Adiabatic Compressed CO_2 Energy Storage

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Outline

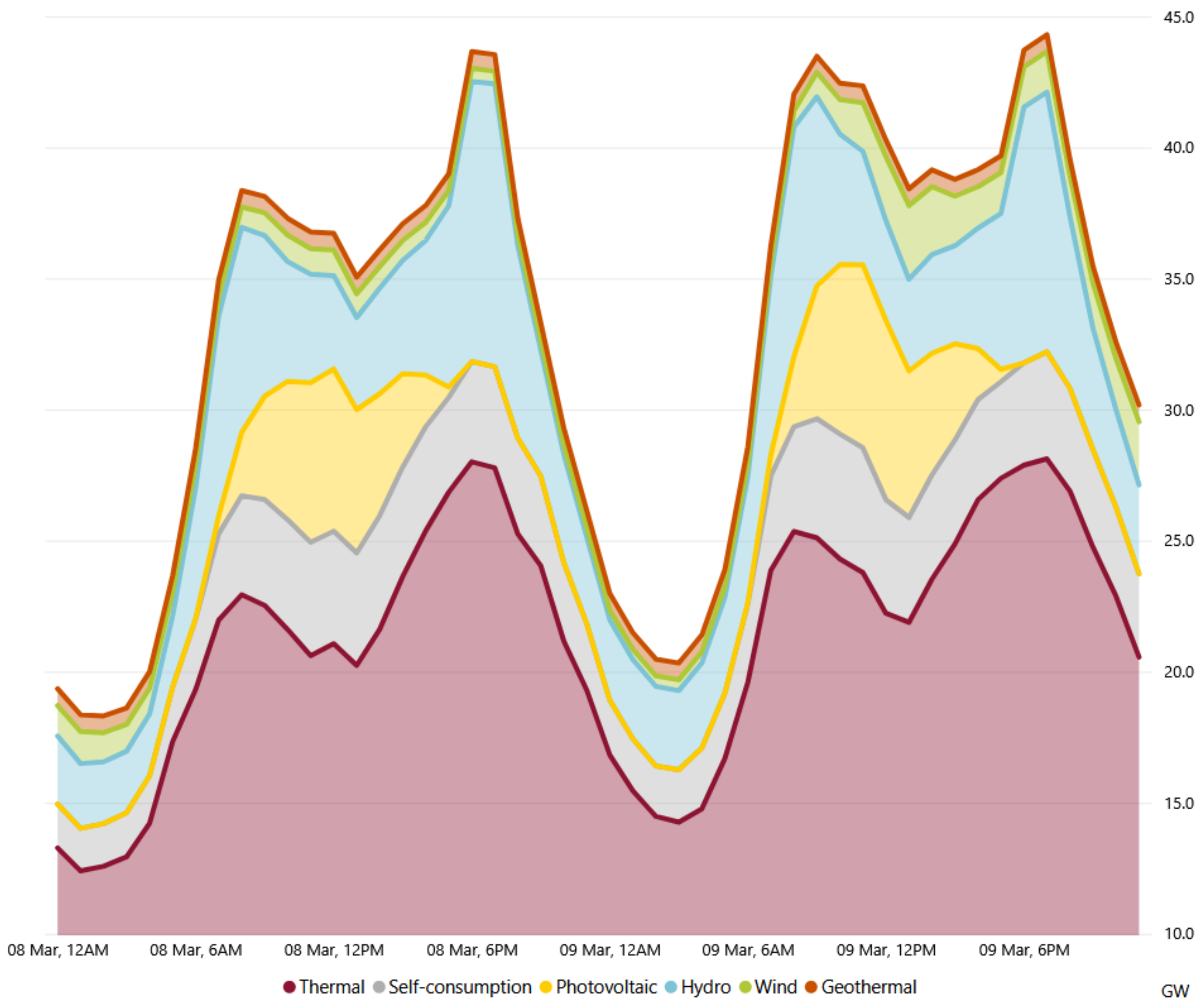
- Introduction
- Layout of the Energy Storage System
- The Subcritical CO_2
- The Supercritical CO_2
- Results & Comparative Analysis
- Conclusions

Introduction

The role of energy storages

Going towards a more sustainable future scenario the importance of renewable energy is constantly growing.

Since many renewable sources are non-programmable, it is important to achieve convenient ways to store energy in order to shave peaks and align production and demand.



This is Italy's actual electrical generation for 8 and 9 of March 2021, taken as example.

Figure: https://www.terna.it/en/electric-system/transparency-report

Energy Storages

Current status

This system can be classified as a thermo-mechanical storage, conceptually similar to an Adiabatic CAES.

This system allows to store Pressure and Thermal Energy separately

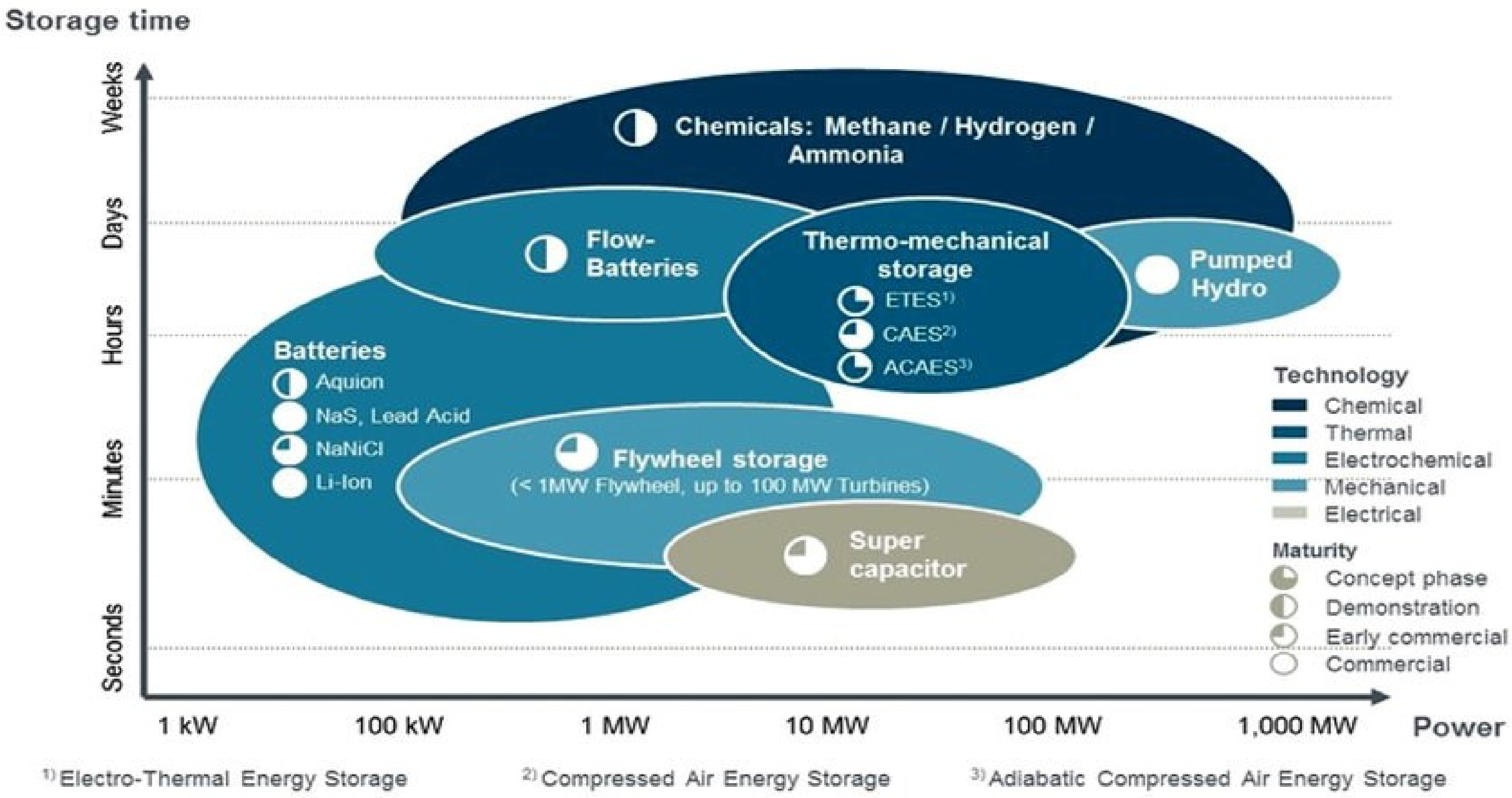


Figure: A. Valera-Medina et al., Ammonia for Power, Progress in Energy and Combustion Science 69 (2018) 63–102

Layout of the Analised Plant

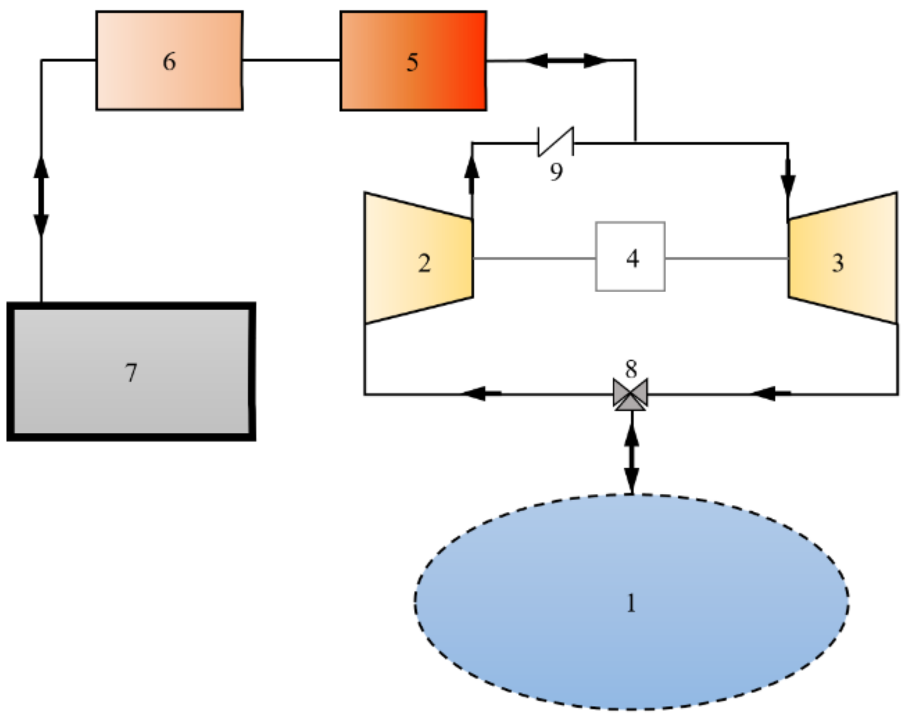
How it is made and how it works

This configuration of a CO_2 loop for an energy storage is firstly analised in the patent by eng. Claudio Spadacini «Energy Storage Plant And Process» (WO 2020/039416 A2).

The simplified plant on the right is composed by:

- (1) Ambient Pressure Tank (deformable balloon)
- (2) Compressor
- (3) Turbine
- (5) Heat Exchanger regenerator (TES)
- (6) Low T Heat exchanger
- (7) High Pressure Tank

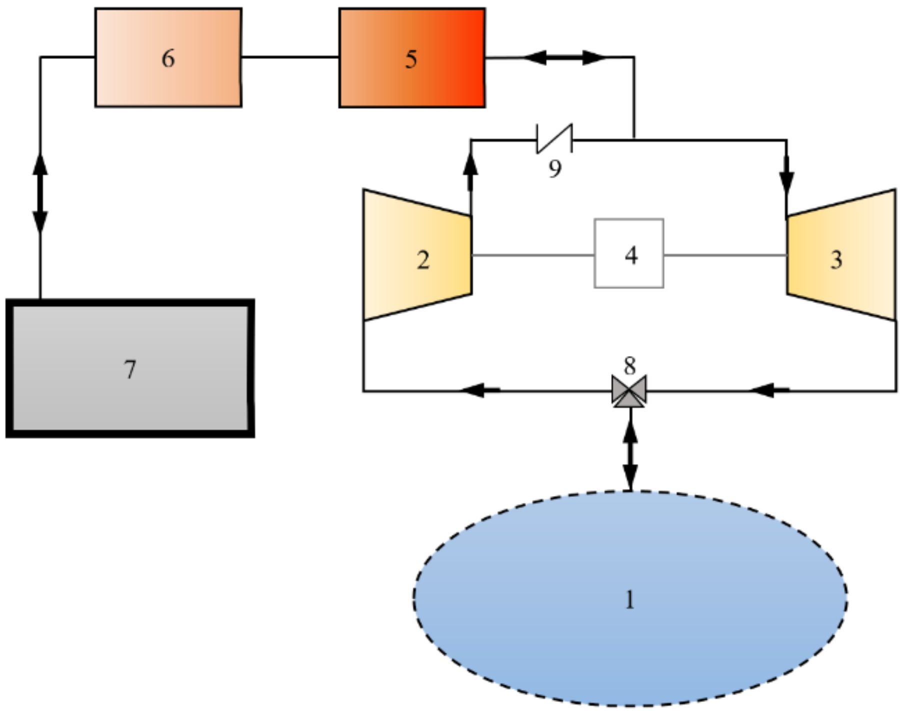
The system is charachterised by a charging phase (1 to 7 through 2) and a discharge phase (7 to 1 through 3)



Layout of the Analised Plant

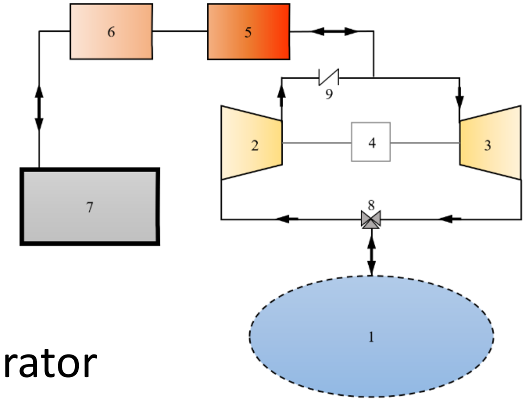
Assumptions made

Component	Assumptions
Heat Exchanger regenerator(s) (5)	Pressure loss equal to 1.5% of inlet pressure Enthalpy loss in the discharge phase equal to 2% of the inlet enthalpy
Compressor (2)	Power set at 10 MW Isoentropic efficiency 0.85 Electrical efficiency 0.98 Mechanical efficiency 0.98
Turbine (3)	Isoentropic efficiency 0.88 Electrical efficiency 0.98 Mechanical efficiency 0.98
High pressure tank (7)	No Temperature and Pressure losses
Ambient pressure tank (1)	In balance with atmospheric pressure
Operating Time	4 hours



Charge and Discharge in the Subcritical case

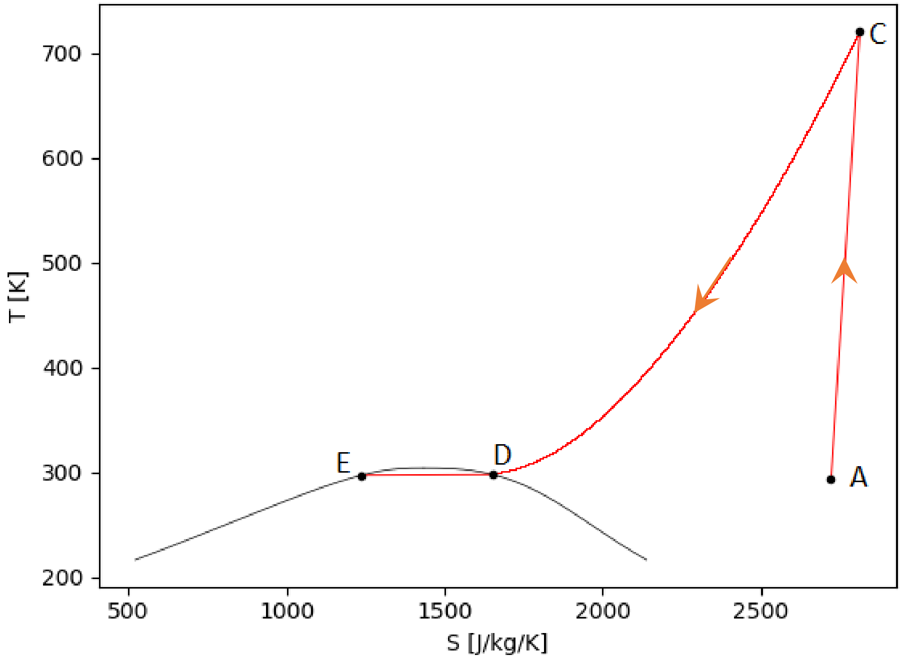
In the T-s diagrams



A-C) Compression up to 65 bar (721 K)

C-D) Heat given to the heat exchanger regenerator

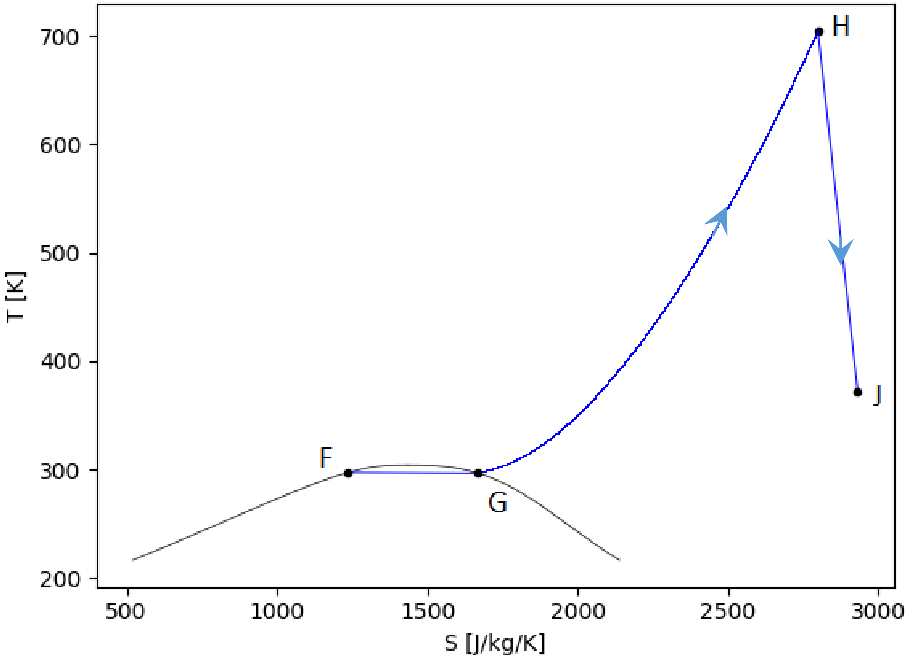
D-E) Heat given to the heat exchanger condenser



F-G) Heat provided by evaporator

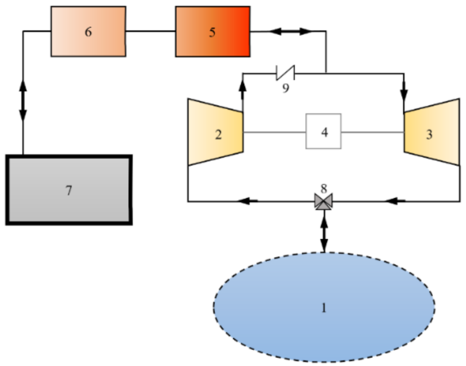
G-H) Heat provided by heat exchanger regenerator

H-J) Expansion in the turbine



Charge and Discharge in the Supercritical case

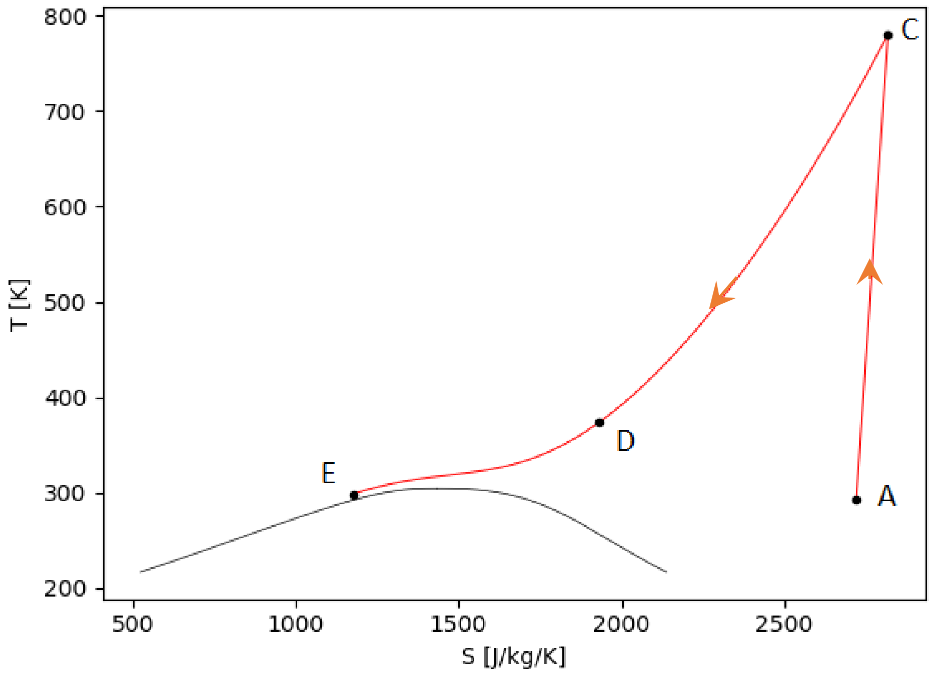
In the T-s diagrams



A-C) Compression up to 100 bar (780 K)

C-D) Heat given to the High-Temperature regenerator

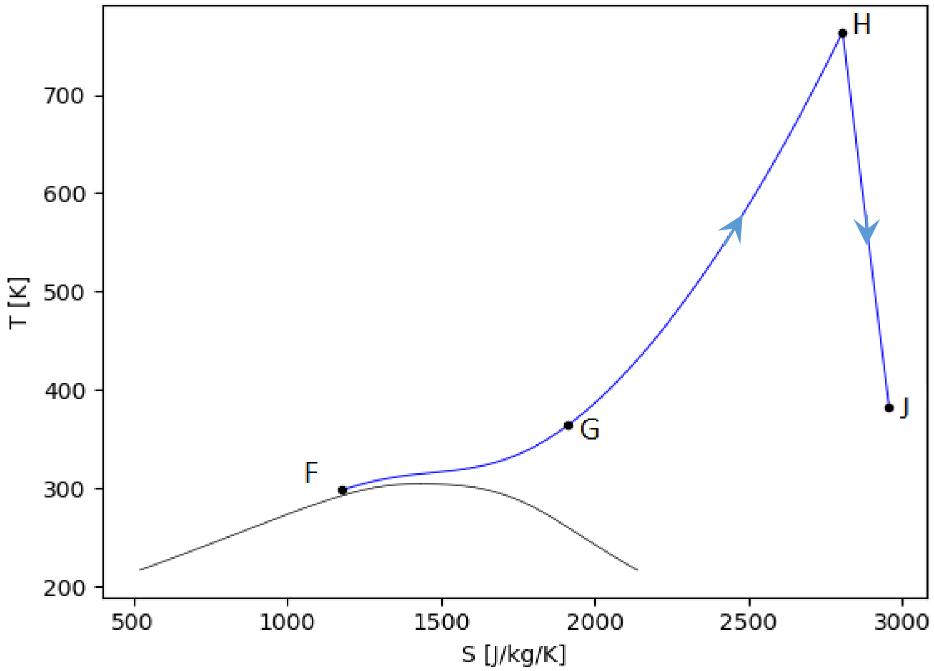
D-E) Heat given to the Low-Temperature regenerator



F-G) Heat provided by Low-Temperature regenerator

G-H) Heat provided by High-Temperature regenerator

H-J) Expansion in the turbine



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Results

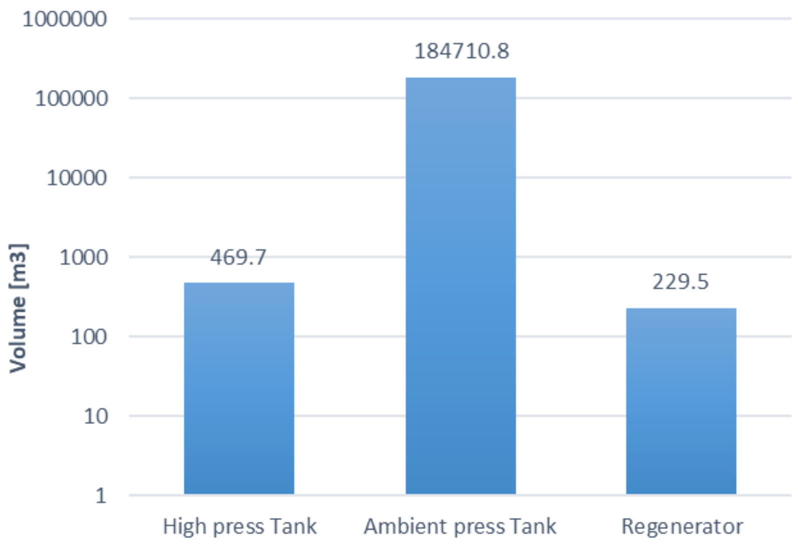
General results for CO_2

Subcritical case Results	
Compressor work	423.8 kJ/kg
Heat stored at high temperature	530.3 kJ/kg
Heat stored at constant temperature	124.03 kJ/kg
CO_2 mass flow	23.59 kg/s
Ambient pressure tank diameter	70.66 m
High pressure tank diameter	9.64 m
SC-RIG mass	861.8 t
SC-RIG volume	219.6 m^3
Turbine work	335.8 kJ/kg
Electrical power in 4 h discharge	7611 kW
RTE	76.1%

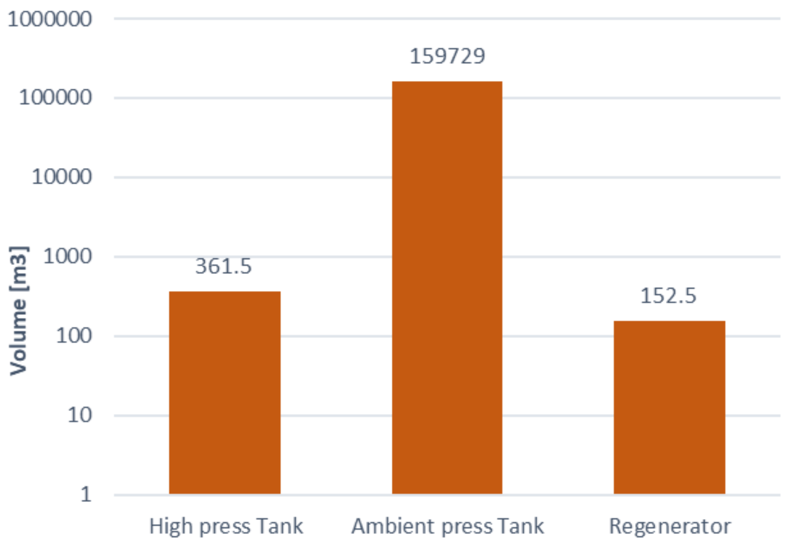
Supercritical case Results	
Compressor work	490.13 kJ/kg
Heat stored at high temperature	486.37 kJ/kg
Heat stored at low temperature	248.2 kJ/kg
CO_2 mass flow	20.4 kg/s
Ambient pressure tank diameter	67.3 m
High pressure tank diameter	8.84 m
High-temperature SC-RIG mass	598.5 t
High-temperature SC-RIG volume	152.5 m^3
Turbine work	391.1 kJ/kg
Electrical power in 4 h discharge	7664 kW
RTE	76.6%

Results

Volumes for CO_2 Systems



Subcritical CO_2



Supercritical CO_2

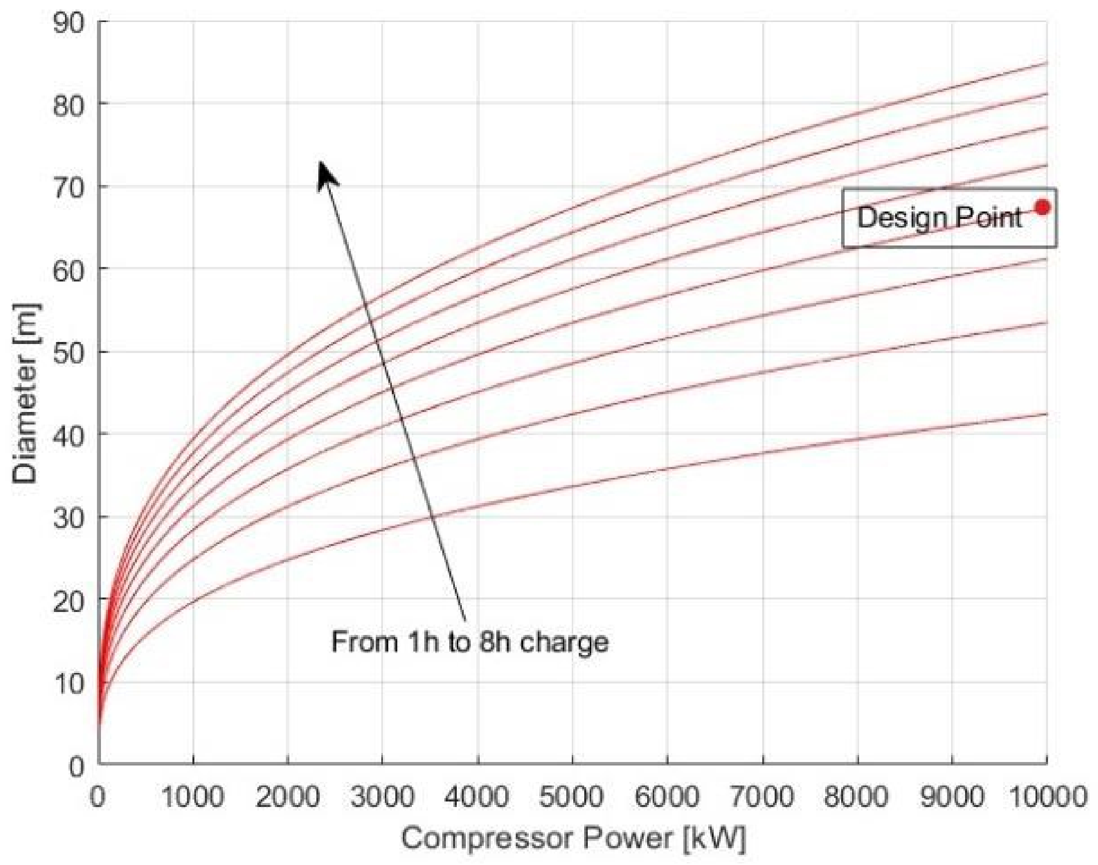
The supercritical case has lower volumes (it has been used the same power, but less mass flow rate is evolving in this system)

General Comparative Analysis

Results

It is possible to change the Volume of the ambient pressure Reservoir by changing the amount of Energy Stored

It is needed to act on the Operating (Charging) Time and on the Power of the Compressor

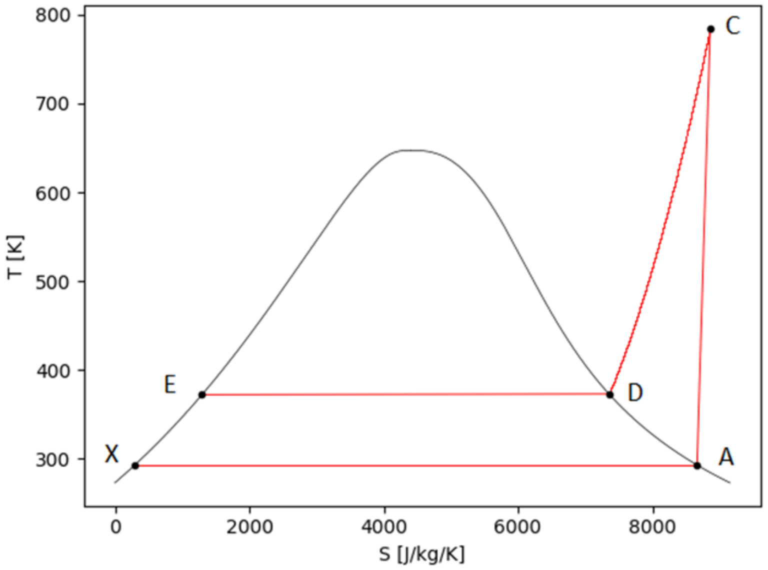


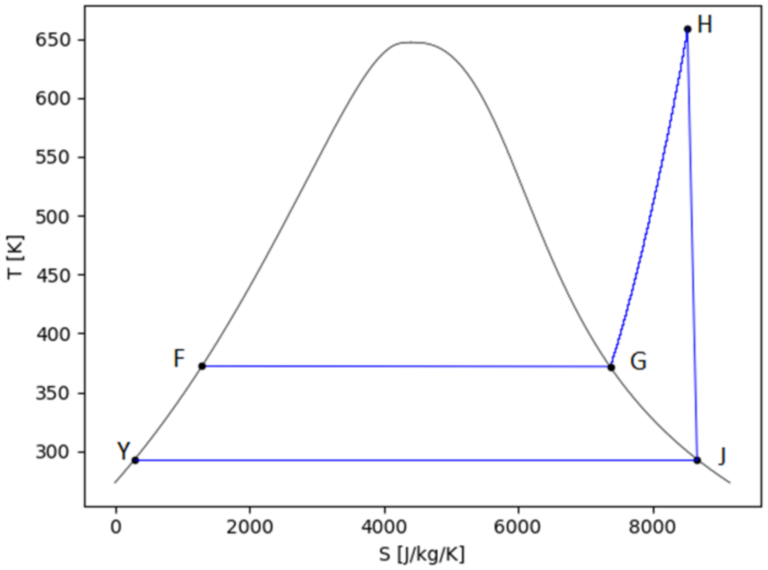
General Comparative Analysis

Tentative with water and other fluids

Other fluids has been analysed even if not reported in the paper.
The same principles, hypotheses and assumptions were made for CO_2 and for the other fluids.

For water it has been studied a different approach (exposed in the following figures), since it is liquid in ambient conditions. This required to store water at a very low pressure in the reservoir at ambient temperature, and to store the fluid at higher temperature in the high-pressure case, near ambient pressure.





General Comparative Analysis

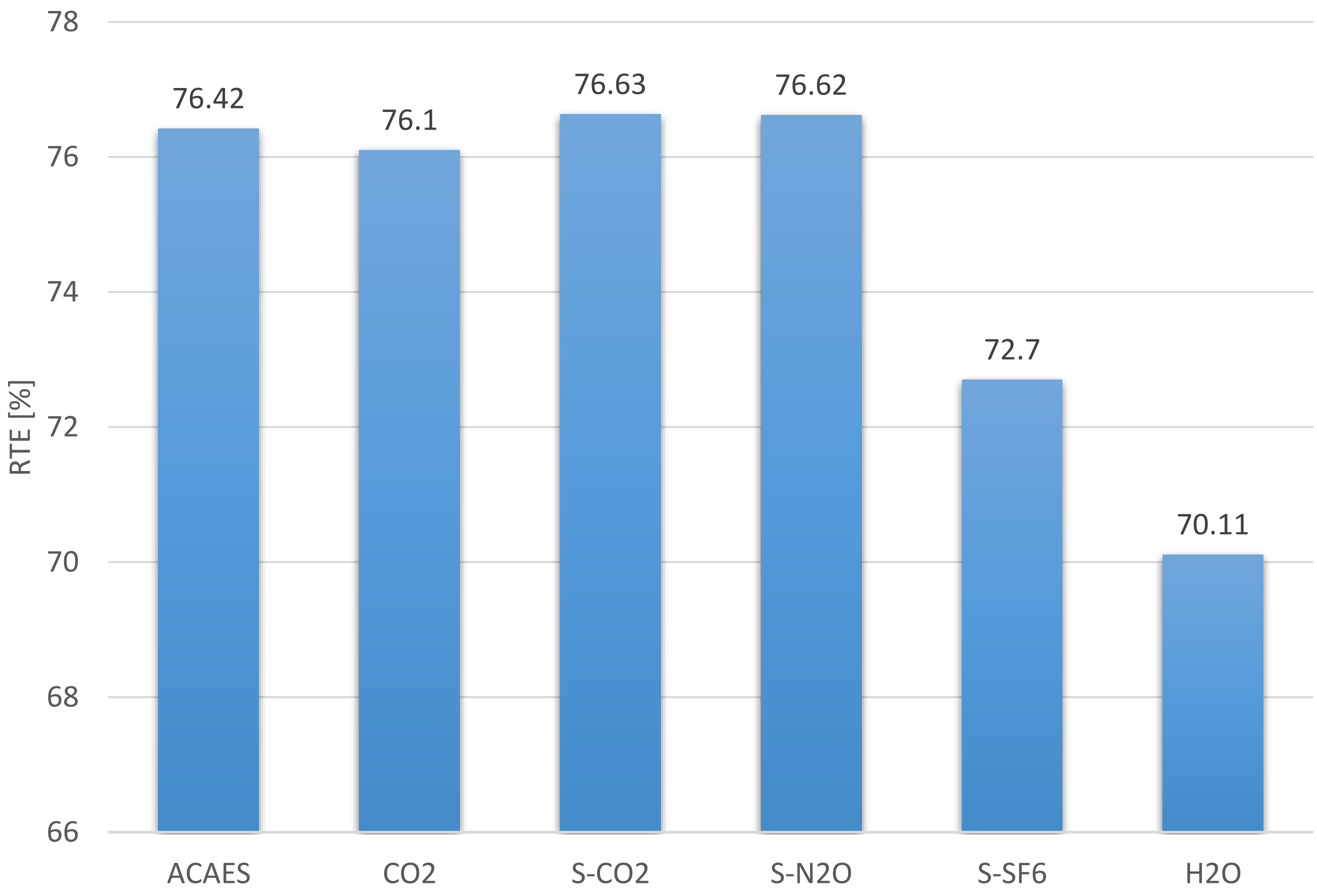
Results

Working fluid	CO_2	S-CO_2	H_2O
RTE [%]	76.1	76.6	70.1
Electrical power [kW]	7611	7664	7012
Compression work [kJ/kg]	423.84	490.13	975.54
Heat stored at high-T [kJ/kg]	530.28	486.37	837.45
Reservoir (low-p) diameter [m]	70.66	67.32	6.56
Tank (high-p) diameter [m]	9.64	8.84	6.65

General Comparative Analysis

Round Trip Efficiency

RTE aligned with that of the Compressed Air Energy System (65%-75% in literature)



Round Trip Efficiency = Ratio between energy produced and energy absorbed in the charge phase.

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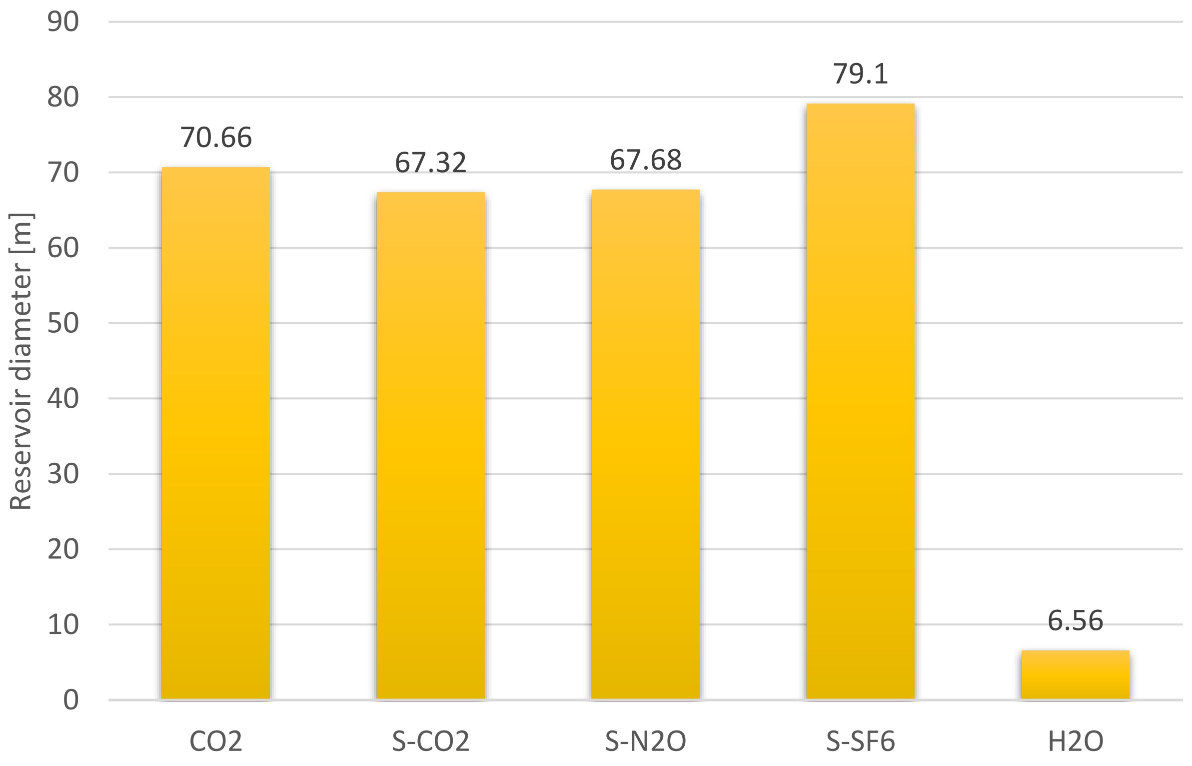
General Comparative Analysis

Low Pressure Reservoir Diameter

This is the diameter of a sphere containing the whole fluid that evolve in the plant and produces work. The water is stored in liquid phase also in the low pressure tank and this causes the difference between the values in the diagram

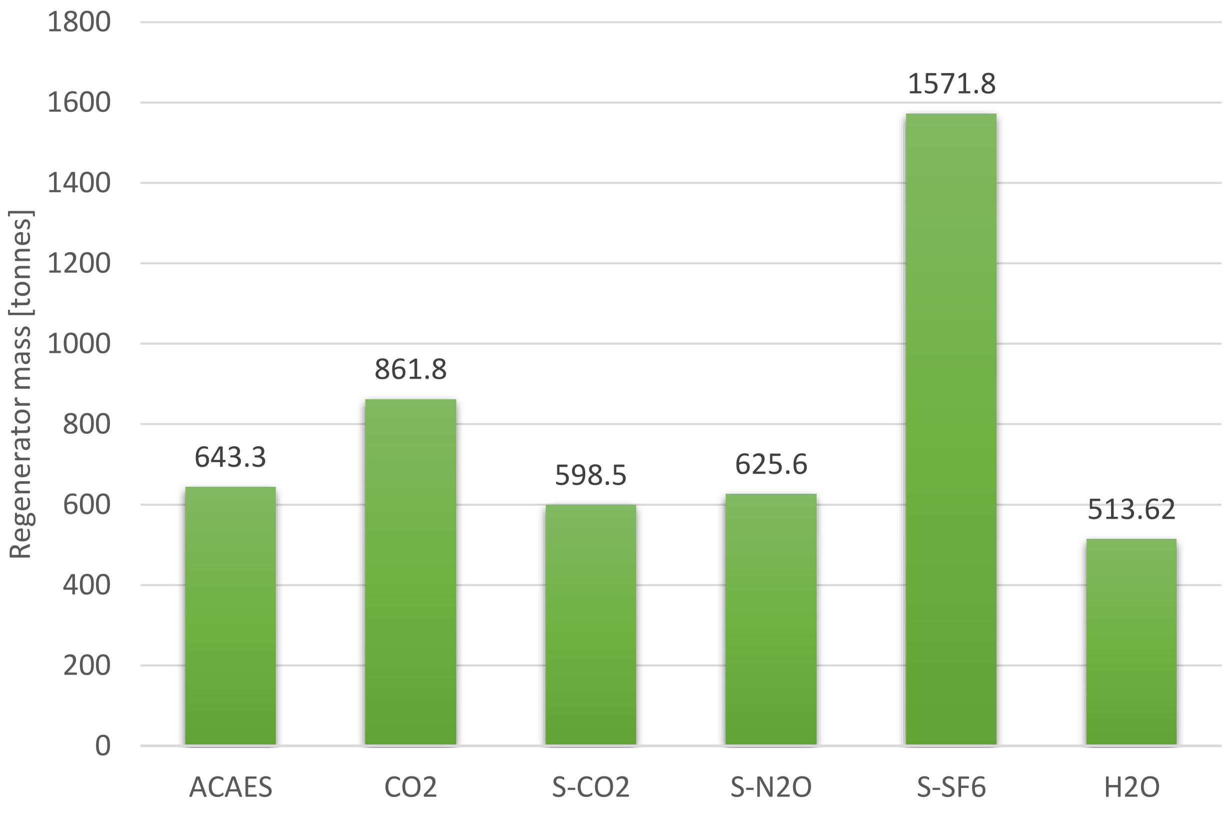
Important to evaluate the footprint of the accumulation volume of the plant varying the fluid



General Comparative Analysis

Dimension of Regenerator

These results are strongly dependant on assumptions made;
The regenerator is supposed to be made of steel, with a void ratio of 50%



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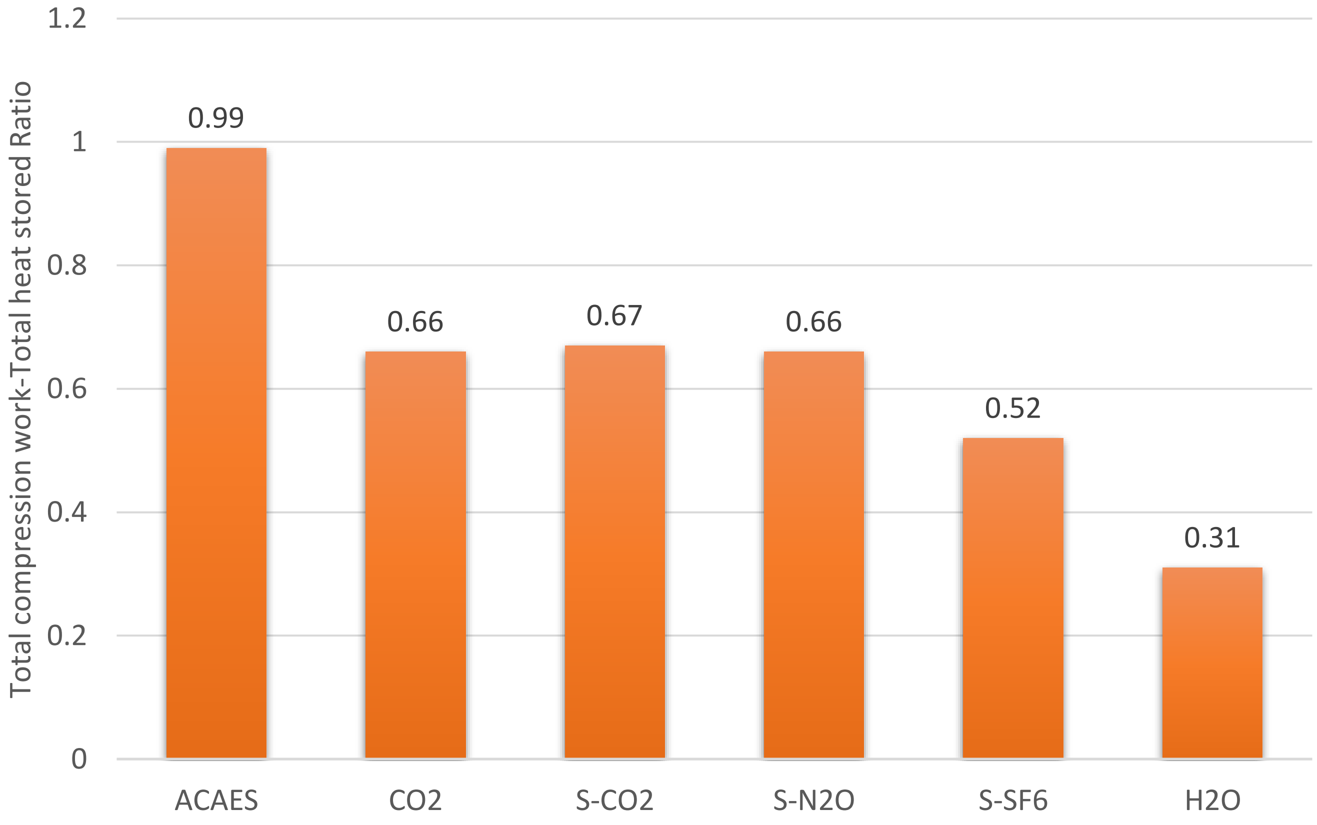
General Comparative Analysis

Work to Heat Ratio

Defined as the ratio between the work of the compressor over heat stored



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Conclusions

- Both supercritical and subcritical solutions have pros and cons:
  - The supecritical one has better numerical results, but with a more complex plant configuration and prospected operation.
  - The subcritical one could be easier to manage and with lower CAPEX due to lower pressures

- Different fluid has been evaluated, with no particular difference in the behaviour and CO_2 seems the most convenient one.

- Water needs a more complex system and but have reduced footprint in terms of low-pressure reservoir

- This system may seem similar to ACAES, with the advantage of constant pressure ratio, thanks to the CO_2 change of state (or cooling, in case of supercritical cycle).

- The knowledge of dynamic behaviour and decisions on storage capacity of this system will be fundamental to understand the role and applications of this systems in the energy market

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