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Innovative Technology Solutions for Sustainability

ABENGOA HIDROGENO

Next generation proton ceramic electrolyzer

Zaragoza, June 2016

AH-16-019

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- ELECTRA is a project of the FCH JU (EU FP7) with project title “High temperature electrolyser with novel proton ceramic tubular modules of superior efficiency, robustness, and lifetime economy”
  - ✓ In this project, Electra partners develop and construct the multi-tubular Proton Ceramic Electrolyzer (PCEC) of 1 kW to produce 250 Nl/h hydrogen at 20 bar and 700ºC. The multi-tubular module has advantages of high pressure operation and possibilities to monitor, close, or replace individual tubes.
  - ✓ Analyze the possibility of integration of this technology with renewable energy sources through process simulations and techno-economic analysis.
- Electra partners: CSIC, Protia, SINTEF, Abengoa Hidrogeno, Marion Technologies, CRI

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High temperature electrolyzer (HTEL) consumes less electrical energy in comparison to low temperature electrolyzer (Alkaline and PEM) because HTEL can utilize heat as well as electricity for electrolysis as it is not possible in case of low temperature.

HTEL : SOEC, PCEC

	Alkaline	PEM EL	HTEL
Capacity range (Nm^3/h)	1-1000+	1-30+	3
System electrical consumption (kWh/Nm^3)	4.8-5.5	6-6.5	3.3-3.7
System price (€/Nm^3/h)	3000-8500	15000	4000

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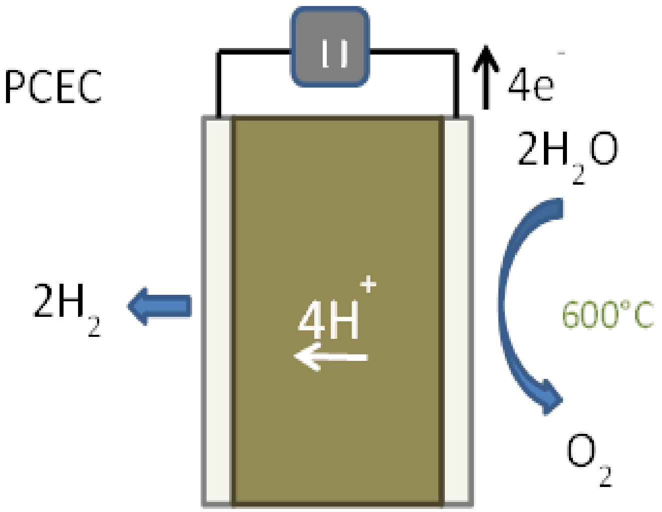
High temperature electrolyzers:

- SOEC:
  - ✓ Uses oxide ion conducting electrolytes
  - ✓ Operates in the range of 700-1000ºC
  - ✓ Water is fed on cathode side
  - ✓ hydrogen produced on cathode side contain water
- PCEC:
  - ✓ Uses high temperature proton conducting electrolyte
  - ✓ Operates in the range of 500 – 700ºC
  - ✓ Water is fed on anode side
  - ✓ Produces pressurized dry hydrogen directly. It is generated at the cathode (no need of separation from the steam)

The advantages in balance of plant of PCEC over SOEC, alkaline or PEM are:

- ✓ It eliminates the need of dryer in BoP due to dry hydrogen at the outlet.
- ✓ The BoP for PCEC does not need any catalytic recombiner because there is no O_2 in the line of H_2. This makes BoP simpler and will reduce the overall cost of the BoP.



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AH Tasks

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WP			Role of AH	Duration
WP4	WT4.1	Develop and analyze the overall system design in integration of electrolysis with solar, wind and geothermal energy.	Integration with renewable energy exploitation, process operability study	August 2014 - February 2015
	WT4.2	Multi-tube module design	Efficiency of the electrolyzer system with heat sources from other renewable energies (wind, photovoltaic, thermosolar); BoP	March 2015 - August 2015
	WT4.3	Techno economic evaluation of integrated processes	Techno-economical analysis of hydrogen production from PCEC integrated with renewable process (going on)	October 2014 - February 2017
WP5	WT5.1	Definition of testing protocols and durability tests	Definition of protocols	February 2015 - August 2015
	WT5.2	Multi-tube module construction and commissioning	Verification of test bench specifications	September 2015 - August 2016
	WT5.3	Testing and optimization of multi-tube module	Support activities for testing and optimization studies.	March 2016 -February 2017

- AH tasks of WP4.2 are:
  - ✓ Evaluations of Electrolyser Efficiency and Balance of Plant:
    - Integrated in various scenarios involving supply of electricity, heat, and steam and uses of hydrogen.
  - ✓ Evaluation of integrated PCEC technology with various sources of energy

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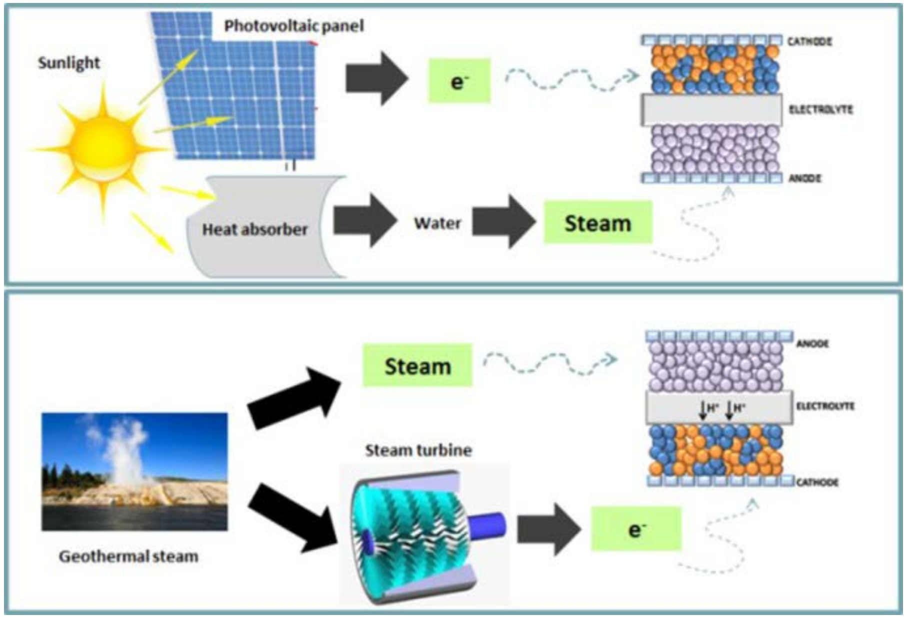
- PCEC electrolyzer can utilize electricity as well as heat for electrolysis.
- Thermosolar is one of the good option because it produces electricity as well heat. This integration will improve the electrical efficiency of electrolyzer.
- However technoeconomic analysis is necessary to know if this option is economically viable or not.



Possible thermosolar options to integrate with proton ceramic electrolyzers are the following:

- ✓ Steam to the electrolyzer directly from the solar receiver (approx 1400ºC), without pre use in gas turbine. Steam obtained from the receiver will have high temperature but it is not desiderable to have this high temperature steam for PCEC electrolysis (700ºC). This option has been discarded due to the high temperature heat available.
- ✓ If the CSP plant is exclusively dedicated to hydrogen production, the extraction could be directly coupled with the electrolyser steam generator.
- ✓ Another option, low pressure steam extracted from the turbine can be used as heat source in the electrolyser steam generator.
- ✓ Integrate intermediate thermal storage (molten salts) system between the extraction and the electrolyser. The performance of molten salt plant is quite stable during the day and can provide heat at 565ºC to the electrolyzer during day and night. This option is to be analysed further in this presentation.

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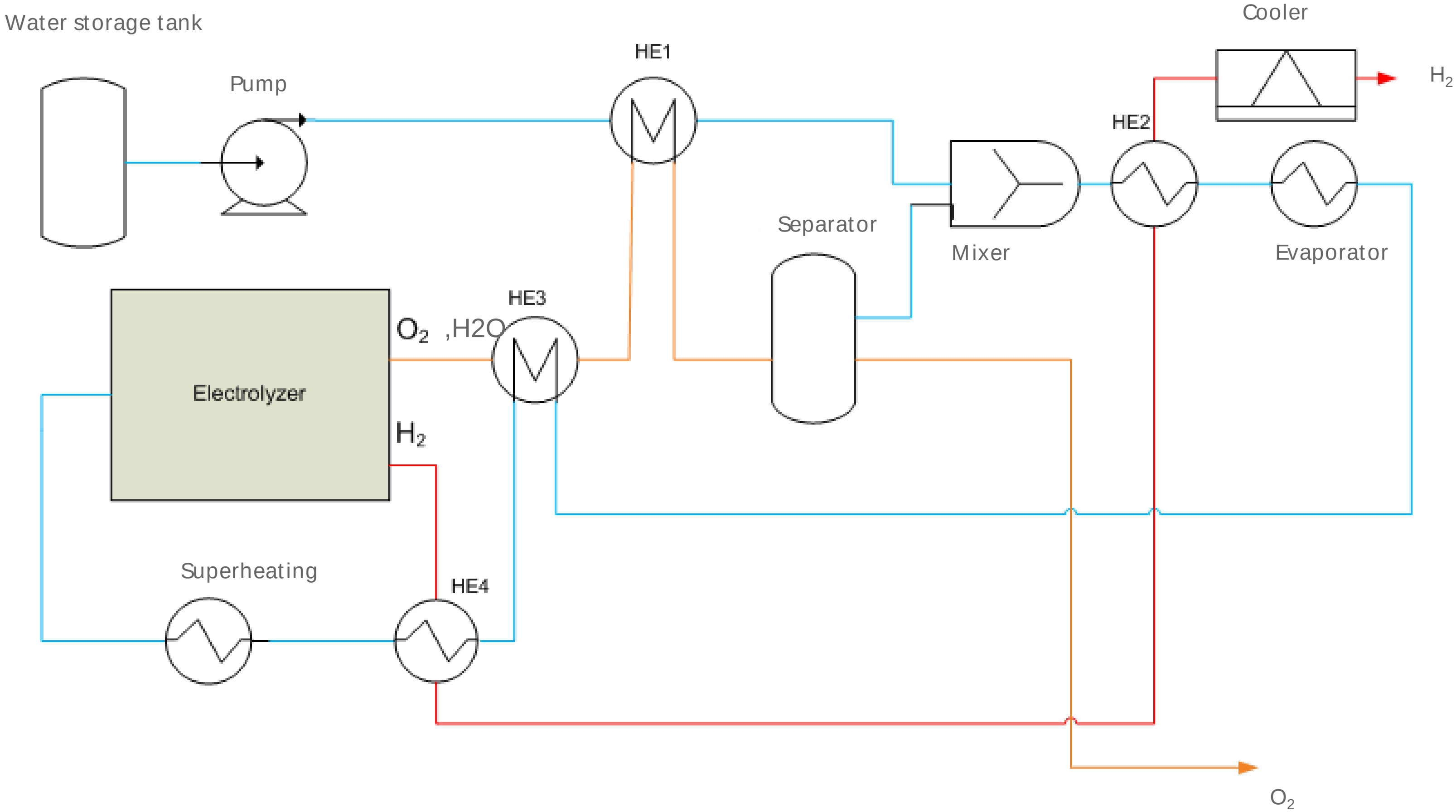
Evaluation of Thermosolar options for integration: Process flow diagram of electrolyzer plant



- Three different cases to integrate have been analyzed through simulations in Aspen plus:

  - ✓ Case 1: Plant with electrolyzer that just needs power from renewable sources or from the power grid.

  - ✓ Case 2: Use of a thermosolar plant with thermal storage to supply heat and power to the electrolyzer if it operates in an exotermic mode (700ºC).

  - ✓ Case 3: Use of a thermosolar plant with thermal storage to supply heat and power to the electrolyzer if it operates in an endotermic mode (450ºC).

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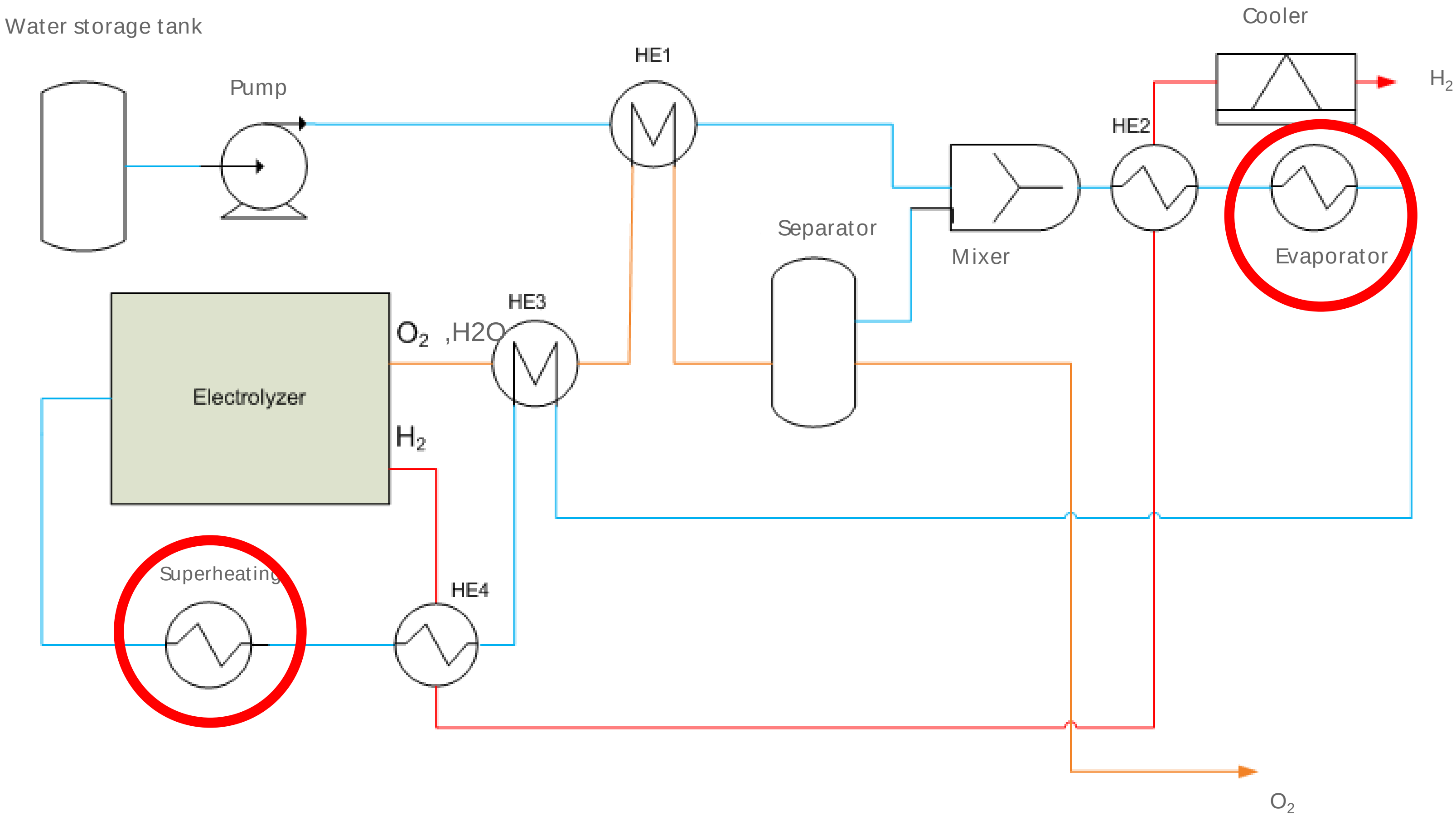
Evaluation of Thermosolar options for integration: Case 1



Outlet gases have been used to heat the water and steam while Heater and Evaporator do require energy from outside.

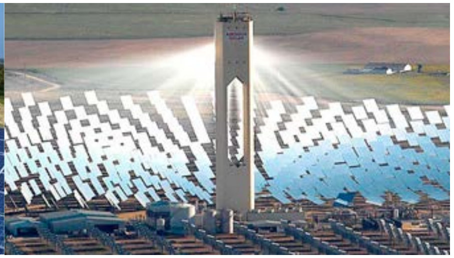
Evaluation of Thermosolar options for integration: Case 1

Power needed can be supplied directly form the power grid or using renewable sources (solar, wind, thermosolar) for evaporation and superheating.

Specifications:

- Operating temperature: 700 ºC
- Electrolyzer power consumption: 1.35 MW
- Energy needed for the vaporization: 0.288 MW
- Superheating: 0.039889 MW
- Hydrogen produced with a 60% of steam conversion: 0.01098 kg/s @20 bar
- Efficiency of the plant: 3.84 kWhe/Nm^3
- Efficiency of the electrolyzer: 3.07 kWhe/Nm^3





In Case 1, power is necessary to produce and heat steam, and operation of the electrolyzer.

- ✓ Power Grids: power available during the whole day.
- ✓ Photovoltaic plants: power available during sunlight periods.
- ✓ Wind power: power available during windy periods.

Thermosolar plants can provide power and heat, so it will be studied in the following cases.

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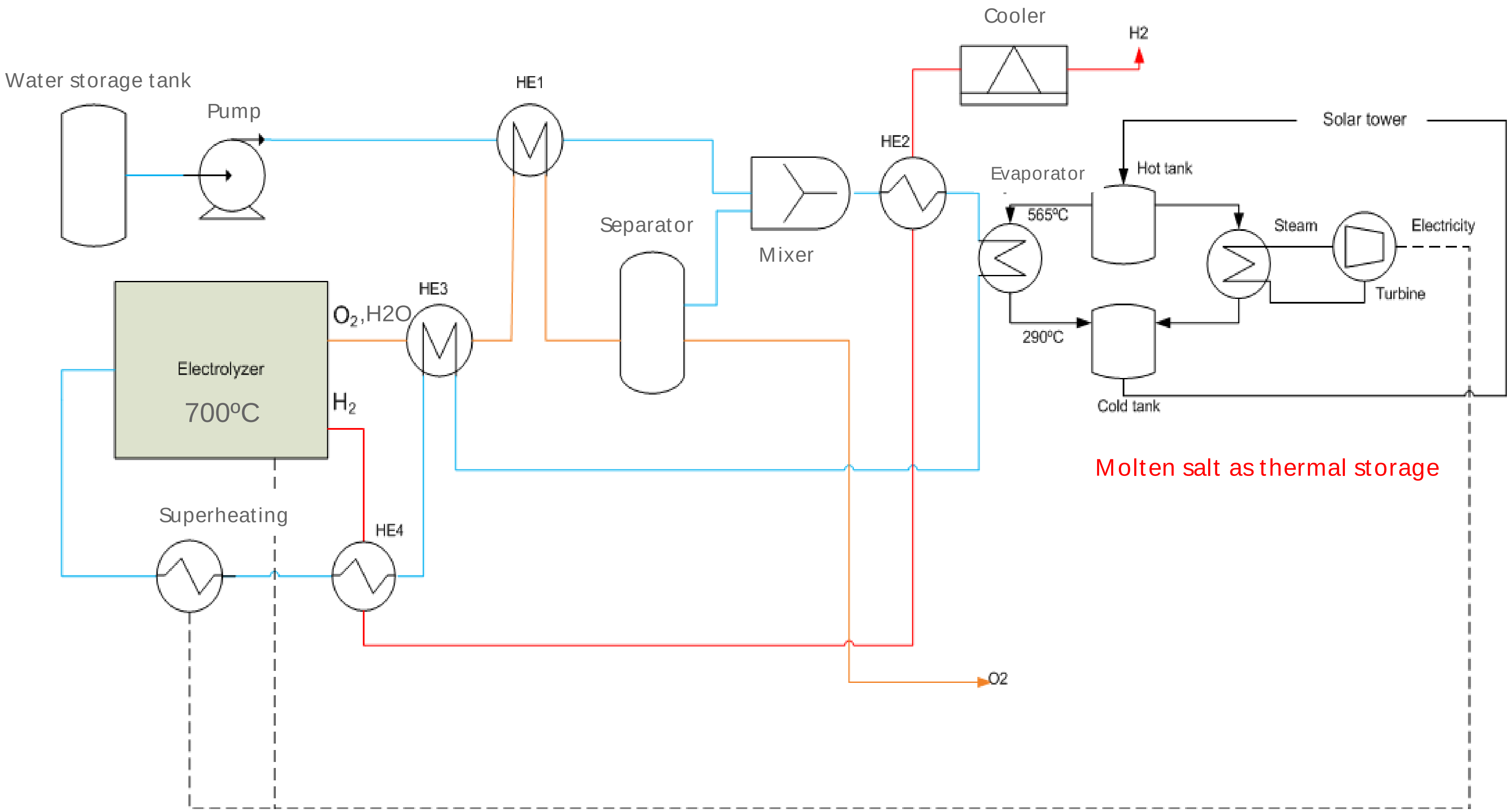
Evaluation of Thermosolar options for integration: Case 2

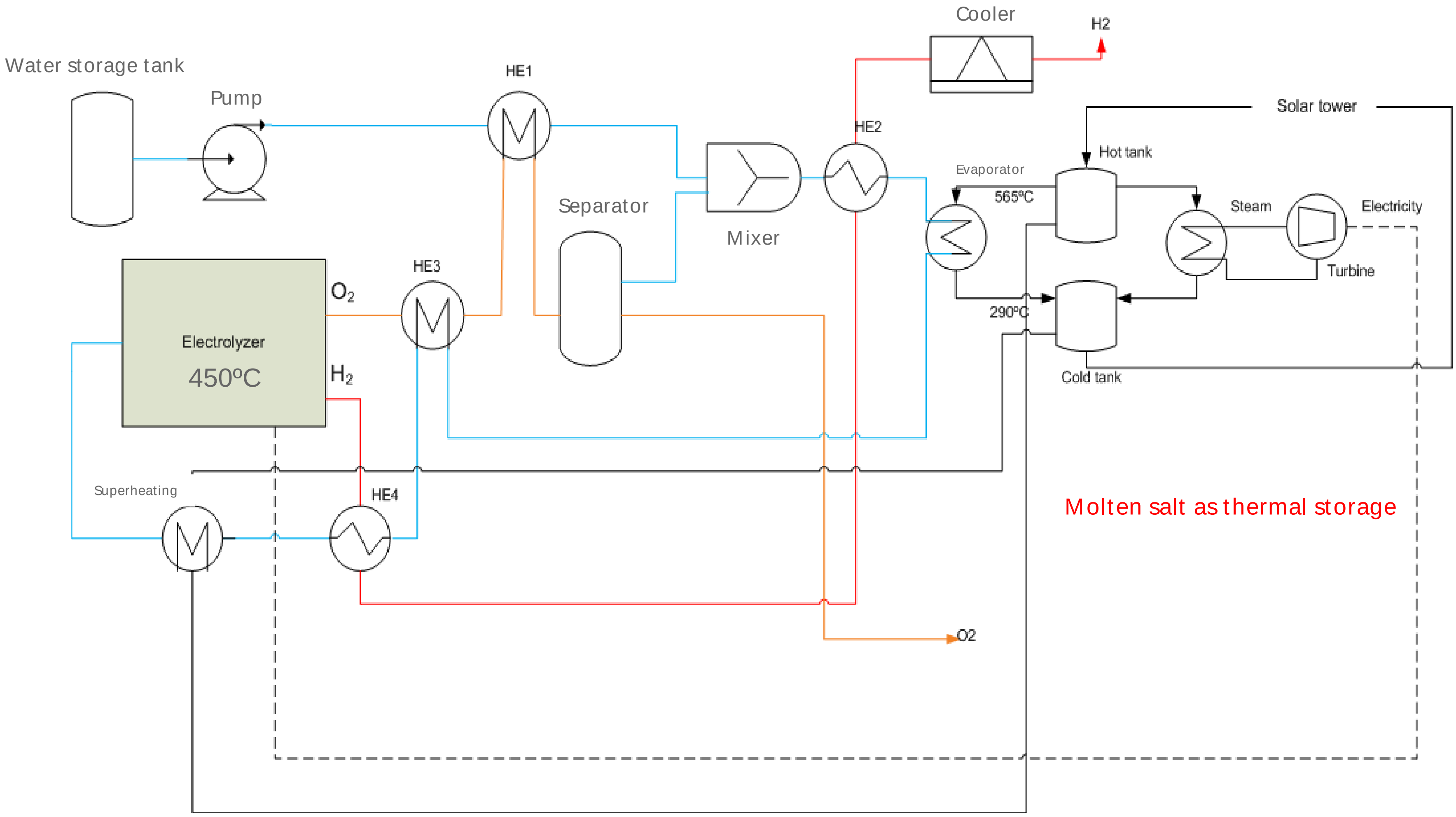


Large size electrolyzer plant of 100 MW electricity consumption considered for case 2 in order to adapt power of the existing solar thermal power plants (with molten salt as thermal storage) of Abengoa (100 MW).

Specifications:

- Operation temperature: 700 ºC
- Electrolyzer power consumption: 97,258 MW
- Energy needed for the evaporation: 20,780 MW
- Superheating: 2,870 MW
- Hydrogen produced with a 60% of steam conversion: 0,79 kg/s (20 bar)
- Efficiency of the plant: 3,16 kWhe/Nm^3
- Efficiency of the electrolyzer: 3,07 kWhe/Nm^3

Evaluation of Thermosolar options for integration: Case 3



Large size electrolyzer plant of 100 MW electricity consumption considered for case 3 in order to adapt power of the existing solar thermal power plants (with molten salt as thermal storage) of Abengoa (100 MW).

Specifications:

- Operation temperature: 450 ºC
- Electrolyzer power consumption: 94,21 MW
- Energy needed for the vaporization: 23,67 MW
- Superheating: 4,43 MW
- Hydrogen produced with a 60% of steam conversion: 0,79 kg/s (20 bar)
- Efficiency of the plant: 2,98 kWhe/Nm^3
- Efficiency of the electrolyzer: 2,98 kWhe/Nm^3

- In Case 1, the optimum is to use power from renewable sources to produce hydrogen using a PCEC electrolyzer, having a sustainable cycle.
- In Case 2,molten salt storage system provide heat for vaporization and electricity for electrolyzer. However it is required to supply power to superheat the steam because heat available from molten salts storage is at 565ºC which cannot not be used to maintain 700ºC.
- While in Case 3, heat produced from molten salt storage plant would be more usable due to operation at 450ºC.
- Thermosolar plants with molten salts tanks can produce heat and power during the whole day.

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Thank you

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