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Hydrogen PROduction by MEans of solar heat and power in high TEmperature Solid Oxide Electrolysers

Hydrogen production by means of solar heat and power in high temperature solid oxide electrolysers

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ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development
capital energy
FONDAZIONE BRUNO KESSLER
SOLID POWER
institute IMDEA energy
snam
EPFL
NextChem
Tecnimont for Energy Transition
Stamicarbon

The project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under Grant Agreement n° **101007194**. The JU receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe Research.

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The Project

PROMETEO is a European Horizon 2020 project

€ 2.5 million funding provided by the public-private platform FCH JU

Duration: 42 months

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Aims to design, construct and test an innovative prototype to produce renewable hydrogen from solar power

9 partners involved from 4 EU countries

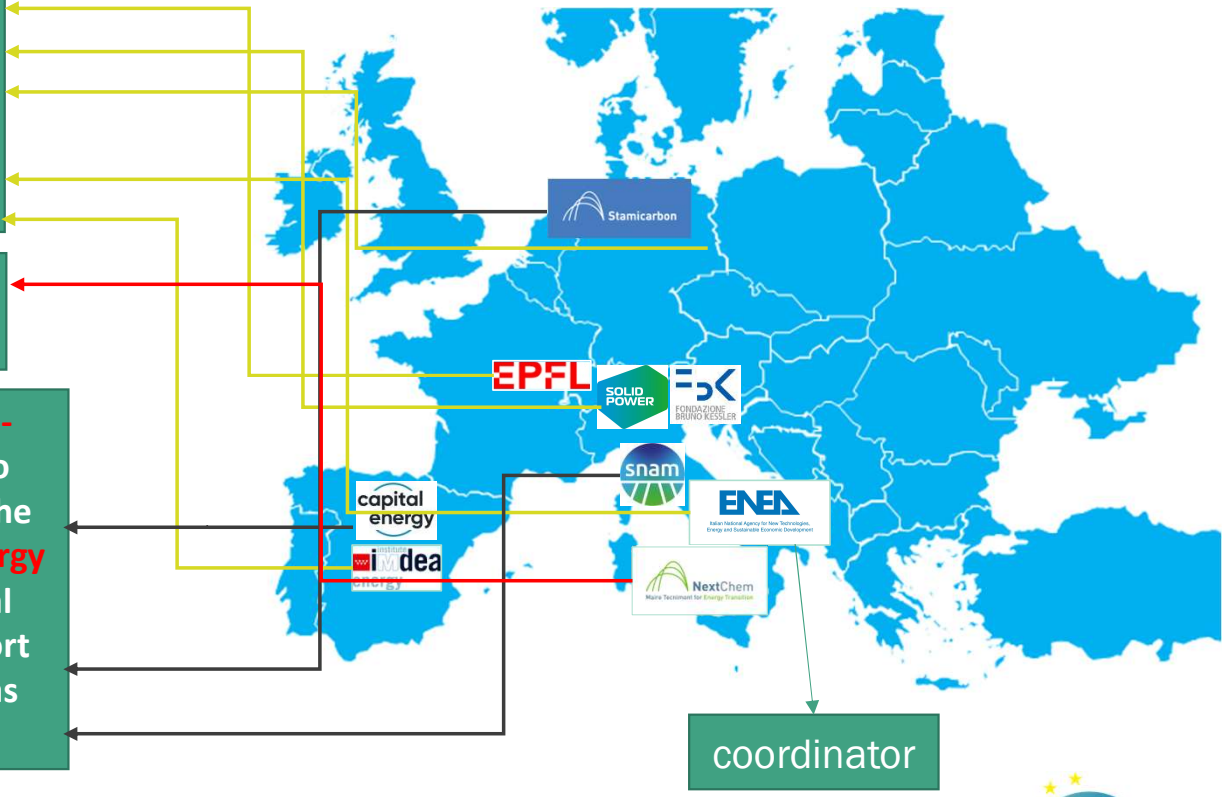
The Consortium

the project is run by an interdisciplinary consortium of European partners from the research and industrial sectors

The Swiss SME **SOLIDpower** SA will supply solid oxide electrolysers (SOE). Fondazione Bruno Kessler, **FBK**, and **ENEA**, in collaboration with the Spanish **IMDEA Energy** and the Swiss research institute **EPFL**, will model the prototype and its integration with the RES.

The Italian engineering firm **NextChem** will support process integration of the SOE and prototyping

A key role in the project is also played by potential **end-users** that will steer the R&D activities in PROMETEO to meet end-users' applications. **Snam** will contribute for the injection of green hydrogen into the gas grid. **Capital Energy** will provide input for the use of PROMETEO in chemical storage of renewable electricity. **Stamicarbon** will support the use of green hydrogen in chemical industries such as ammonia and fertilisers production.



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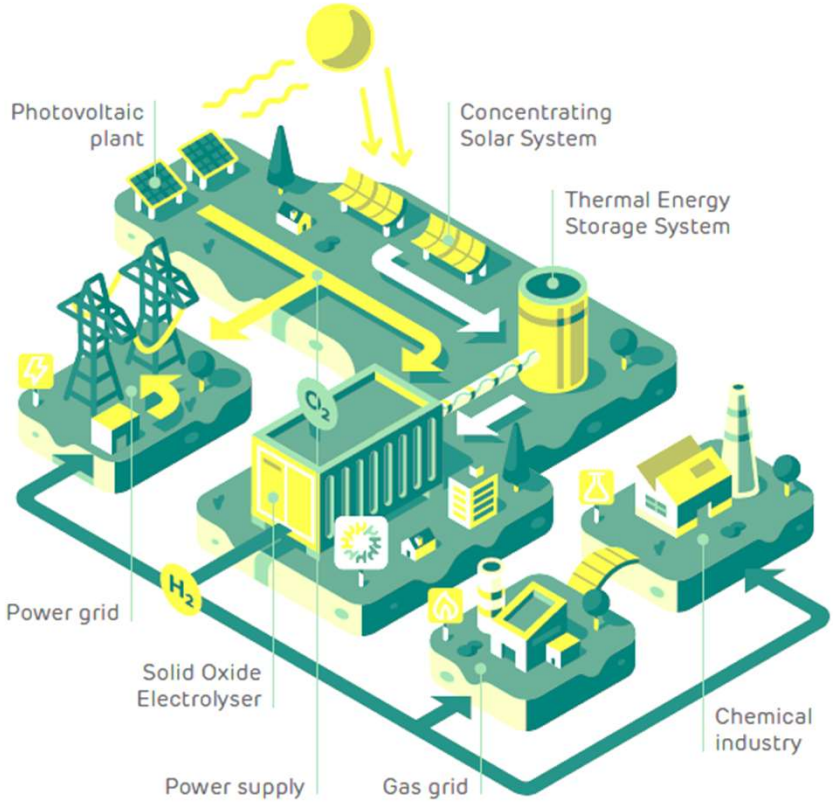
The Concept



PROMETEO's prototype will be based on high temperature Solid Oxide Electrolysis (SOE) coupled with an innovative Thermal Energy Storage (TES).

TES will optimize the use of intermittent solar heat in hydrogen production, ensuring steam supply to the SOE when low-cost electricity is made available considering three industrial applications as end-users.

The project will use the solid oxide technology to build a 25 kWe prototype electrolyser capable of producing 15 kg of hydrogen per day.

The system prototype will be modular, with the potential to be replicated on the MWe industrial scale.

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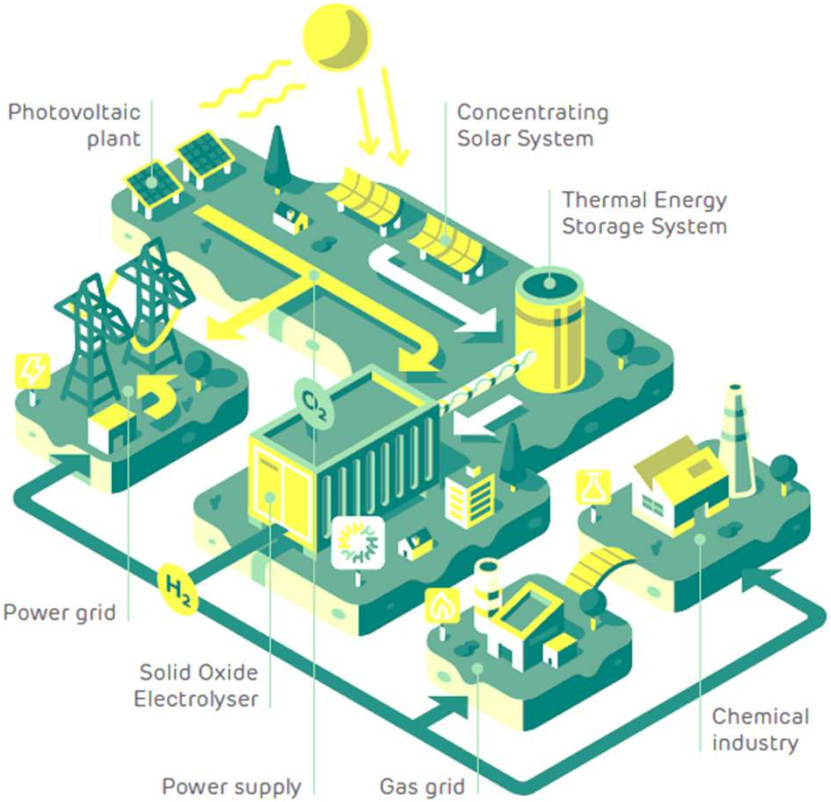
The implementation



WP1
PROJECT COORDINATION AND MANAGEMENT

WP2
ENGINEERING DESIGN PROCESS

WP5
SYSTEM INTEGRATION & PROTOTYPING

WP3
DESIGN AND CHARACTERIZATION OF BASIC COMPONENTS

WP4
SYSTEM MODELLING

WP6
EXPERIMENTAL VALIDATION

WP7
ASSESSMENT & EXPLOITATION OF RESULTS

WP8
DISSEMINATION OF RESULTS

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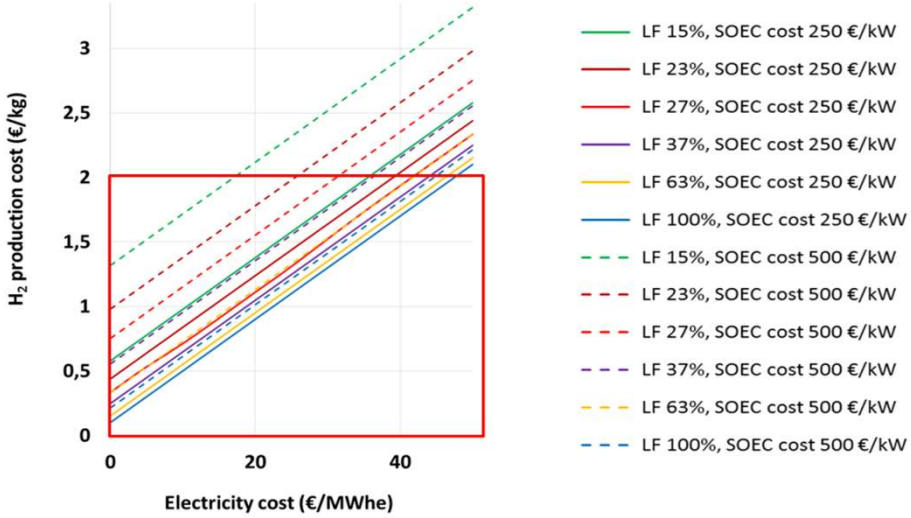
The Ambition: cost reduction

Key Performance Indicators (KPI)		Unit	Target	WP related
ID	Definition			
F-prod	Hours of SOE operation (with hydrogen production) vs. **total** test hours	%	≥ 98%	WP6
F-op	Hours in which the SOE has been kept "hot" ≥ 650°C (i.e. ready-to-start) vs. total hours			
F-tes	Hours in which the SOE has been driven with heat directly discharged from the TES vs. total hours	%	≥ 50%	WP6
T-op	Hours of experimental validation runs of the prototype	hours	≥ 1,000 hr	WP6
R-av	Average H_2 production rate: tot. H_2 produced vs. tot. hours of experimental validation of the prototype	kgH_2/day	≥ 5 kgH_2/day	WP6
R-max	Maximum measured instantaneous hydrogen production rate at full-capacity	kgH_2/day	≥ 15 kgH_2/day	WP6
Loss	Measured efficiency production loss after 1,000 hours operation	%	< 1.2%	WP6
Eff-%	Power-to-hydrogen energy conversion efficiency of the heat- integrated SOE system (LHV basis)	%	≥ 85%	WP6
Eff-w	Power-to-hydrogen conversion efficiency of the heat-integrated SOE system	kWhe/kgH_2	< 39 kWhe/kg	WP6 WP7
Sol-%	Solar-to-Hydrogen energy conversion efficiency: from global solar radiation to H_2 energy (LHV basis)	%	≥ 10%	WP6 WP7
Eff-tes	Heat-to-TES-to-Heat conversion efficiency of the TES system on charge/discharge cycles	%	≥ 85%	WP3 WP6
LCOH	Levelized Cost of Hydrogen for the medium-long term (>2030)	€/kgH_2	≤ 2 €/kgH_2	WP7
C-tes	Cost of the Thermal Energy Storage system per kWh thermal capacity	€/kWht	< 20 €/kWh	WP3 WP7
CAPEX	Capital investment of a fully-integrated multi-MW SOE ready for connection to heat & power sources	€/kWe	< 300 €/kWe	WP7
O&M	O&M costs of a fully-integrated 25 MWe SOE (not including electricity and water costs)	€/year	<750 k€/year	WP7



Preliminary evaluation of the H_2 production cost vs. electricity cost, Load Factor (LF) and CAPEX of the electrolyzer (50 €/MWh Concentrating Solar heat cost assumed, incl. TES).

In PROMETEO, the higher power-to-hydrogen efficiency of the SOE technology will increase the hydrogen output per kWe (compared with alkaline and PEM electrolysis), while the load factor can be maintained high thanks to the integration with the TES.

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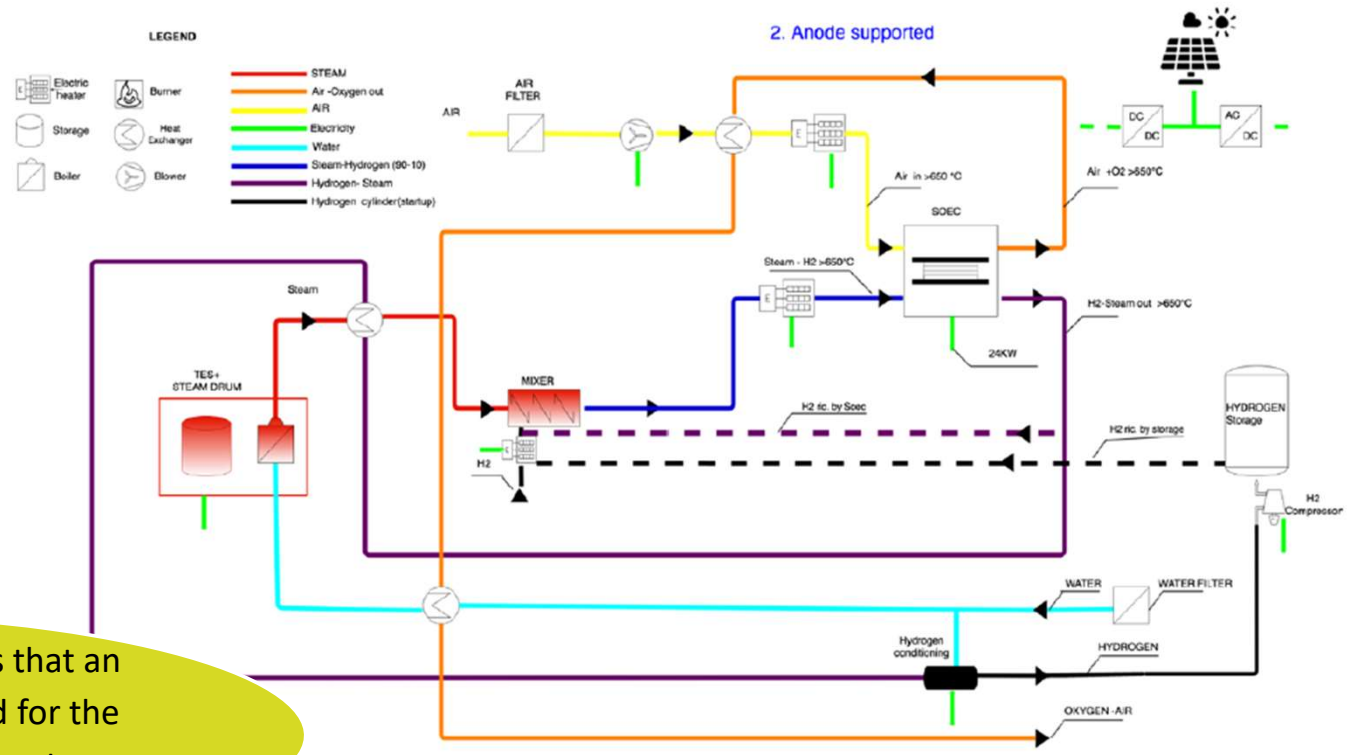
Main technological challenges Vs PROMETEO solutions

Dedicated solar steam generators from heat storage and handling are necessary to buffer the intermittent nature of solar heat and avoid thermal cycling of the SOE in variable operation	Thanks to the integration with the TES-SG system, steam is smoothly supplied "on-demand" with required quality (150°C) regardless the direct availability of solar radiation
Performance and durability of SOE in a relevant testing environment, given the fluctuations of renewable energy sources	Durability tests will be performed at the laboratory level for at least 1,000 hours under representative conditions, including thermal cycling. Operation range and performance assessment carried out in specific laboratory tests and with a prototype
Expected implications on system efficiency and economics considering the production of hydrogen.	In PROMETEO, besides an experimental proof-of concept, a specific Work Package (WP7) will be implemented by industrial end-users to evaluate system performances from a techno-economic perspective and considering up-scaling issues.

Results: Preliminary PFD identified

process flow diagrams (PFD) have been mapped and selected for a preliminary study on the possible PROMETEO layout, based on energy and mass balance in a steady state. The complexity and external power required to ensure the self-thermal balance condition of the system, as well as the TES heat effort required, have been identified as preliminary KPIs regarding the goodness of the proposed layout.



The pinch point analysis estimates that an external amount of power needed for the thermal self-sustainability of the system equals 2.12 kW

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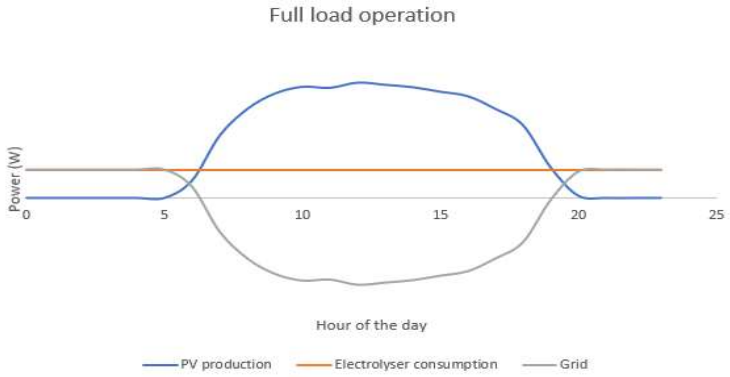
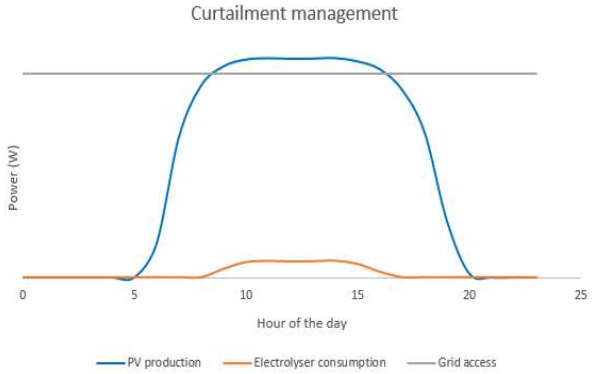
Results: design for end-users' cases

Upstream requirements

Operation modes		Full Activacion Time	Response time	Availability time	Reversible mode
on-grid	Full load operation	-	-	Indefinite	No
	Curtailment management	< 2 min	< 30 seconds	Indefinite	No
	Grid services	< 5 min	< 30 seconds	2 hours	Yes
off-grid	Balancing of microgrids, chemical energy storage	< 30 seconds	< 2 seconds	15 minutes	Yes





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Results: design for end-users' cases

Downstream requirements

Production of fertilizers / green ammonia	
Operation profile	Continuous (24/7)
Temperature	38 °C
Pressure	10 barg
Oxidizing agents, concentration	≤10 ppm
Water, concentration	2E-5 (% mol)
H_2 flowrate	+5/-10 %

Injection in natural gas grid	
Operation profile	Continuous (24/7)
Stream purity*	< 2% H_2 in NG mixture
Pressure	5 - 75 barg
Higher calorific value	34,95 – 45,28 MJ/Sm^3
Relative density	0,555 – 0,7

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* Higher % of Hydrogen are also possible if the gas quality specifications are respected

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Results: TES architecture identified

- Input represented preliminary PFD received from Task 2.4: 5.5-6.0 kW (thermal) SG to supply steam with the following specs: 9.37 kg/h, 130.15°C, ~ 1.05 bar
- Technical options discussed with IMDEA in June
- Option 1 with 2-tanks evaluated too complex for the prototype scale (<10 kW thermal) and also probably too complex also for larger-scale SOE on MWe scale (e.g. 430 kW thermal for 900 kg/day H2)
- Option 2 with PCM: experimental tests in progress in ENEA to validate the system (Task 3.2)
- Option 3 with thermocline: validated by ENEA, optimization in progress (Task 3.2)

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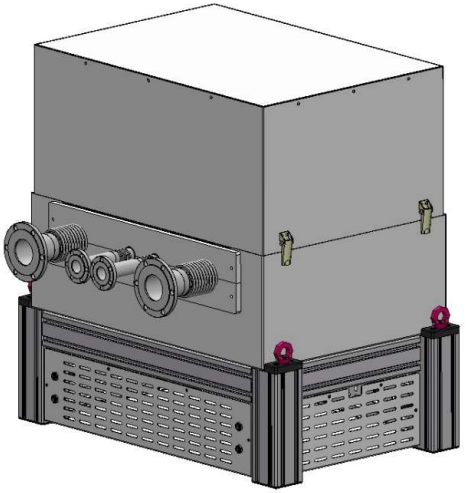
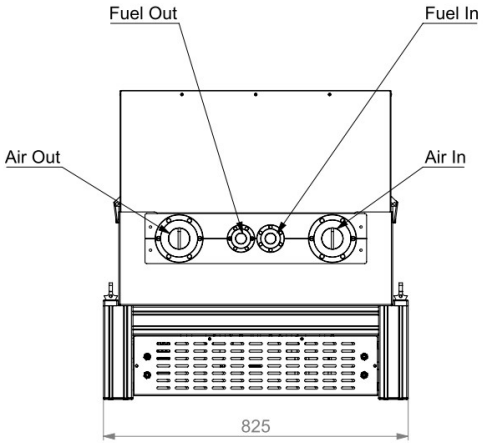
Results: SOE Stack design

StackBox development

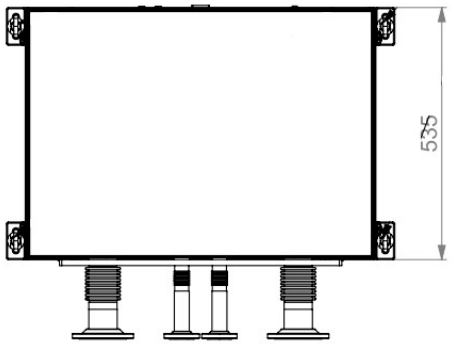
- A first version of the StackBox for the 25kWe stack has been designed and built for internal evaluation.
- Other iterations might be required.





Features

- High quality thermal insulation
- Flanged connections for gases
- High current connections
- Voltage probes
- Thermocouples
- Connections for pressure measurement (inlet/outlet)



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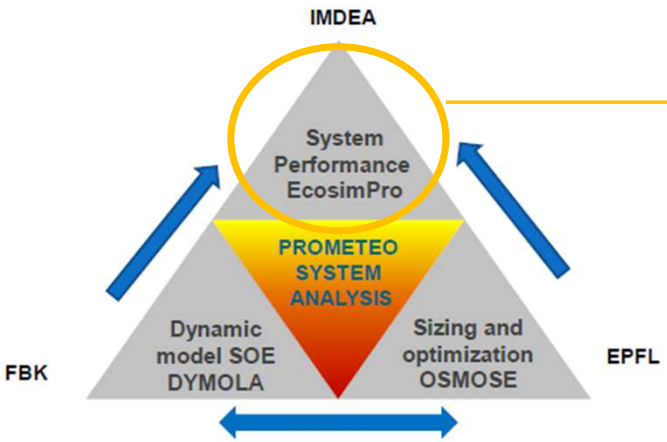
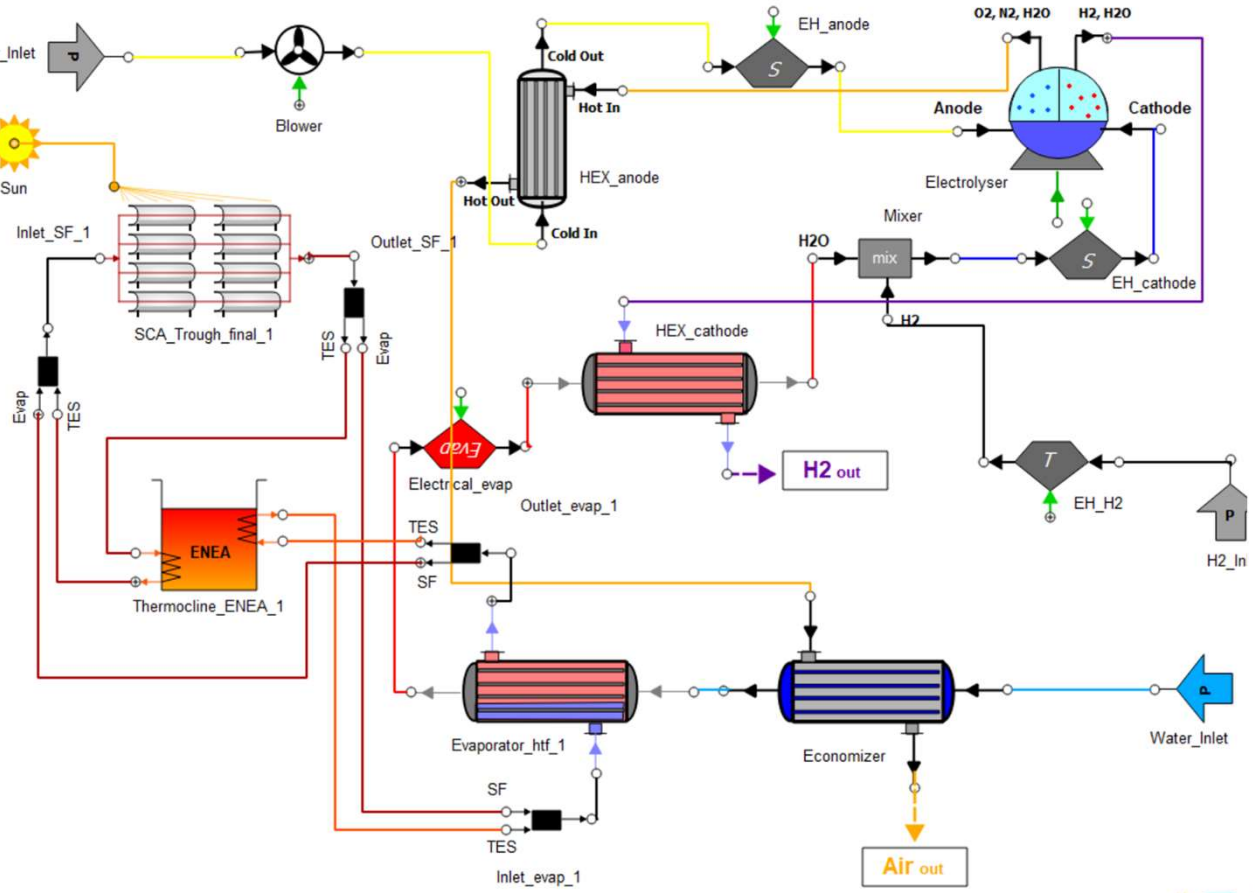
Results: modelling and component sizing



Simulate the different options of PFD with mass and energy balance vs. the main KPIs of the project.



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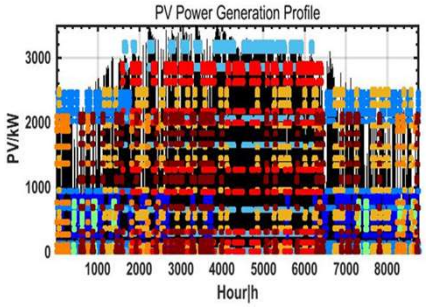
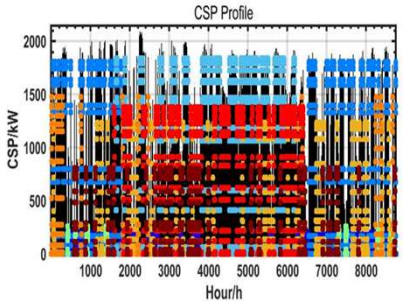
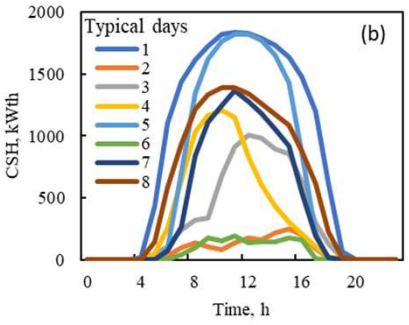
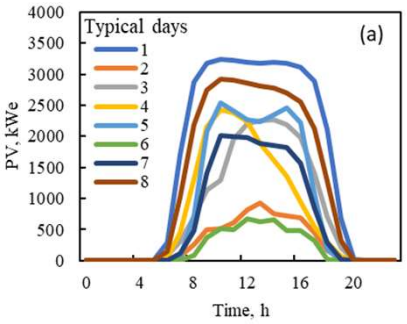
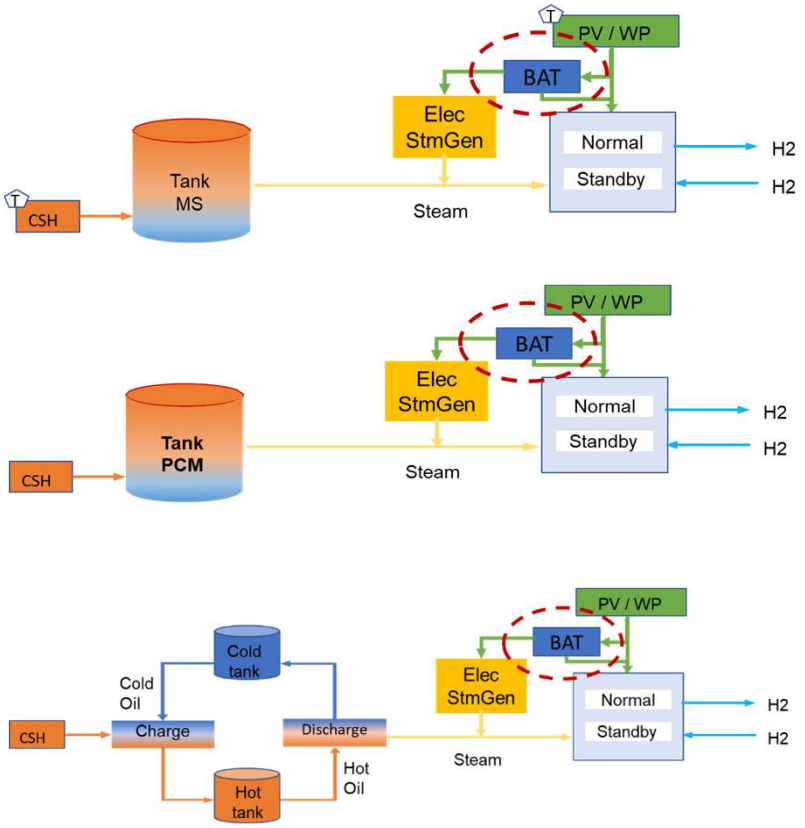








Optimization to identify optimal components sizes and the operating strategy were carried out considering multi-time heat and mass integration



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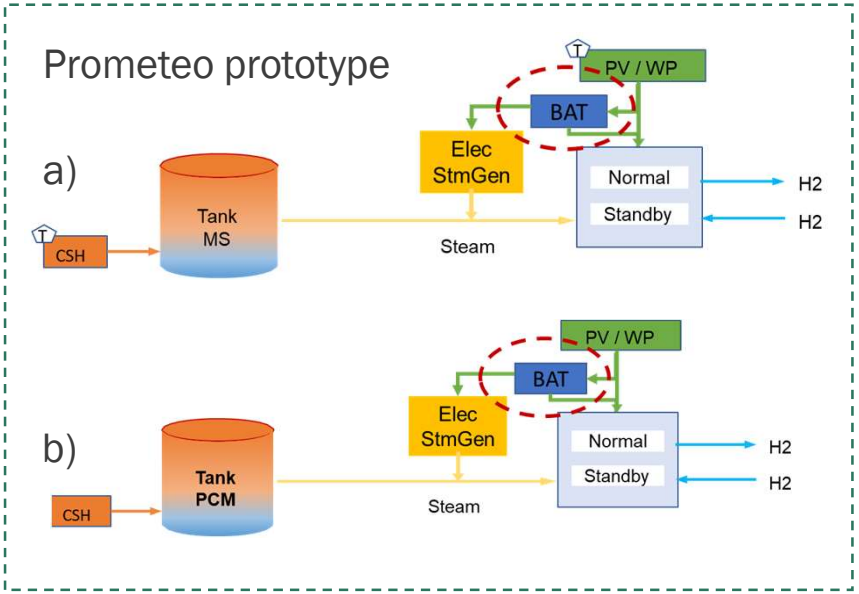
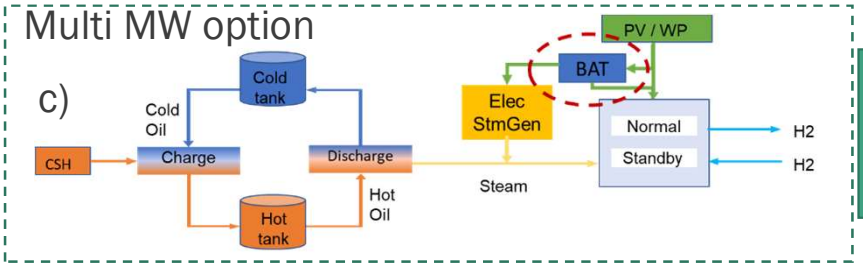
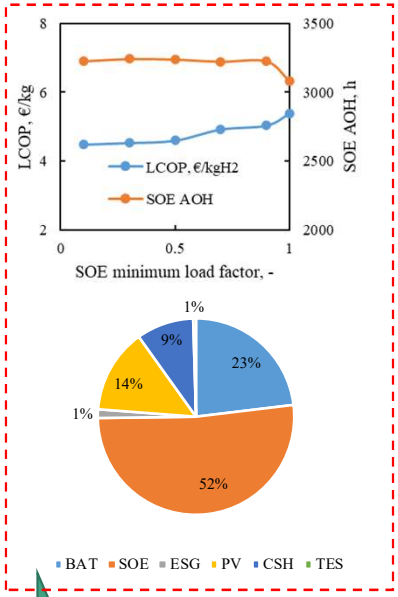
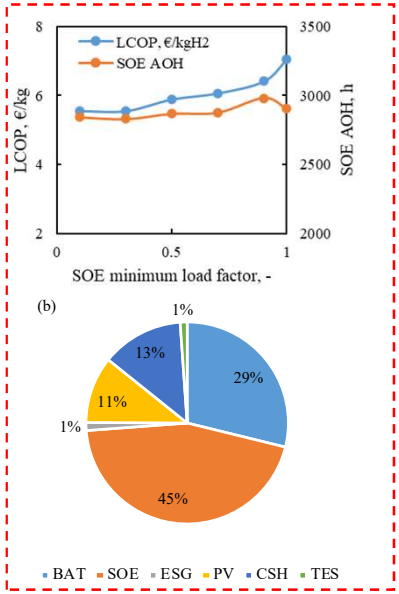
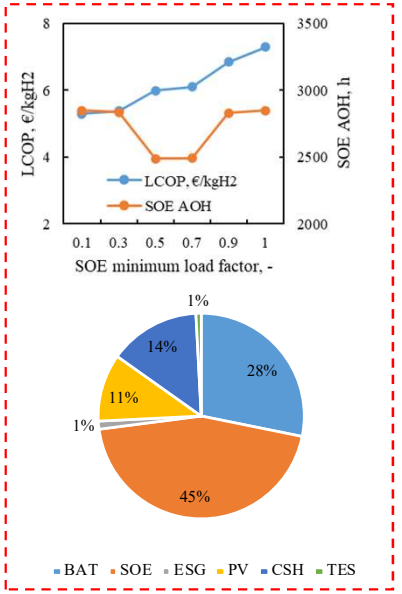
Results: from prototype to multiMW











A first iteration of preliminary results (task 4.1) showed how for future upscaling of Prometeo concept the implementation of TES with two tanks will allow to decrease the LCOP. Moreover the cost breakdown of the system clearly highlights that reduction of SOE CAPEX is crucial to reach a price of 2€/kg H2 produced

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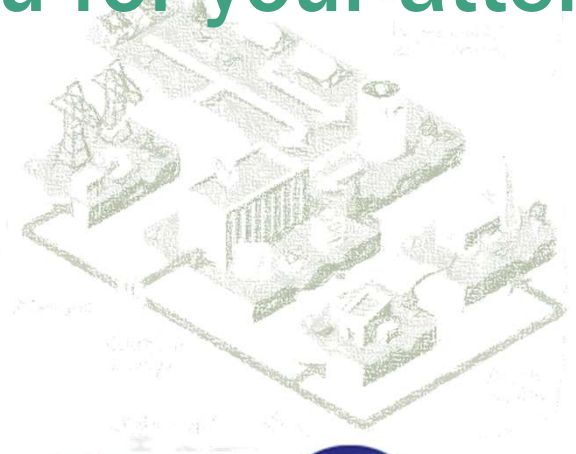
Thank you for your attention



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