Components' and Materials' Performance for Advanced Solar Supercritical CO_2 Powerplants (COMPASsCO$_2$)

FINAL INDUSTRIAL DESIGN AND BUSINESS CASE

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John Cockerill

COMPASsCO2 Final Workshop

Back to the Future: A Forward-Thinking Approach to Concentrating Solar Technologies - Key Takeaways from the COMPASsCO$_2$ Project

April 24th, 2025

9h30 – 14h30 CEST

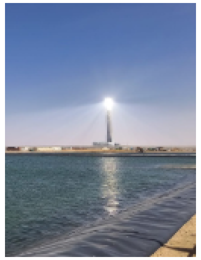
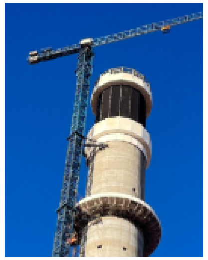
Husinec u Řeže, Czech Republic & Online lifesize

Presentation Structure

- John Cockerill Renewables – Power & Storage - Activities
- Review of the state of the art
- Innovations & contributions of the COMPASsCO2 Project
- Lessons learned & challenges

John Cockerill Renewables – Power & Storage - Activities

➢ Expertise in CSP Tower

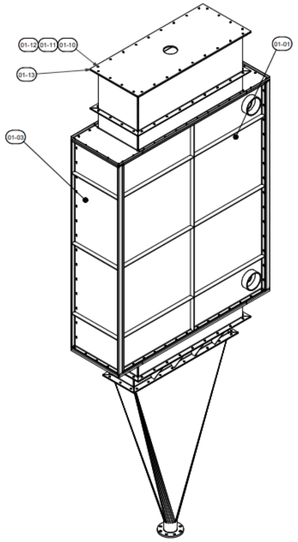
Year	2012	2014	2017	2018	2021
Project	**KHI Solar One**	**CED - Cerro Dominador**	**HAI - Haixi**	**DEW - Dewa**	**RED - Redstone**
Picture					
Customer	Abengoa	Abengoa/Acciona	Sepco 3	Shanghai Electric	Sepco 3
Owner	Eskom & Abengoa	Grupo Cerro	Luneng	DEWA & Acwa Power	Acwa Power
Technology	SGSR - Steam Generator Solar Receiver	MSSR - Molten Salt Solar Receiver	MSSR - Molten Salt Solar Receiver	MSSR - Molten Salt Solar Receiver	MSSR - Molten Salt Solar Receiver
Plant Power	50 MWe	110 MWe	50 MWe	100 MWe	100 MWe
Receiver Power	250 MWth	760 MWth	280 MWth	600 MWth	600MWth
Storage time	Several hours	17.5	12	15	12
Status	In operation	In operation	In operation	Comissioning	Comissioning

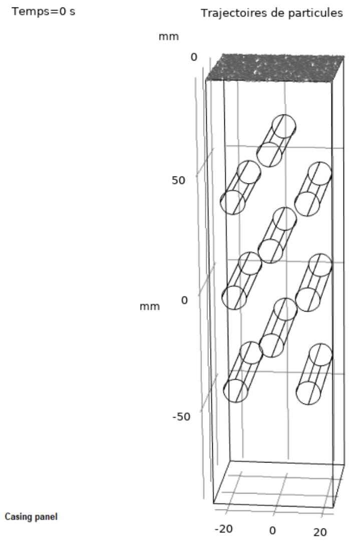
John Cockerill Renewables – Power & Storage - Activities

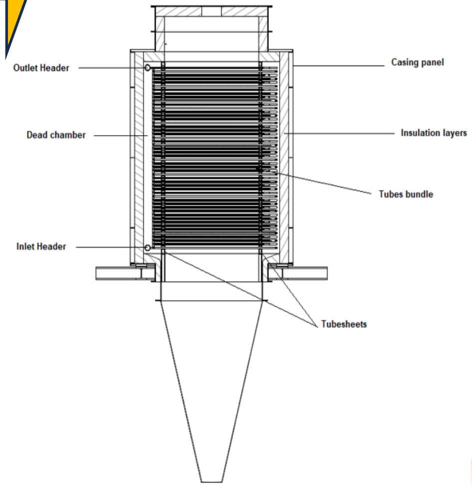
➢ Expertise in Heat exchangers

SR HEX

MS HEX



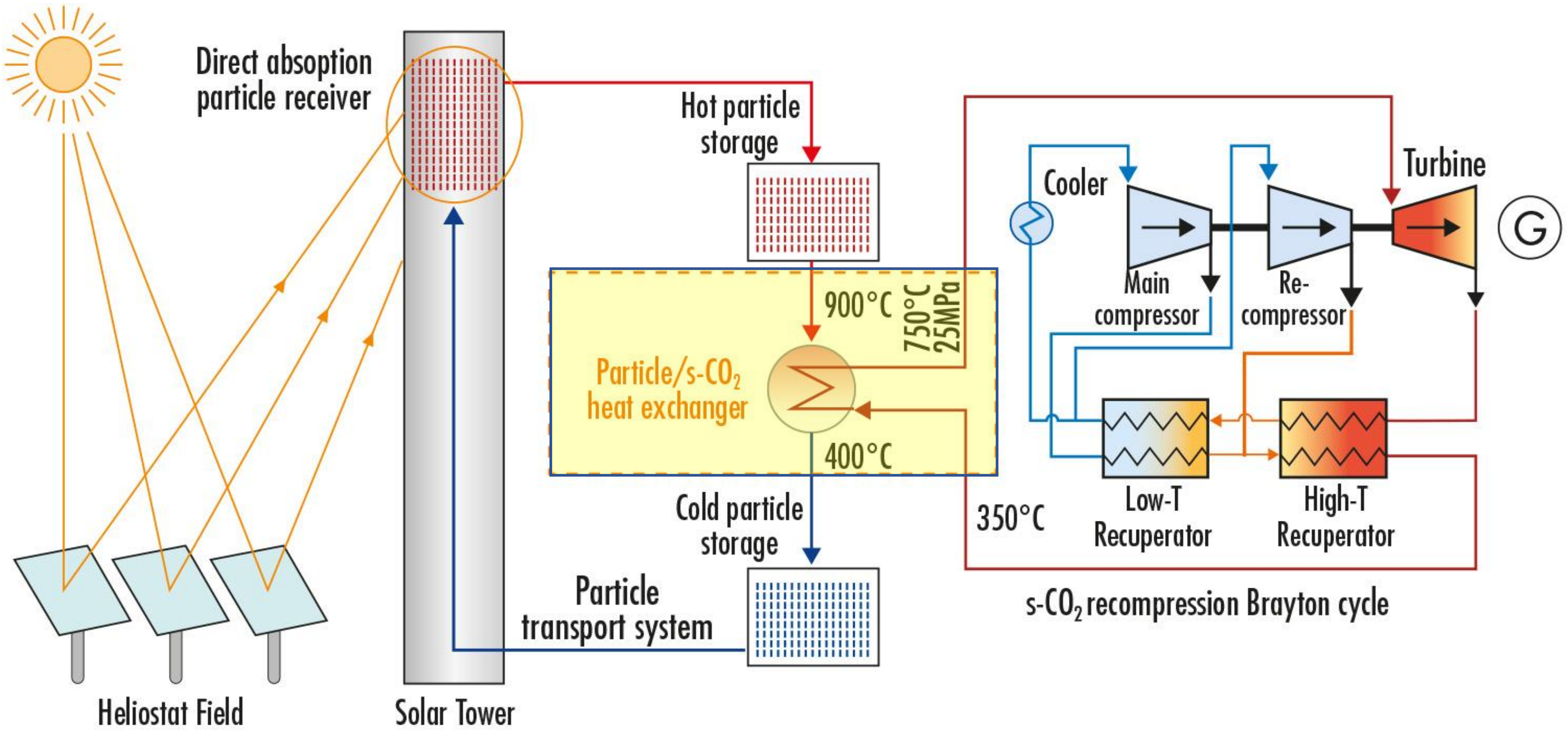




Particles HEX

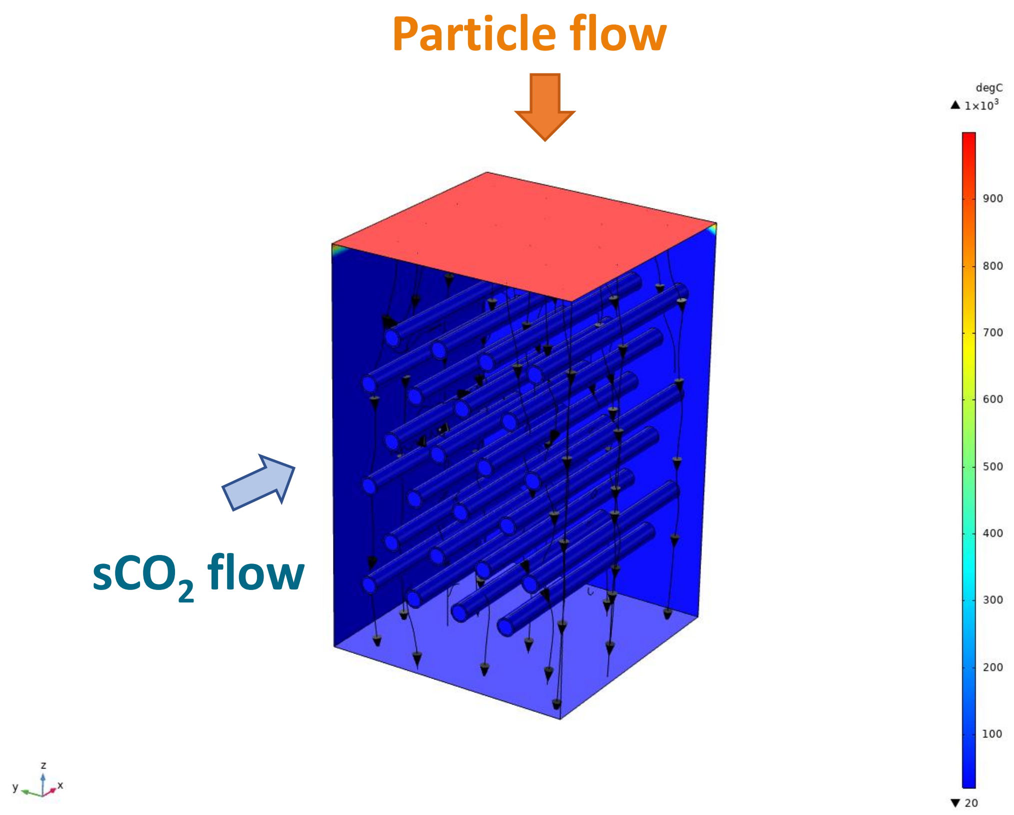
Objectives in CompassCO2 Project

The role of **John Cockerill Renewables** was **focused on the particle/sCO2 heat exchanger design**



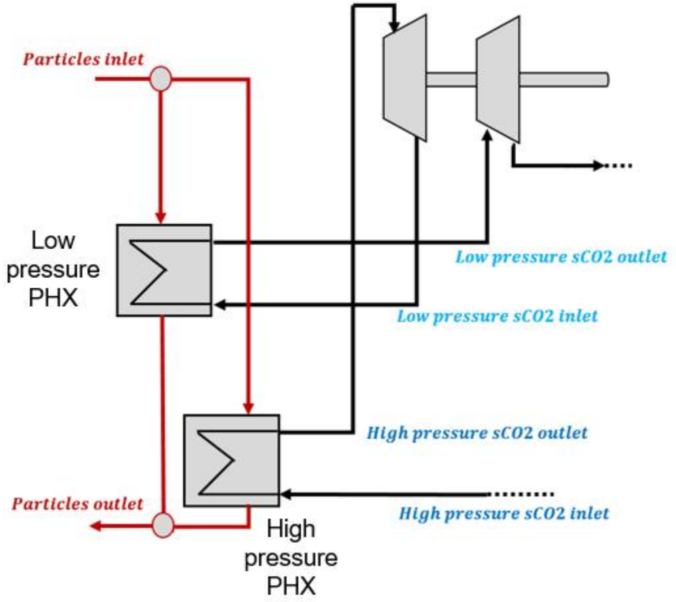
Particle/sCO2 Heat Exchanger Design

- **HEX requirements:**
  - **High mechanical strength** @ high temperatures
  - **Creep resistance** under long-term operation
  - **Corrosion and oxidation resistance** in sCO_2 (high press./temp.)
  - **Abrasion resistance** against particle impacts
  - Long-term **thermal stability**
  - **Compatibility** with current manufacturing technologies
  - **Cost-effectiveness** for commercial application



Particle/sCO2 Heat Exchanger Design

➢ Process parameters



Parameters	Particles (high pressure PHX)	Particles (Low pressure PHX)	sCO2 (high pressure PHX)	sCO2 (low pressure PHX)
PHX inlet temperature [°C]	900	900	532.8	583.4
PHX outlet temperature [°C]	582.8	633.4	700	700
PHX inlet pressure [bar]	/	/	265.3	110.4
PHX outlet pressure [bar]	/	/	260	108.2
Mass flowrate [kg/s]	355.9	288.3	632.6	632.6

Particle/sCO2 Heat Exchanger Design

➢ HEX design steps:

- Material selection
- Pre-sizing based on HTC. Many iterations based on:
  - Tubes diameter
  - Particles inlet & outlet temperatures
  - Spacing of tubes (V & H)
  - Mass flow rate variations
  - Tubes surface temperature
  - Number of rows
  - More accurate HTC

Transportation

- Height = 3,5m max.
- Width = 4 m max.
- Length = 25 m
- Weight = 50T-60T
- Road surveys necessary

HEX design constraints:

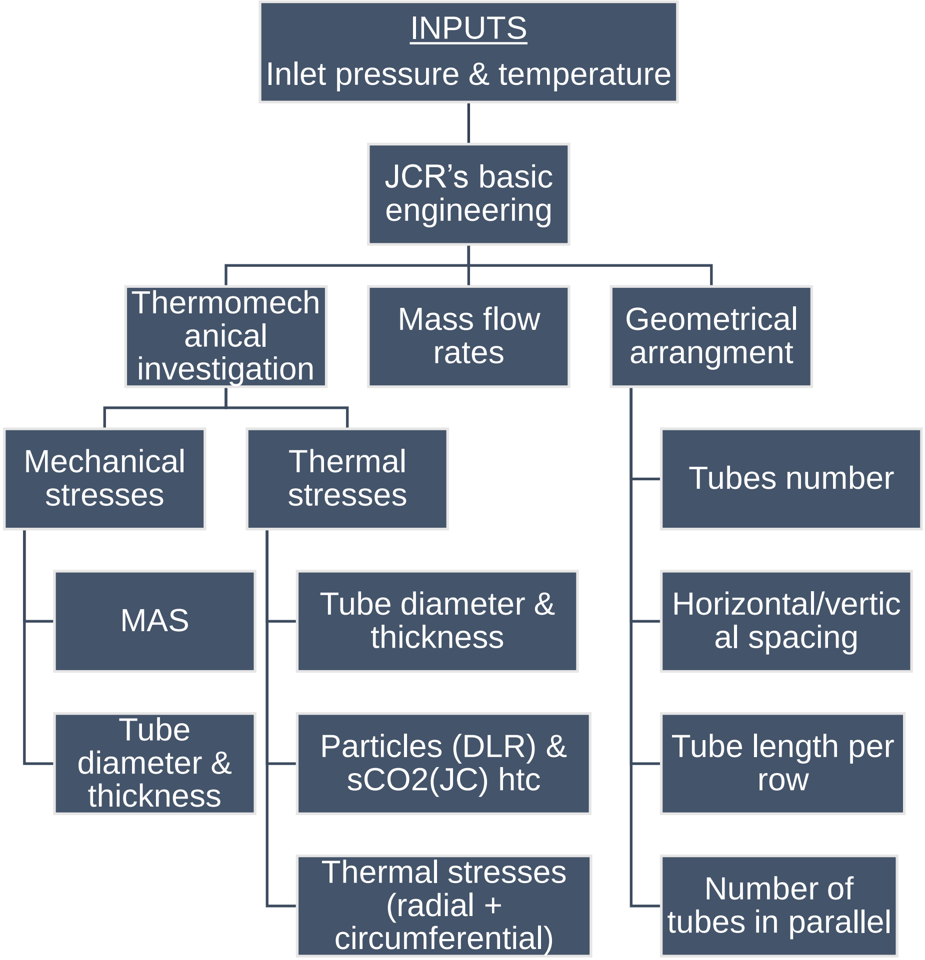
- Optimized thermal performances
- Design restrictions
- Minimum spacing between tubes
- Minimum allowed elbows bending radius
- Tubes horizontal spacing

Manufacturing

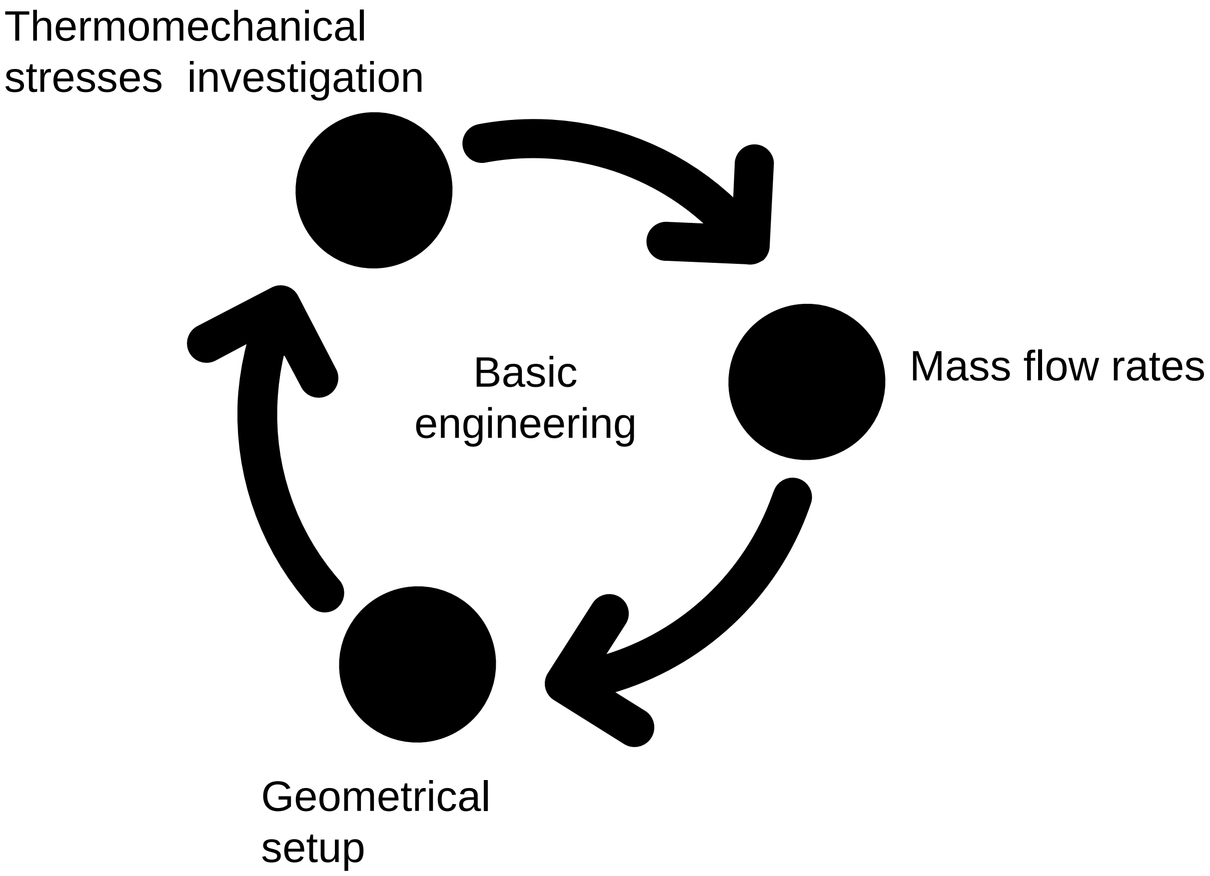
- Tailor-made tubes (high pressure)
- Material procurement (Long lead time)
- Weldings on site. Dissymmetric, heterogeneous
- Non-destructive test on large equipment
- Accessibility

Particle/sCO2 Heat Exchanger Design

➢ HEX design: Thermomechanical stress analysis

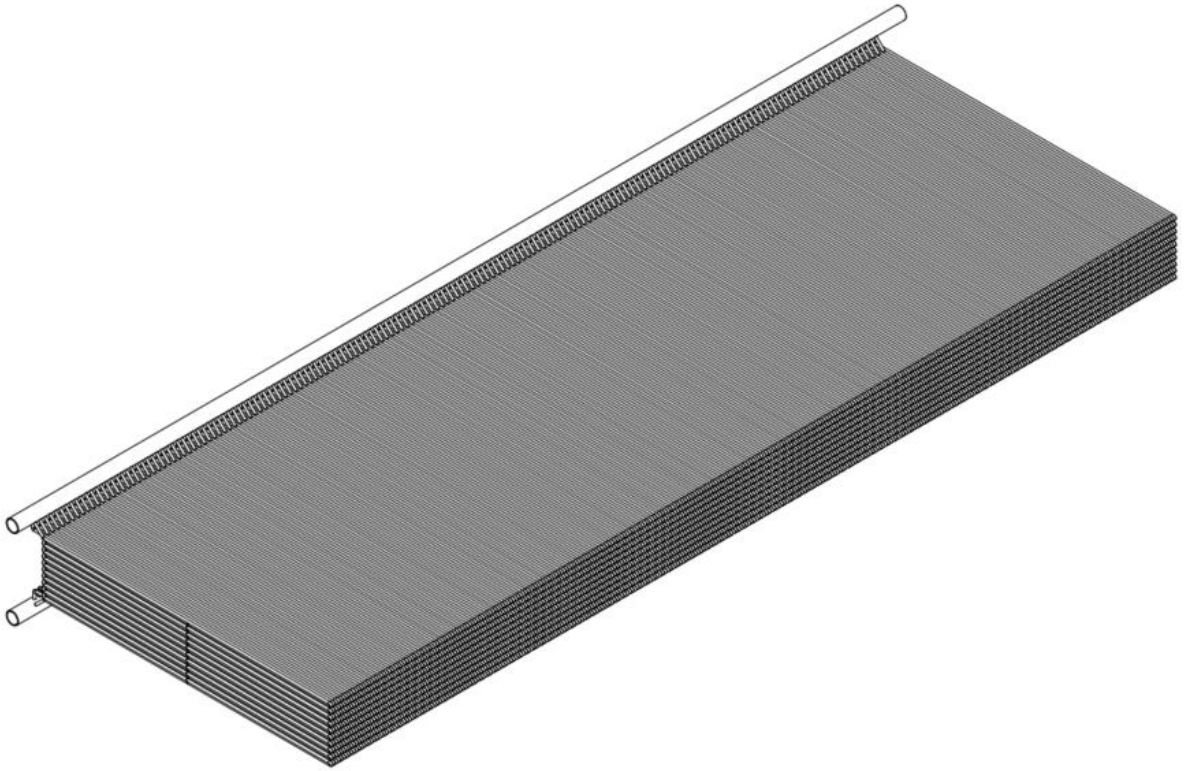


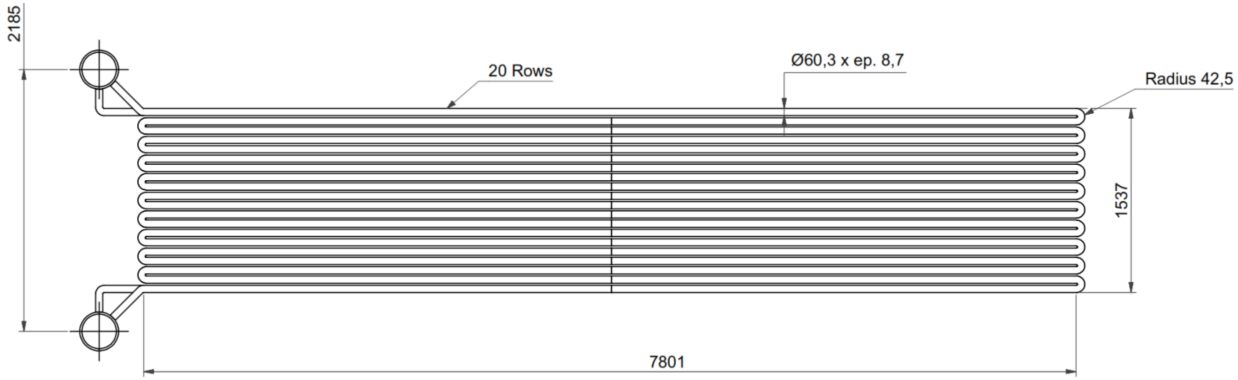
Iterative process



Particle/sCO2 Heat Exchanger Design

➢ **Basic design – 1 Module**

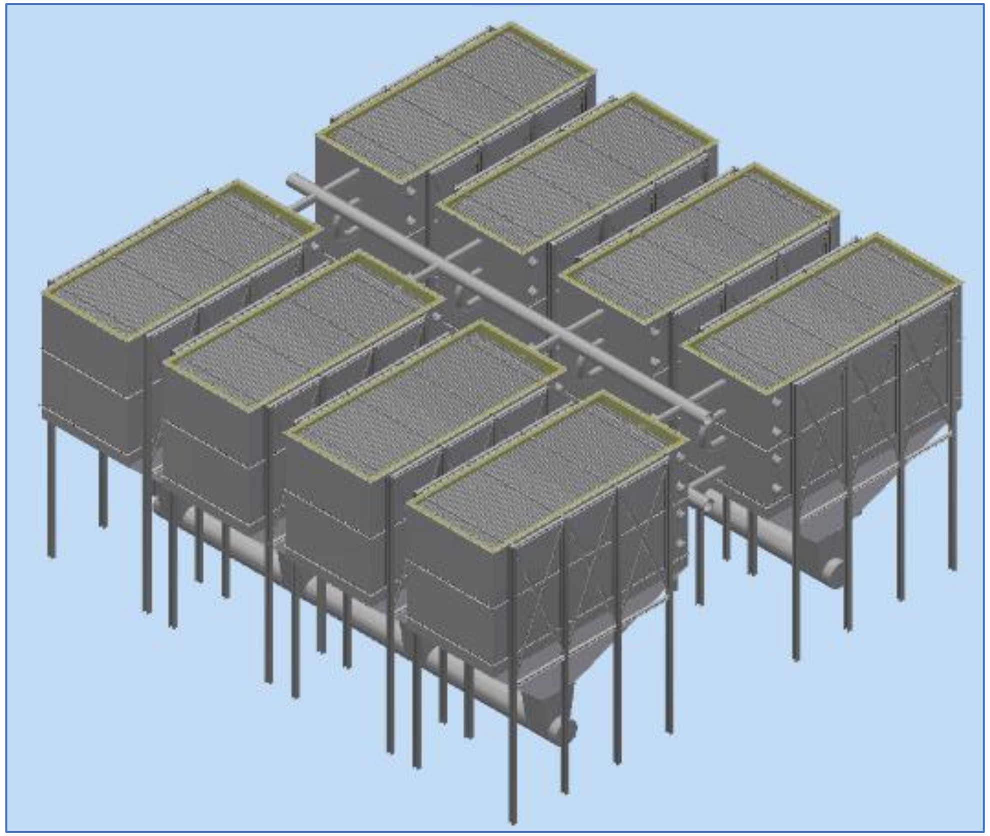




First design:
⇒ Very big HEX
⇒ Not fabricable nor transportable

Particle/sCO2 Heat Exchanger Design

➢ Design optimization – Modular solution



Modular design:

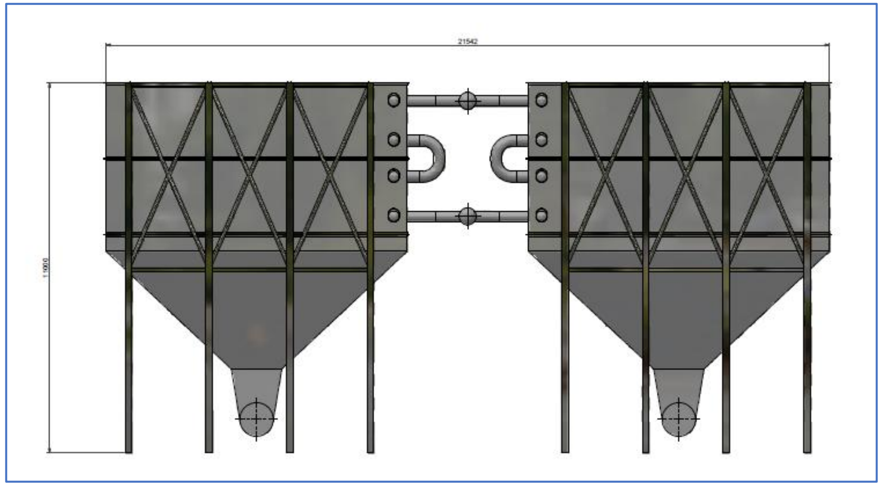
- 8 modules of 15 MWth each for HP
- 8 modules of 15 MWth each for LP

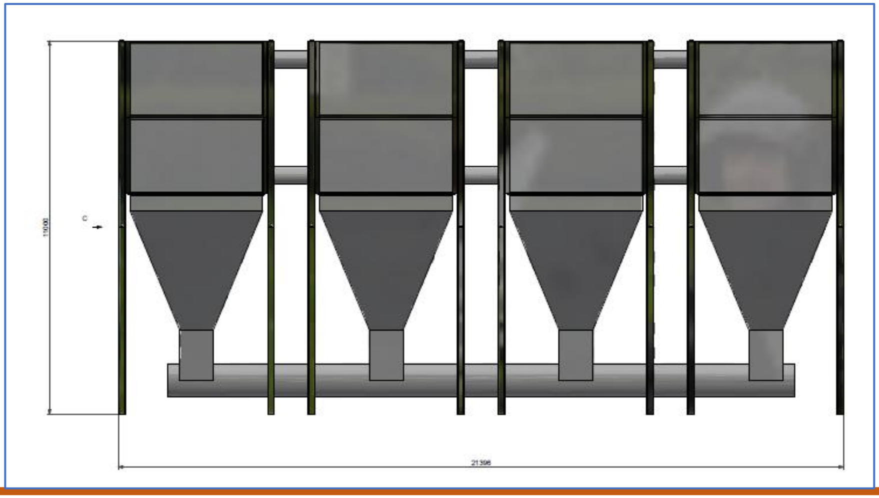
Advantages:

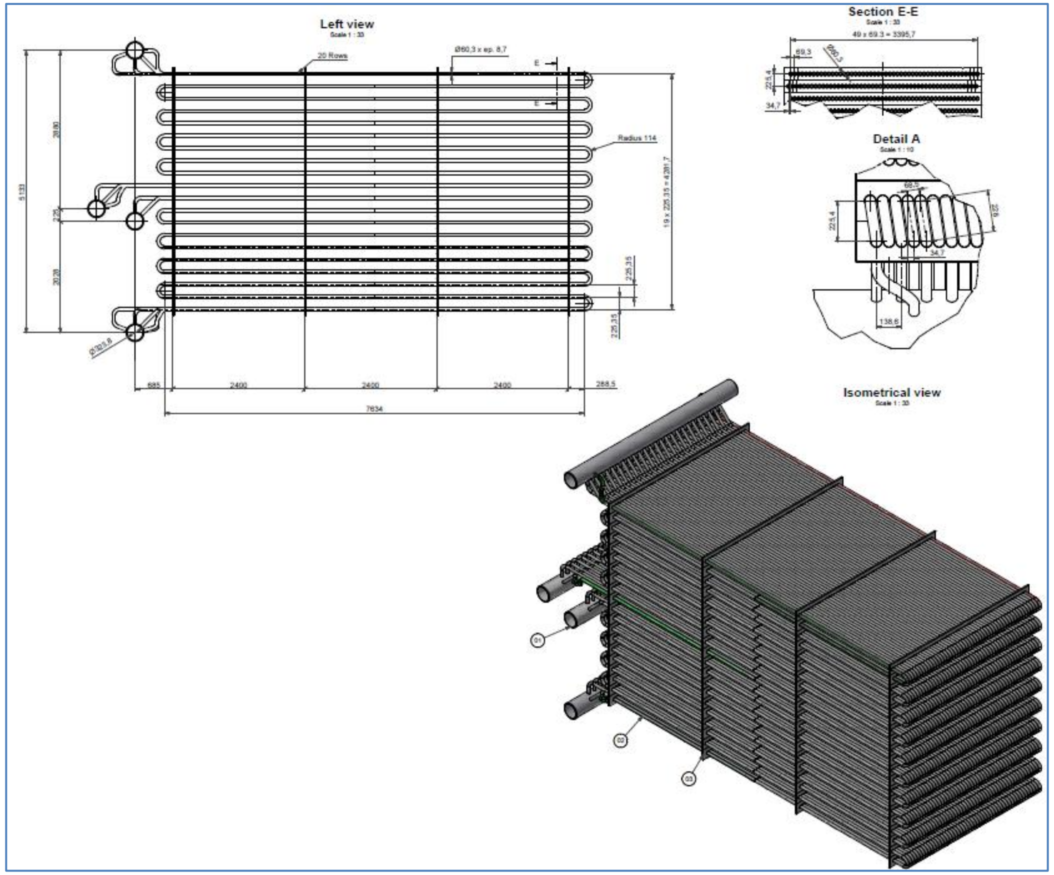
⇒ Each module is made of 2 HEX units
⇒ Same design for HP HEX and LP HEX
⇒ Easy to manufacture and transport
⇒ Intermediate headers to connect each 2 HEX units
⇒ Reduce the size and the weight for transport

Particle/sCO2 Heat Exchanger Design

➢ Particles/sCO2 Heat exchangers: Design optimization – Modular solution



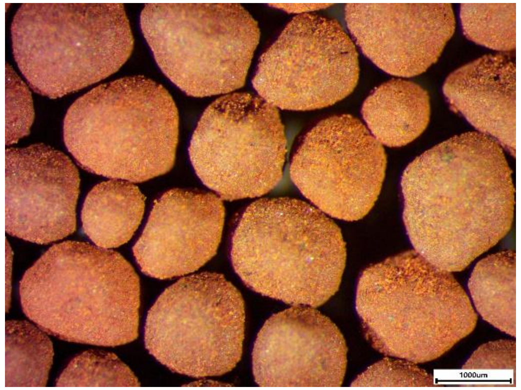


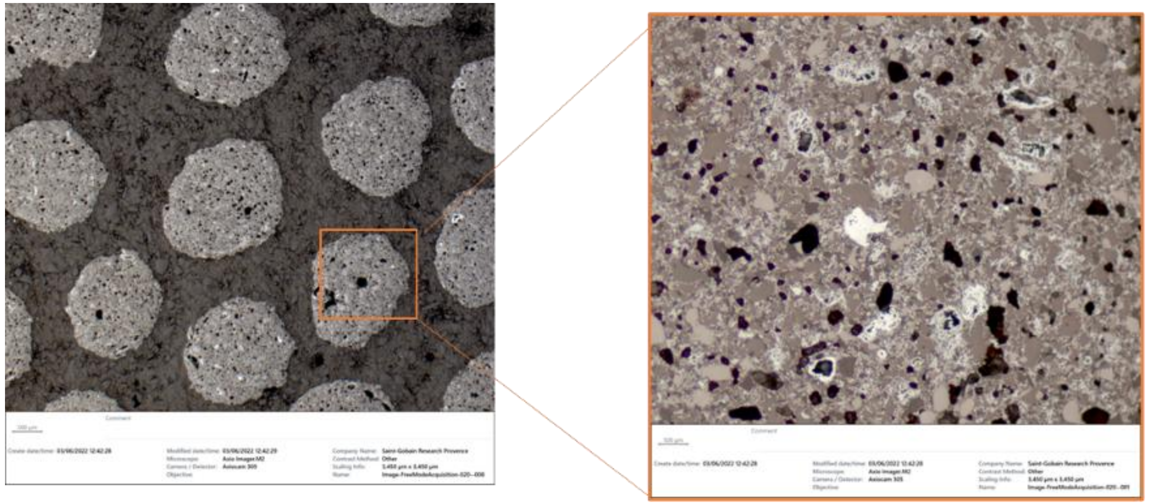


The approximate weight of each module is 133 Tons. The total weight is 1064 Tons

Techno-Economic Assessment

➢ Particles: New development





The best compromise in terms of mechanical and optical properties: Granulated particles GEN4, named FerOX.

Saint-Gobain FerOX compared to state-of-the-art proppants:

- ❑ Similar cost range (~1€/kg) (without coating)
- ❑ Similar mechanical and optical properties
- ❑ Higher or same specific bulk energy density ($\rho_b \cdot c_p \approx$ 2.2 J/(cm³·K) vs. ~1.8…2.2 J/(cm³·K))
- ❑ Higher softening temperature (940°C vs. ~850°C)
- ❑ Better thermal stability (about one order of magnitude lower absorptance loss than proppants during exposure to 1000°C)

Techno-Economic Assessment

➢ HEX Materials: New development & Cost estimation

Bulk Materials

✓ **Ni-based alloys** met the performance requirements

But they are **cost-prohibitive** for enabling broad adoption of large scale CST technologies

✓ **Novel Cr materials** were investigated, attempting to access enhanced performance comparable to, or even above, Ni at lower cost.

Bulk Cr(Fe)-NiAl (developed by project partner University of Birmingham (UoB))

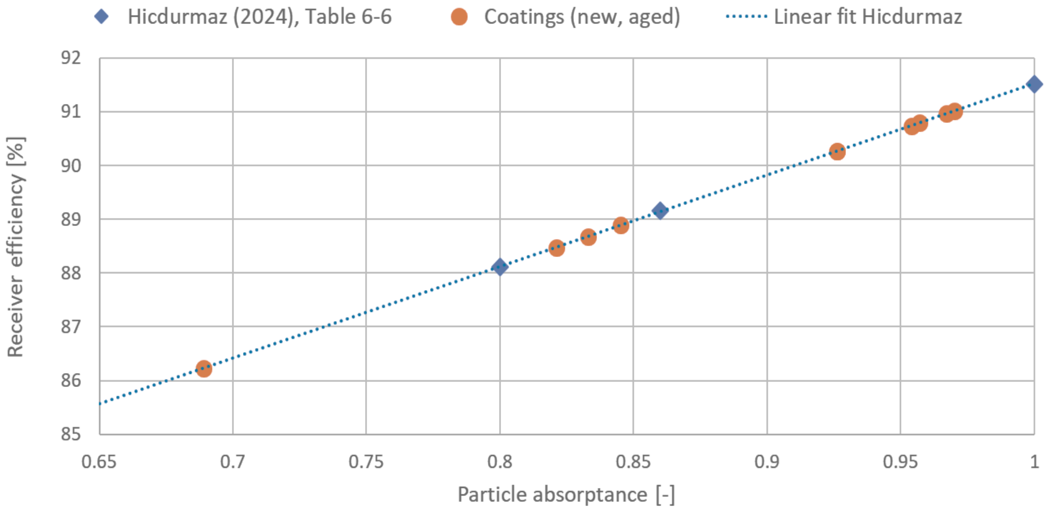
Bulk Cr-Si (investigated by DFI, too brittle at room temperature)

Cr-Si coating (developed by project partner DFI), **estimated cost 750 euro /m^2**

Innovations & contributions of the COMPASsCO2 Project

➢ CSP Plant and LCOE: Parameters

- Particles: SB, FerOx and coated FerOx (all aged)
- Receiver efficiency as function of particle's solar absorptance estimated
- Solar field geometry optimized for minimum LCOE



	SB_a	*FerOx_a*	*Coat_CIE_a*
Case Definition			
Particle type	SB	FerOx	CIEMAT
Particle condition	aged	aged	aged
HEX cost model	JCR	JCR	JCR
Particles c_p [J/(kg K)]	1280	1100	1100
Particles density [kg/m^3]	1850	2000	2000
Particles cost [EUR/kg]	1.00	1.00	1.50
HFLCAL results			
Tower height [m]	134.4	128.9	123.8
Receiver aperture area [m^2]	44.75	45.43	47.65
Heliostat field η_{dp} [%]	63.5	63.5	63.6
Heliostat field η_a [%]	53.9	54	54.2
Receiver η_{dp} [%]	86.9	89.2	90.9
Receiver η_a [%]	84.7	86.9	88.5

Innovations & contributions of the COMPASsCO2 Project

CSP Plant and LCOE: Main Results

- *FerOx_aged* vs. *SB_aged:*
  - cost savings in the solar field due to the higher absorptance => efficiency
  - higher cost of particles inventory due to the particles' lower heat capacity
  - virtually unchanged LCOE (+0.6 %)
- *CoatingCiemat_aged* vs. *FerOx_aged*:
  - coating leads to increase in absorptance and thermal efficiency
  - savings in solar field cost far exceeded by cost increases for the particle inventory
  - Slightly higher LCOE (+2.4 %)

	SB_a	*FerOx_a*	*Coat_CIE_a*
Subsystem costs [MEUR]			
Heliostat field	104.6	101.9	99.8
Land	10.2	10.0	9.7
Towers	22.5	21.2	19.9
Receiver	21.5	21.8	22.9
Vertical transport	11.8	13.2	12.8
Horizontal transport	6.2	7.3	7.3
HEX	73.0	73.0	73.0
Particle inventory	28.2	32.8	49.3
TES containment	15.6	16.4	16.4
Power block	146.2	146.2	146.2
Total direct cost	439.9	443.9	457.4
Indirect costs	138.4	139.6	144.0
Overnight costs (CAPEX)	578.3	583.5	601.4
Annual electricity [GW_e h/a]	576.2	577.0	578.0
LCOE [EUR-cent/(kW_e h)]	**8.32**	**8.36**	**8.56**

Summary

- ✓ Brayton cycle for highest efficiency selected (not necessarily lowest LCOE)
- ✓ Boundary conditions for particle/sCO_2 HEX defined
- ✓ State-of-the-art materials for particle/sCO_2 HEX selected
- ✓ Novel materials for harsh environment (high pressure, temperature, corrosion, erosion) identified & first cost estimated
- ✓ Assessment of HEX design, manufacturing, transportation & assembly constrains
- ✓ Overall plant techno-economic assessment

Lessons learned & challenges

- ✓ The materials and components developed, namely the particle/sCO2 heat exchanger, the ceramic particles and the novel Cr-alloys and coatings seem to be at cost levels similar to current alternatives. Nevertheless, further improvements regarding performance and costs are recommended.
- ✓ Higher solar absorptance of new particles can be more beneficial for falling curtain receiver types than cavity.
- ✓ These new materials have been designed to withstand extreme conditions under which state-of-the-art materials may not be able to perform during long-term operation.
- ✓ Regardless of the very high efficiency, a clear commercial advantage of the solar sCO_2 Brayton power plant, cannot be identified. Cycles with lower efficiency and lower LCOE could be more interesting.
- ✓ Further research and development work to optimize production methods and costs would be needed to make the technology competitive
- ✓ Regarding the world market, CSP is currently facing very strong competition from other technologies such as solar PV. CSP plants still have the advantage of low-cost & large capacity thermal storage.
- ✓ Other applications such as CST for high-temperature process heat can be interesting for some of the components developed

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THANK YOU

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