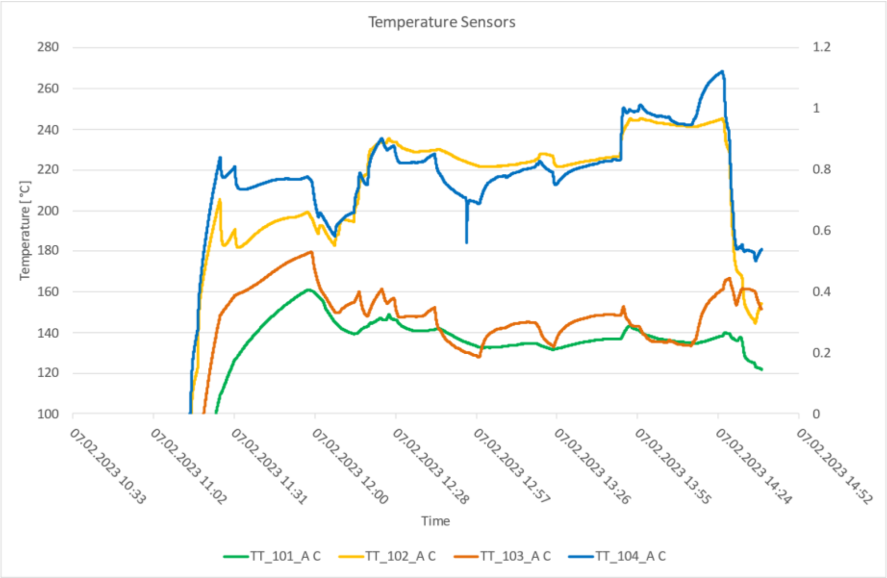
Test rig in SINTEFs laboratory

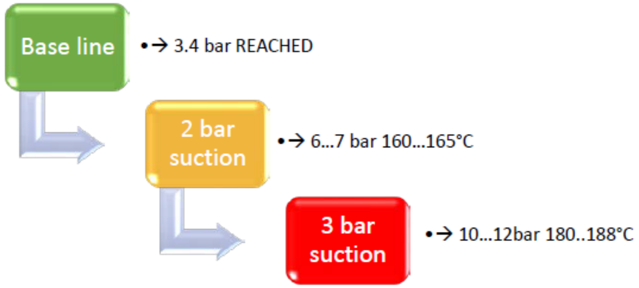
Very High Temperature Heat Pump

Commissioning and first results

- Aim: test water injection, test of new sensors, optimize water purge
- Results testing:
  - Media: steam
  - Up to 243 °C and pressure 3.4 barA.
- No remaining issues for test with suction pressure 1 bar
- No issues due to high temperatures were detected
- Step Wise Approach







High-Density Combined Heat Storage

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Status

- Prototype manufacturing ongoing and test campaign coming soon at CEA
- Deliverable: D5.1 Detailed design of PCM storage
- Dissemination: IN-POWER workshop 2020, SolarPACES 2021
- 1 video on Heat Storage : https://vimeo.com/814166694

High-Density Combined Heat Storage

Material characterization - binary eutectic

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Proportions mixed and heated 4h @ 250°C, then characterized

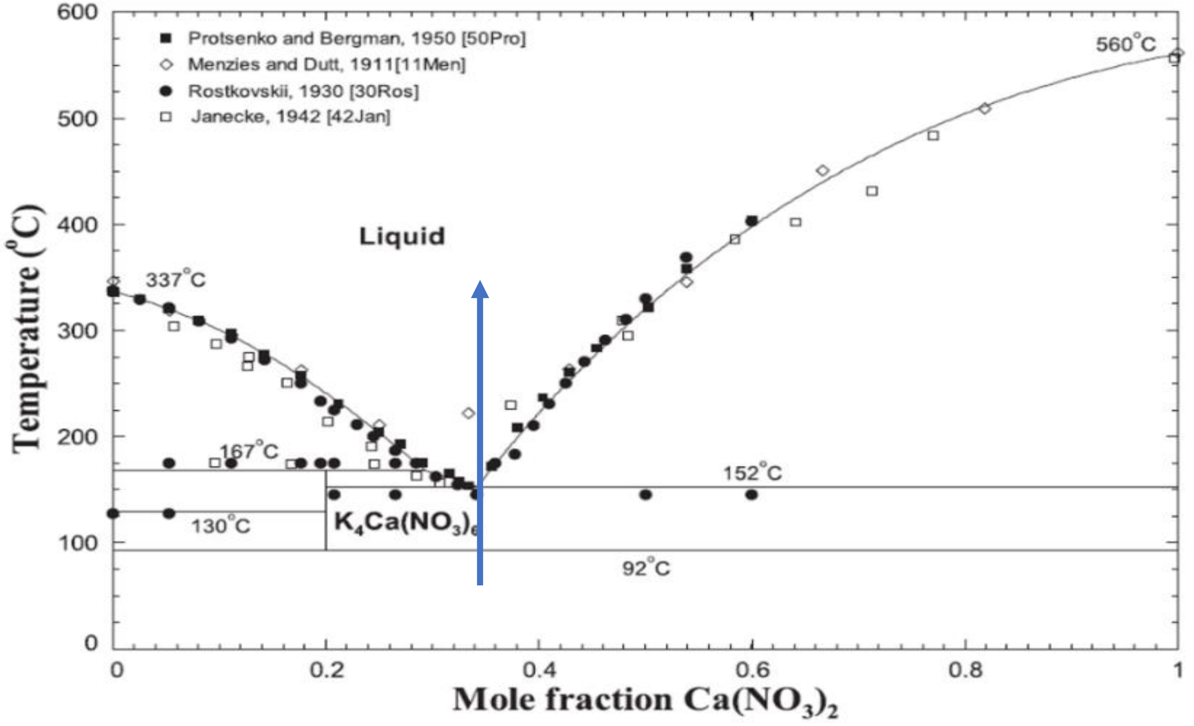
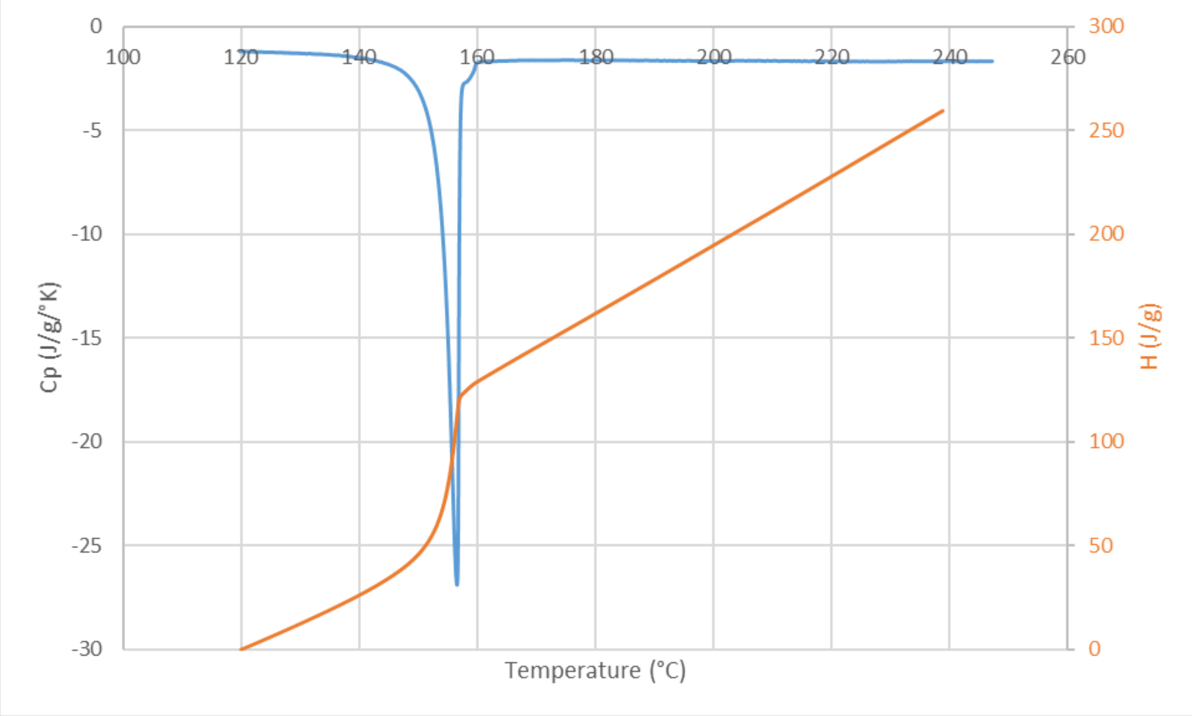


Figure 1. Calculated KNO_3-$Ca(NO_3)_2$ phase diagram.

Source: Chartan et al., 2019, The Journal of Chemical Thermodynamics, 2019



T_{onset}=152°C, H_f=70 J/g, $H_{[140-180]}$=130 J/g
Density Solid @ 22°C: 2 151 kg/m^3
Liquid @ 185°C: 2 074 kg/m^3

High-Density Combined Heat Storage

Design of the CHS

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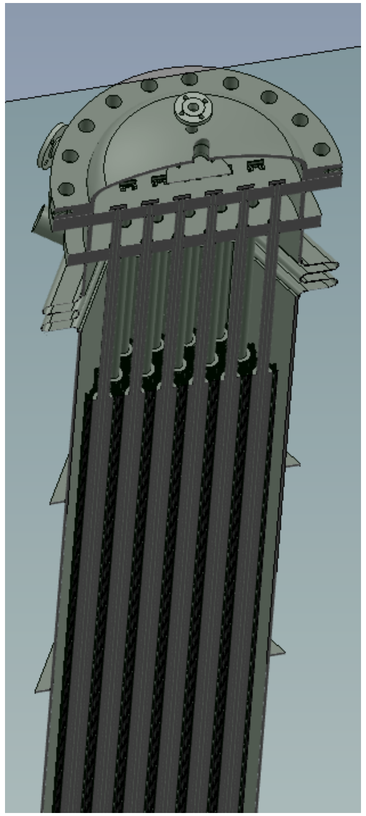
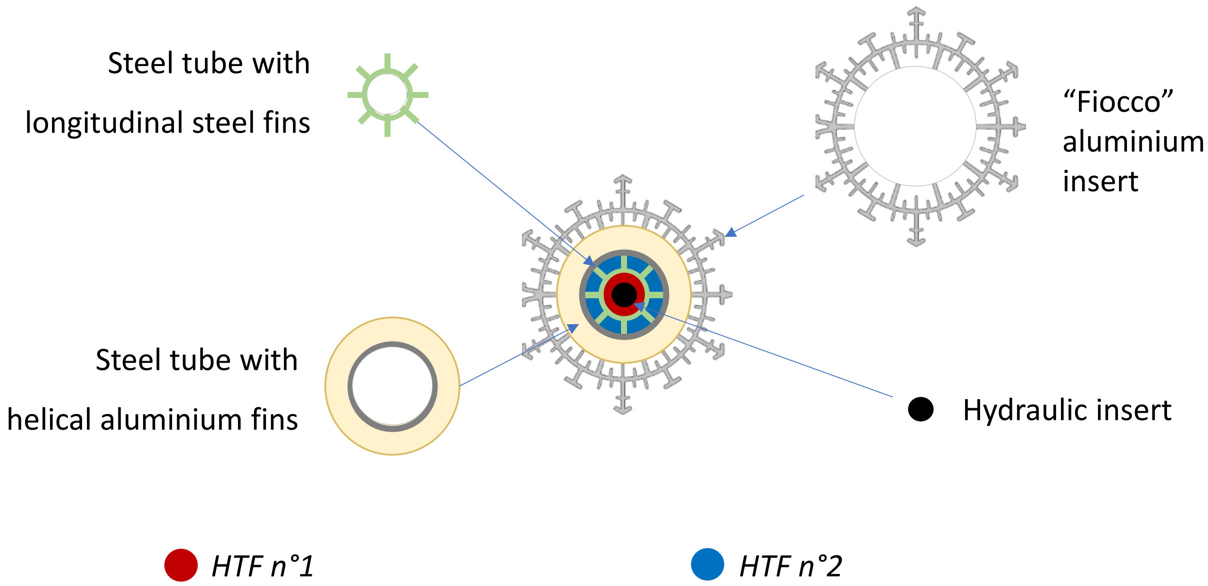
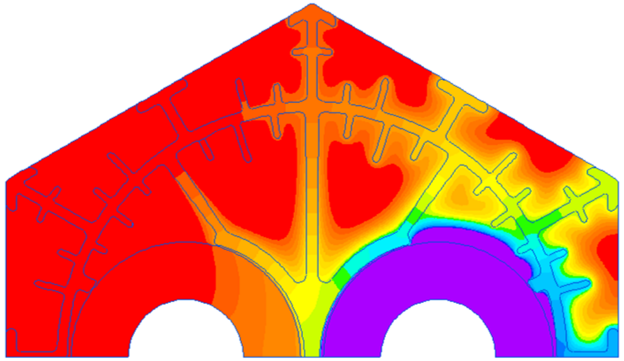
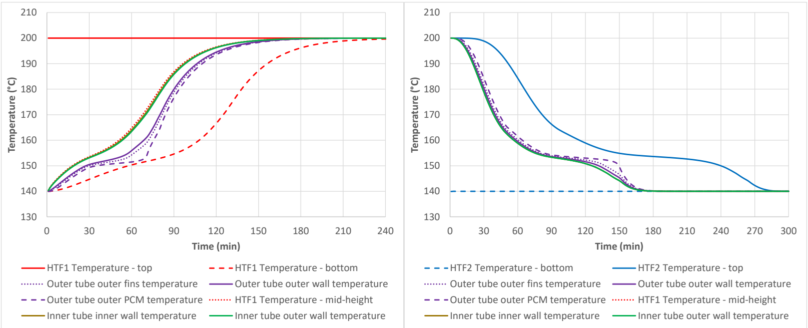


24 double-tubes arranged in a 98 mm triangular pitch in a hexagonal shell.





CFD simulation of CHS elementary volume



Dynamic simulation of CHS in charging and discharging modes

High-Density Combined Heat Storage

Manufacturing of the CHS

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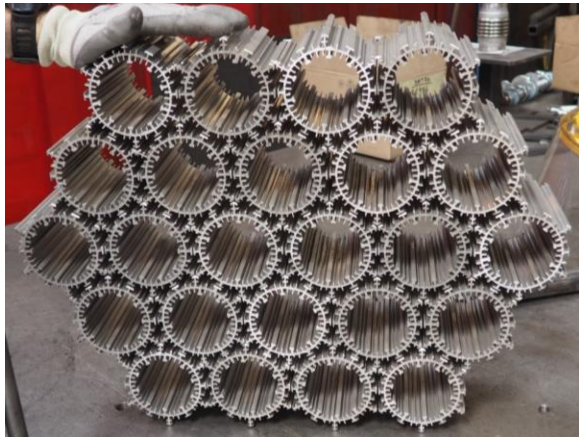
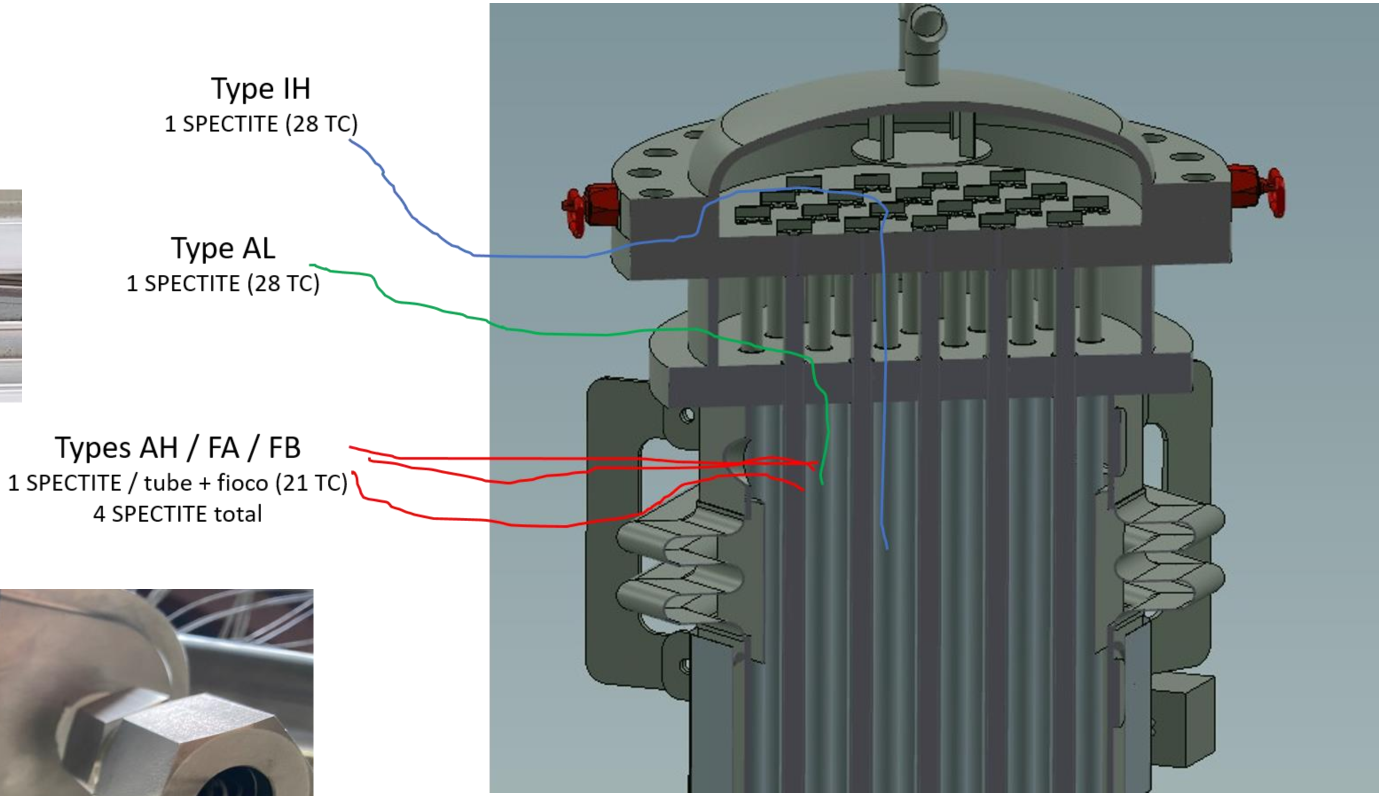
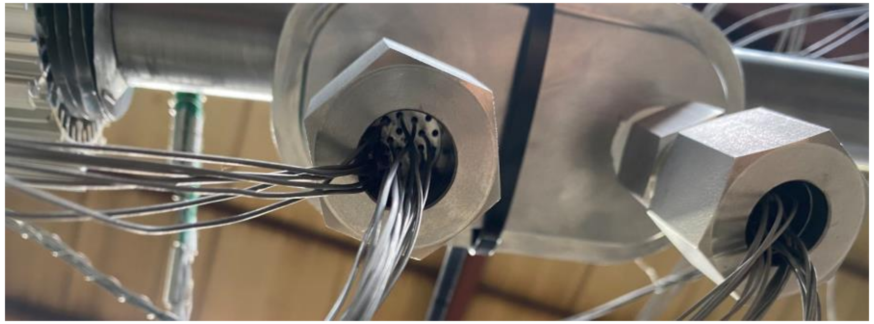


High-Density Combined Heat Storage

Installation of instrumentation of the CHS





Generator-Absorber heat eXchange Chiller

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Status

- **Prototype commissioned and tested at CEA**
- Deliverable D4.3 Optimal design of absorption chiller concepts targeting cold production down to -20°C (short term) and -40°C (long-term)
- Deliverable: D4.2 Optimal design of ejector chiller concepts targeting cold production down to 5 °C (short term) and -10 °C (long-term)
- 2 Papers :
- Choked liquid flow in nozzles: Crossover from heterogeneous to homogeneous cavitation and insensitivity to depressurization rate; Wilhelmsen Ø.; Aasen A.; Chemical Engineering Science 2022, 248, Part B.
- One-dimensional mathematical modeling of two-phase ejectors: Extension to mixtures and mapping of the local exergy destruction; Wilhelmsen Ø., Aasen A., Banasiak K., Herlyng H., Hafner A.; Applied Thermal Engineering 2022, 119228.
- Dissemination: SolarPACES 2021, ICR 2023, Pôle Cristal 2023

Generator-Absorber heat eXchange Chiller

Design of the GAX

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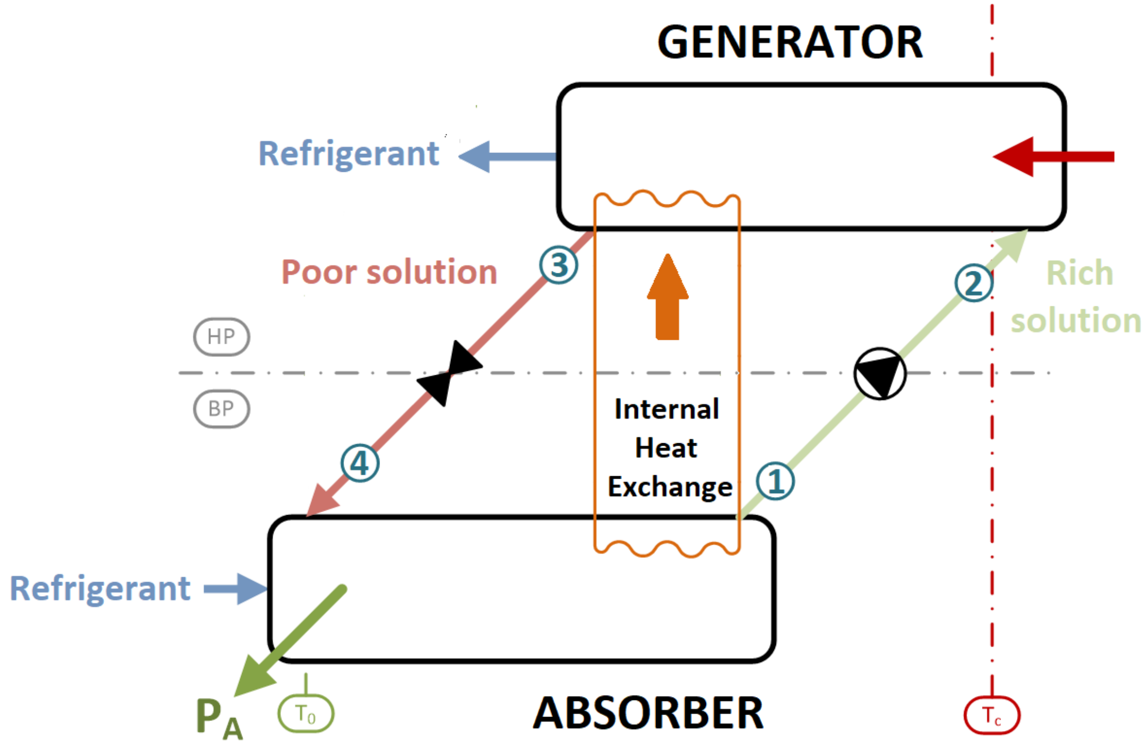
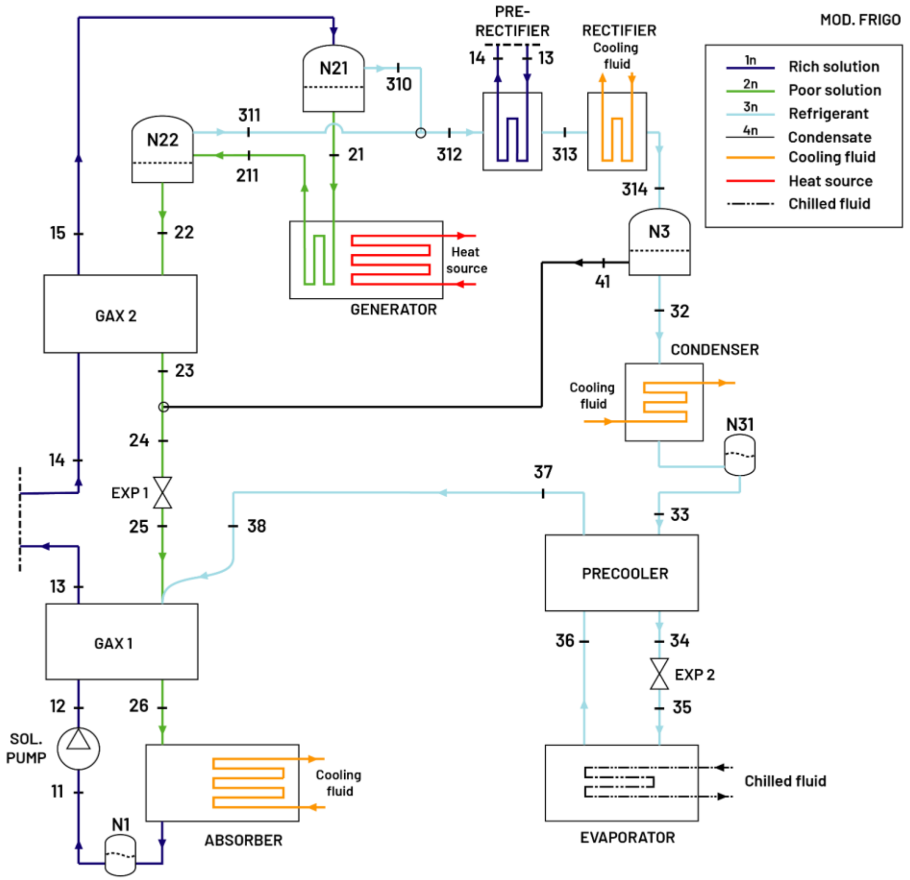
Architecture studies: multi-effect



Absorption Gax Cycle simulation with EES



Generator-Absorber heat eXchange Chiller

GAX Prototype

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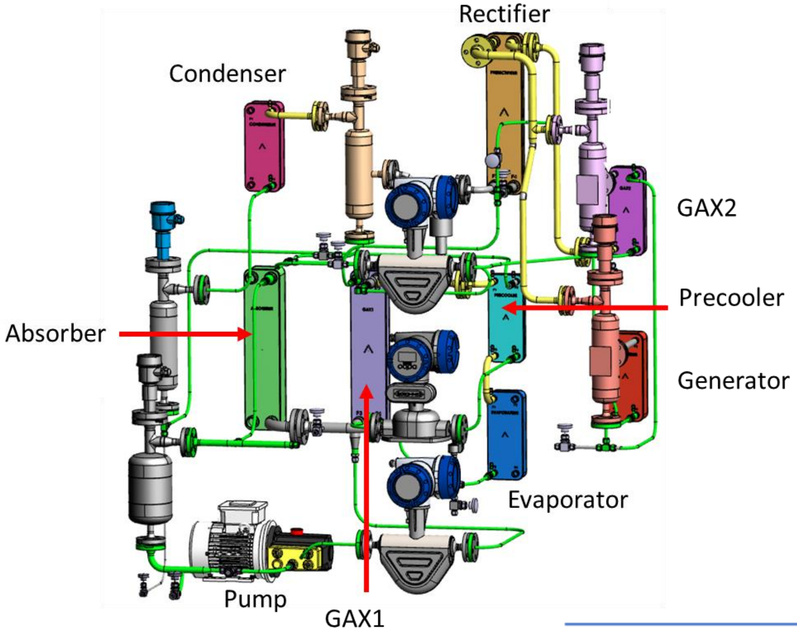
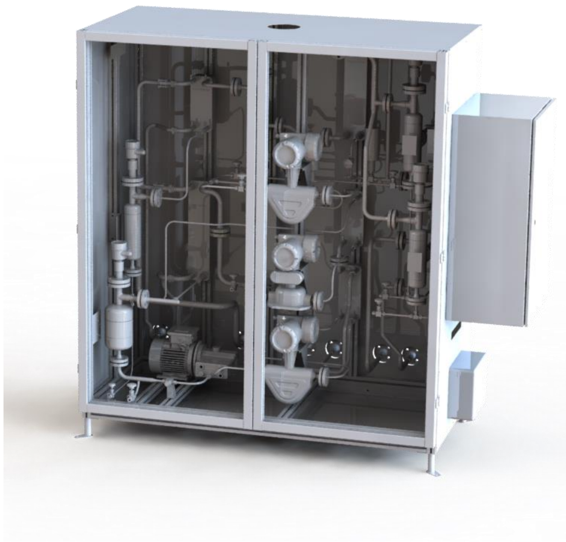
Use of common welded **plate heat exchangers:**

- widely **available** technology
- **reduced-cost**,
- **compact**
- **easy-to-manufacture** machine
- easier to **scale up**

GAX :

- Requires a **higher generator temperature**
- Temperature **overlap** between absorption and desorption → possible **recovery of internal energy**
- Higher performance allows **lower cold** temperature production





Parameters	Value	Measure Unit
Generator inlet temperature	130	°C
Absorber inlet temperature	20	°C
Evaporator outlet temperature	-20	°C
Maximum output	10	kW

Generator-Absorber heat eXchange Chiller

GAX prototype unit tests

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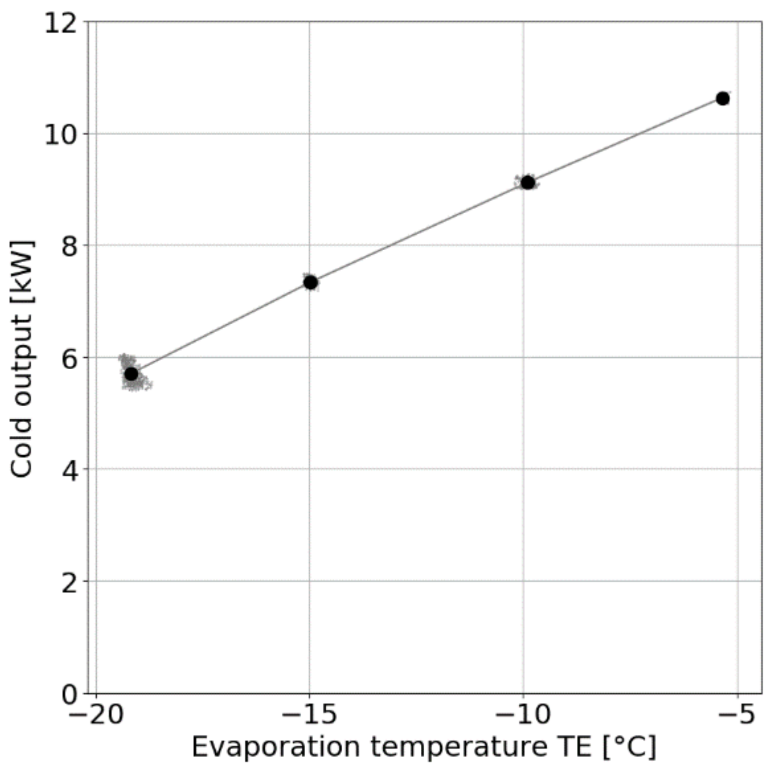
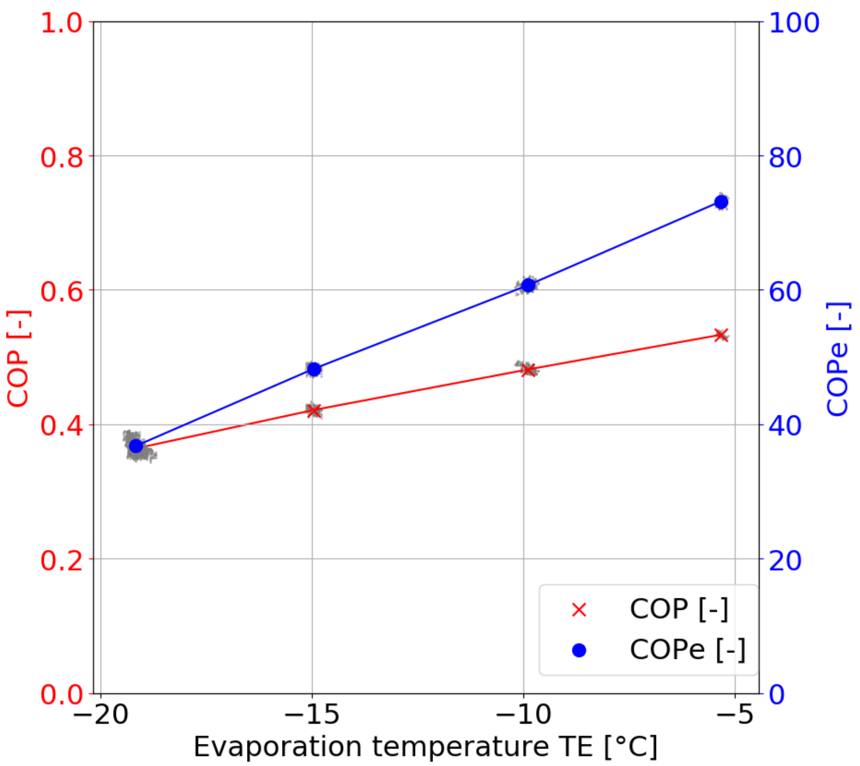
- Dynamic and steady state conditions
- High-precision sensors to measure flow rates, temperatures and pressures

Parameters	Sensors type	Quantity	Uncertainty (+/-)
Heat transfer fluid temperature	Pt100	8	0.1 K
Refrigerant/Solution temperatures	Thermocouples	25	0.3 K
Refrigerant/Solution pressure	0-10 bar and 0-40 bar	4	0.2 % full scale
Refrigerant/Solution flow	Mass flowmeter	3	0.20 %
External fluid flow	Mass flowmeter	4	0.30 %
Density	Mass flowmeter	3	2 kg/m^3
Liquid level	Capacitance level sensor	3	0.50 %

Generator-Absorber heat eXchange Chiller

Performance measurements





- At -5°C, the prototype provides nearly 11 kW of chilled water with a **thermal COP of 0.54**
- **At -20°C, 6 kW is produced with a COP around 0.36**
- Electric COP_e ranges from **~35 to ~70**

Generator-Absorber heat eXchange Chiller

Dynamic behaviour

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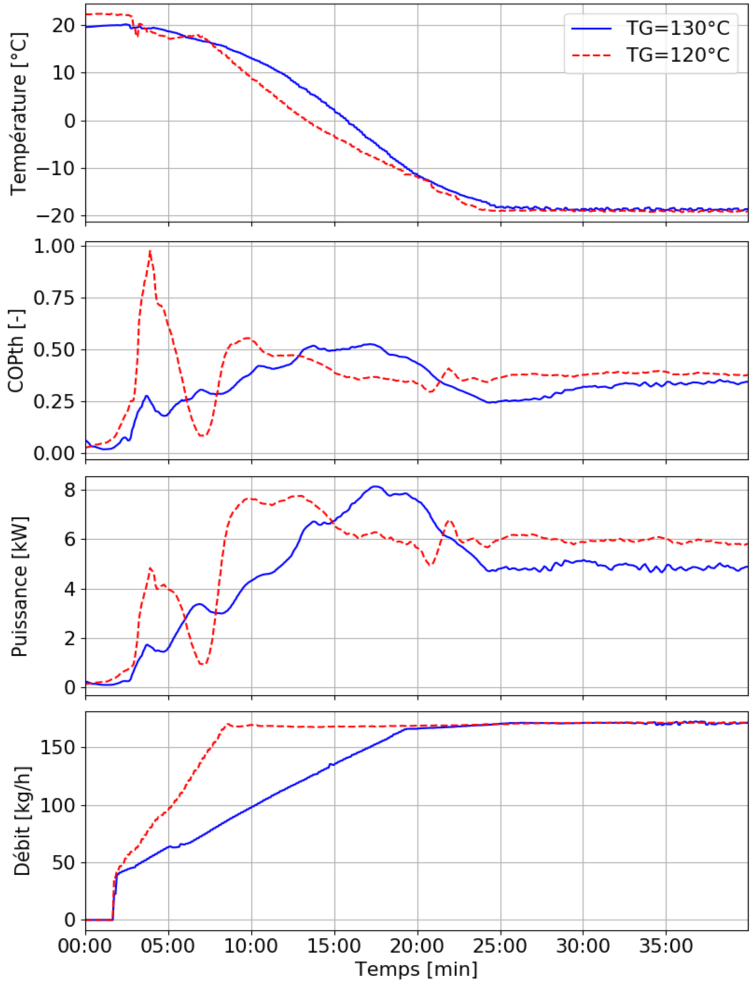
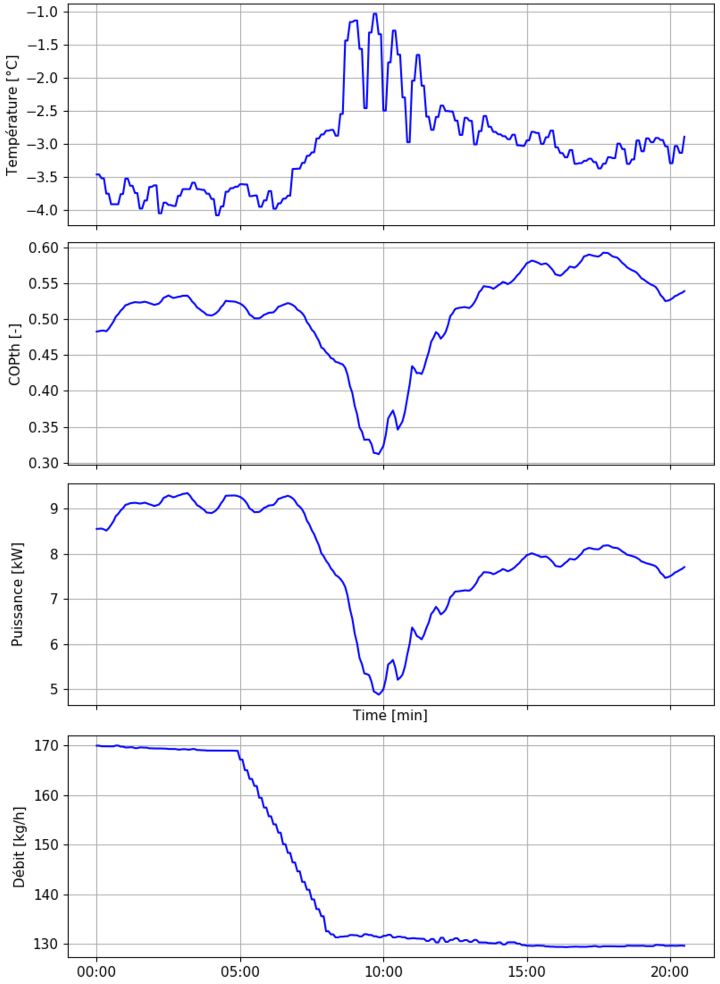


*← Evolution of various parameters during **start-up** for different generator temperatures (TG=120°C TG=130°C) and different pump start-up ramps (6 and 15 min).*

*Dynamic behaviour to a **drop of the pump flow rate** from 170 kg/h to 130 kg/h. →*

The inertia of the prototype depends on the stabilization of the hydraulic conditions and the thermal inertia of the exchangers. **Generally, a good stability is obtained around 10 minutes after the target mass flow rate is reached.**



Advanced Control Management

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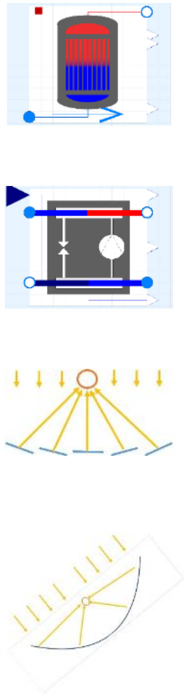
Status

- Modelling of digital twins in Modelica ongoing at CEA
- 1 Paper:
- Solar Field Output Temperature Optimization Using a MILP Algorithm and a 0D Model in the Case of a Hybrid Concentrated Solar Thermal Power Plant for SHIP Applications; Kamerling, S.; Vuillerme, V.; Rodat, S.; Energies 2021, 14, 3731.
- Dissemination: SWC 2021, EuroSun 2022

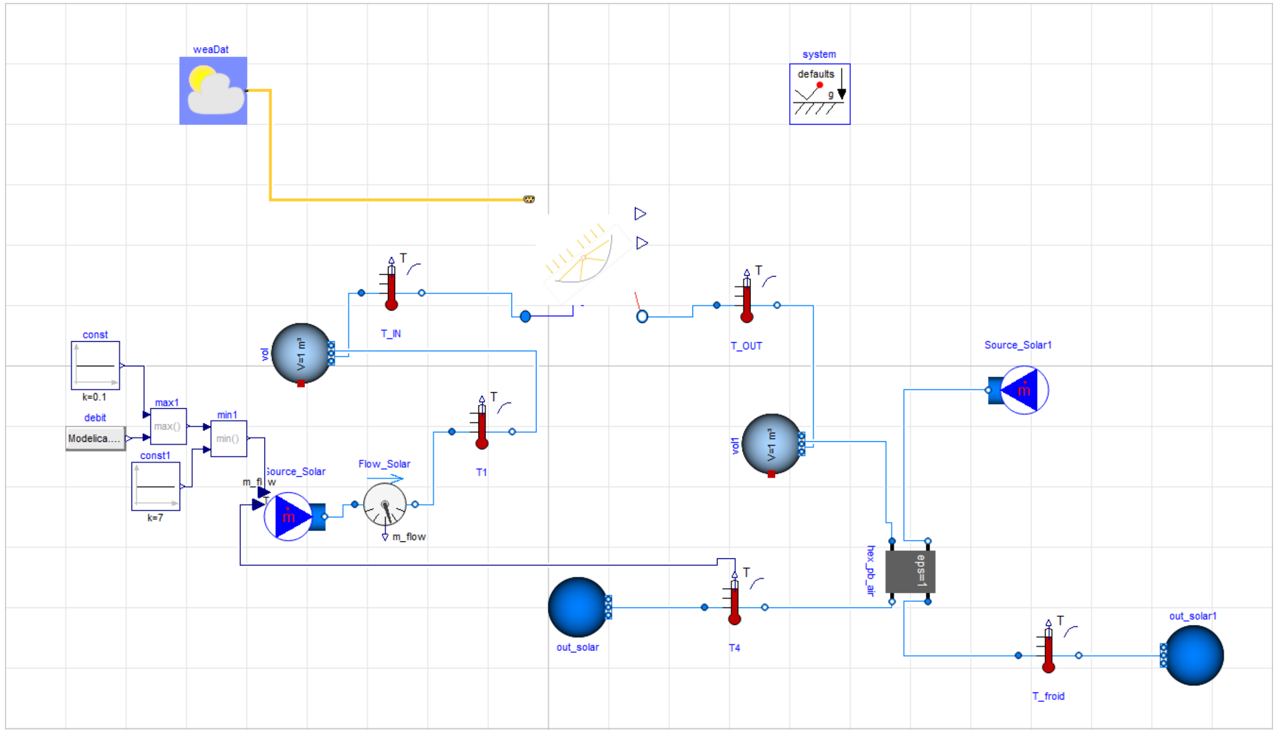
Advanced Control Management

Dynamic Modelling using Dymola

Development of a library of specific components



Development of SHIP200 and SHIP300 digital twins



What else?

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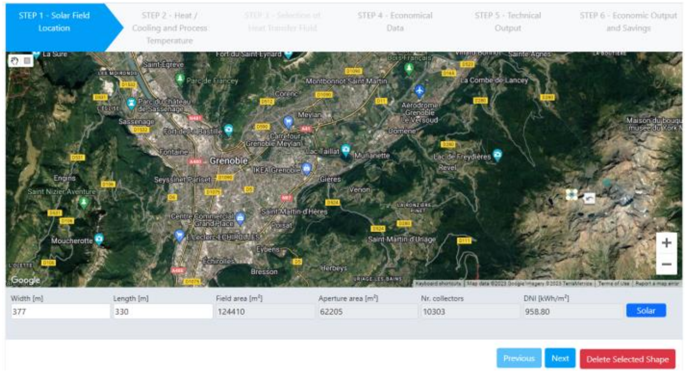
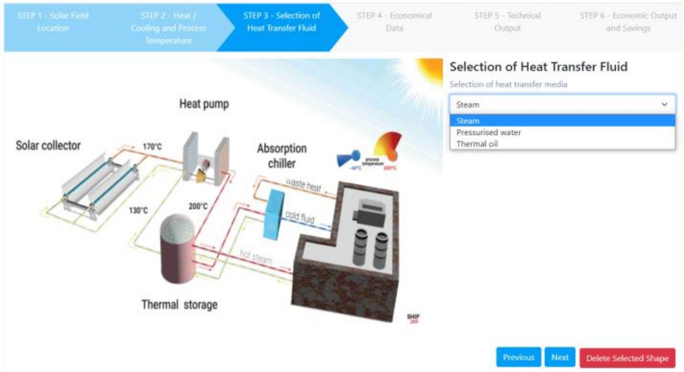
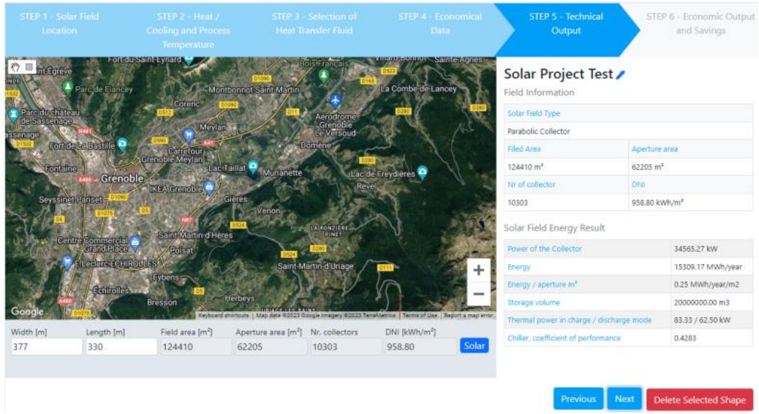
✓Online pre-design tool to simulate the performance of SHIP200 and SHIP300, including an economical evaluation

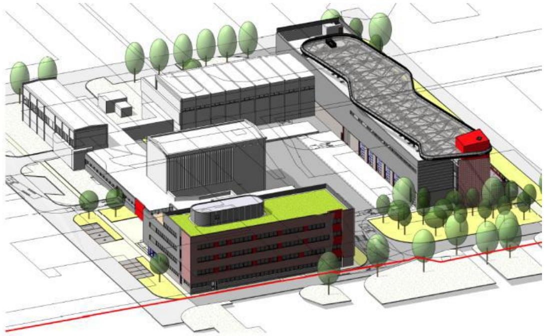






Coming soon

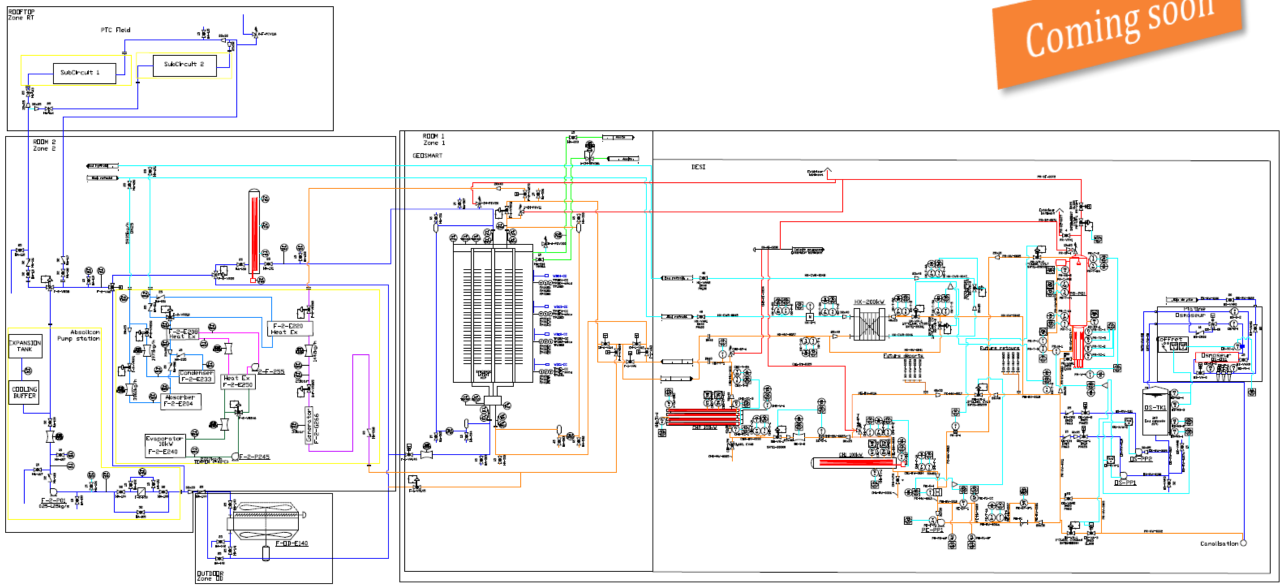
Final DEMO

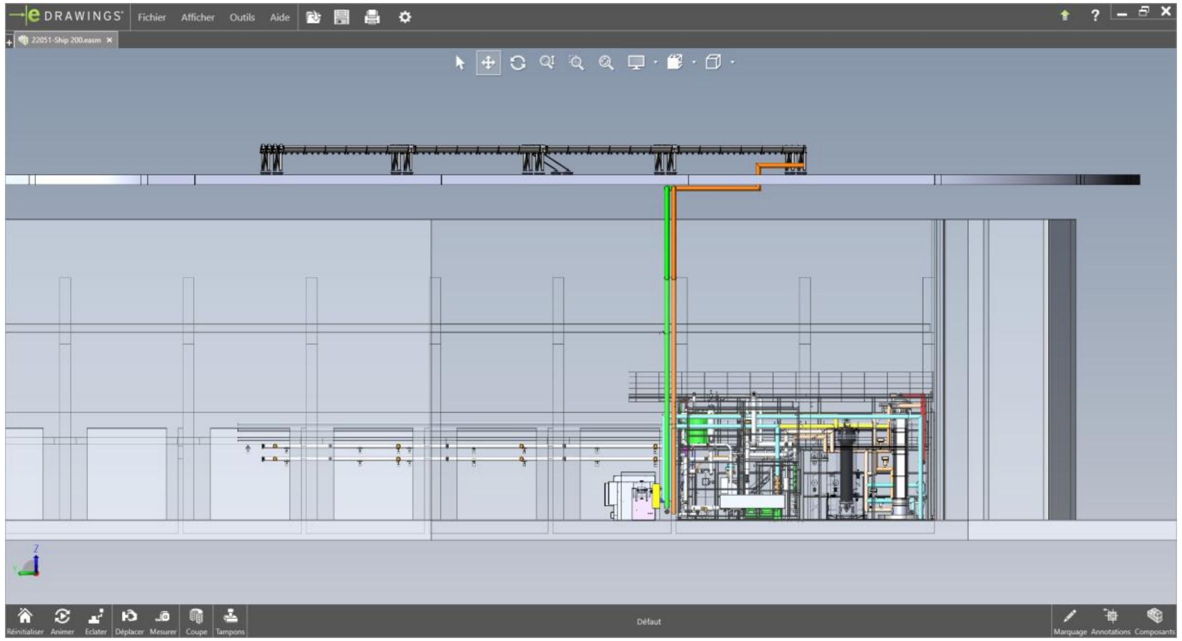


- FINAL OBJECTIVE 2024:
  - **Validation of SHIP200 in relevant conditions**

Demo site in Grenoble (FR) Annual DNI 1,400 kWh/m²

Coming soon





FRIEND SHIP

Forthcoming Research and Industry for European and National Development of SHIP

Thank you for your attention !

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