R&D activities on sCO$_2$ in Europe: Components Challenge – Expanders

5th episode – 28 September 2023

This webinar is in cooperation with 9 European R&D projects

COMPASsCO_2

SCARABEUS

iSOP

$CO_2OLHEAT$

sCO_2-4-NPP

CARBOSOLA

DESOLINATION

SOLAR sCO_2OL

sCO_2-Efekt

Webinar content & speakers

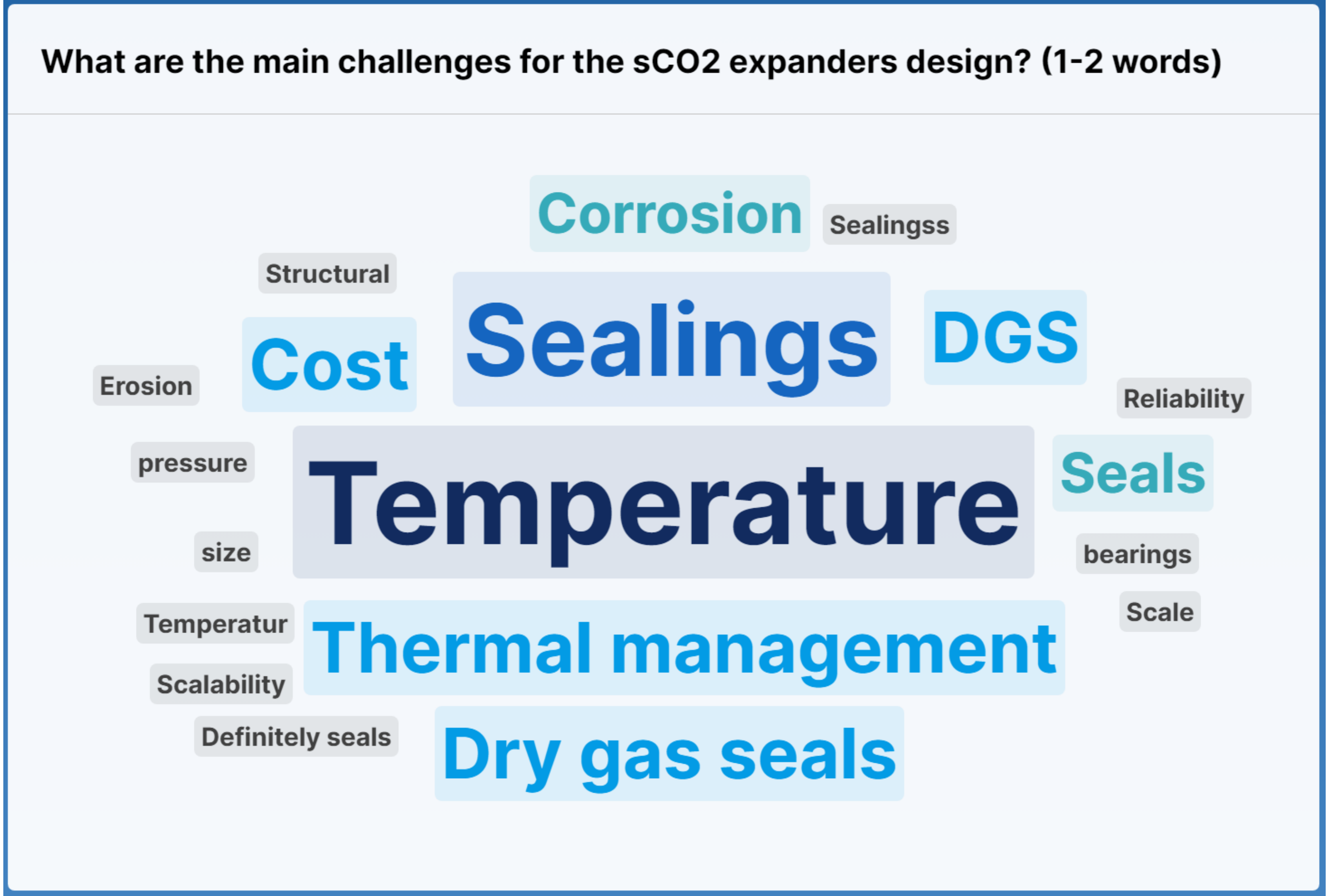
- **Which boundary conditions for CO_2 turbines?** (Alberto Traverso – University of Genoa)

- **Expander stage of an sCO_2 Compander for 2 MW output power** (Markus Sauerborn – Atlas Copco)

- **Benefits and design challenges of axial sCO_2 turbines** (Stefan Glos – Siemens Energy)

- **Baker Hughes Design Experience with unfired Expanders** (Andrea Paggini – Baker Hughes)

Opening Slido question



What are the main challenges for the sCO2 expanders design? (1-2 words)

Corrosion

Sealingss

Structural

Sealings

DGS

Cost

Erosion

Reliability

pressure

Temperature

Seals

size

bearings

Temperatur

Thermal management

Scale

Scalability

Definitely seals

Dry gas seals

Which boundary conditions for CO_2 turbines?

Prof. Ing. Alberto Traverso

Chair of Energy and Environmental Systems
University of Genoa, Italy

Presentation outline

- sCO2 application panorama

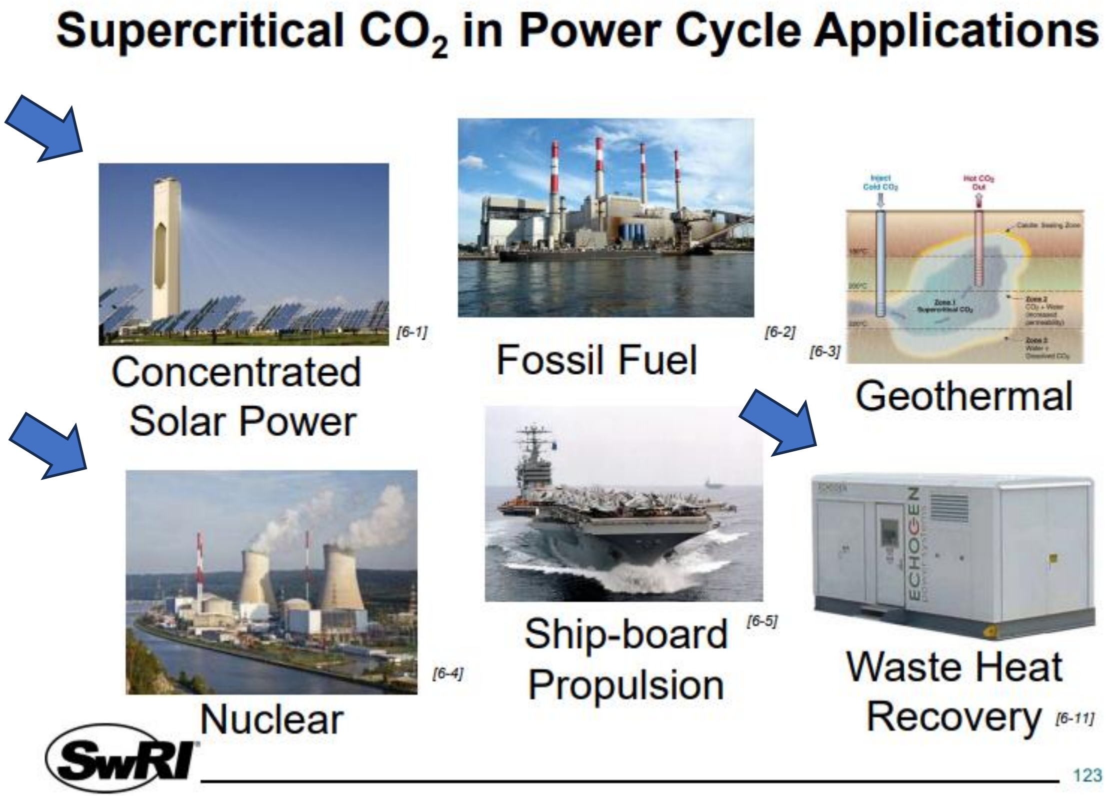
- Turbines for CSP plants
- Turbines for Waste Heat Recovery plants
- Turbines for Nuclear power plants

- One outlier turbine

- Turbines for Energy Storage application
- Two-phase sCO2 nozzles

- Summary conclusions

sCO2 cycle potential applications



Supercritical CO_2 in Power Cycle Applications

Concentrated Solar Power [6-1]

Fossil Fuel [6-2]

Geothermal [6-3]

Nuclear [6-4]

Ship-board Propulsion [6-5]

Waste Heat Recovery [6-11]

SwRI

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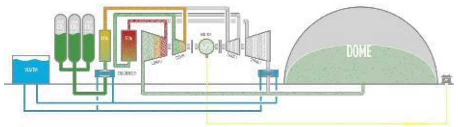


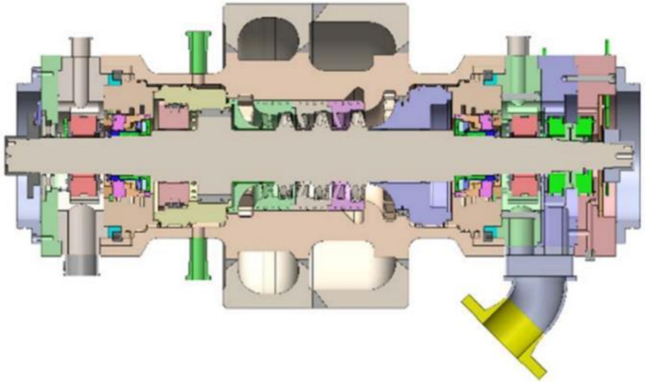
Energy storage

CO2 refrigeration

Jason C. Wilkes, Fernando Karg Bulnes, Aaron M. Rimpel, Rob Pelton, Fundamentals of Supercritical CO2, ASME2022 Tutorial of Basics

The STEP project, US (supercritical transformational electric power)

A schematic of the 16 MW (gross) sCO2 turbine (27,000 rpm)



The turbine casing was fabricated from IN 625 for cost and schedule reasons, as well as an unfavorable experience with HA282 casting (the predecessor SunShot project).

Figure 12 –Turbine Casing – fabricated IN 625

Single piece Nimonic 105 multi-stage STEP turbine rotor

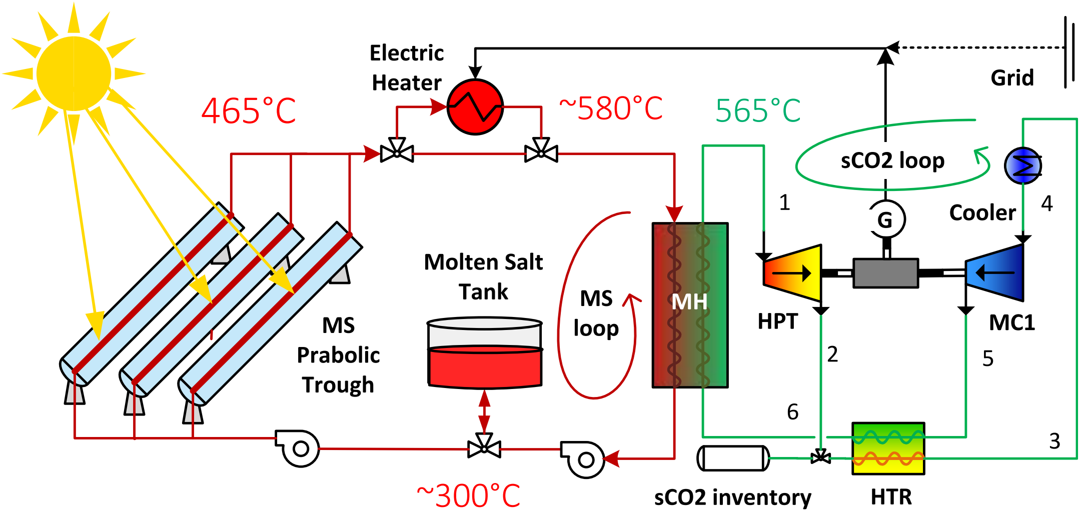
Figure 11 –Turbine Nozzles for each stage

https://www.gti.energy/step-demo/step-demo-resources/

A critical risk is the short distance from the high **temperature inlet at 715°C** to the seal/bearing locations, limited to 200°C.
Inlet and outlet pressures are **250bar** and 92bar, respectively.

The SOLARSCO2OL demo project in EU (SOLAR based sCO2 Operating Low-cost plants)

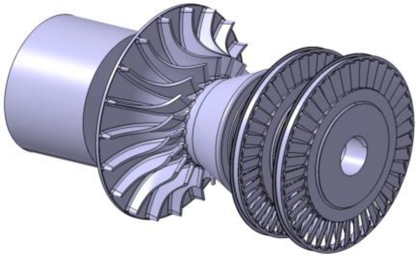
Plant integration and demonstration will occur at Evora (PT) large sscale CSP facility, with a gross power of 2MWe



MS hot side tie

Turbine (FTM)

- 2,000 kW, 30,000 rpm, **185.5 bar, 565°C**
- 3 stages: 1 radial, 2 axial (up-scaling 10 MW)
- Rotor: length 790 mm, shaft Ø 76 mm
- Blades Ø: 115 mm (axial), 150 mm (radial)



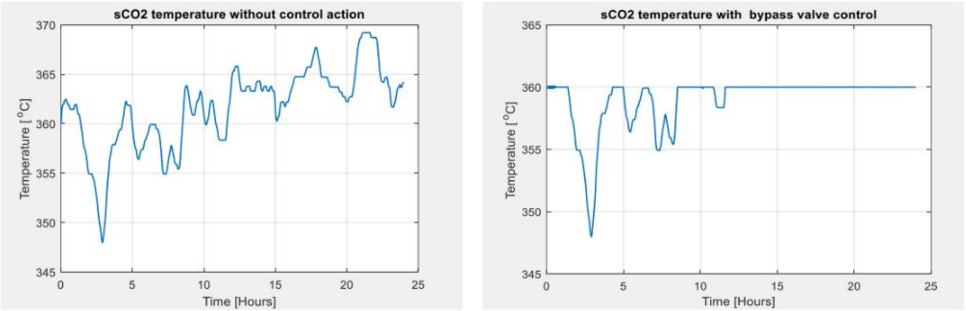
FRANCO TOSI MECCANICA

https://www.solarsco2ol.eu/

The CO2OLHEAT project in EU (Supercritical CO2 power cycles demonstration in Operational environment Locally valorising industrial Waste HEAT)

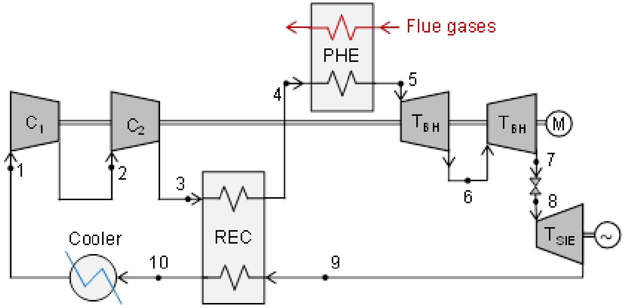
The project focuses on Waste Heat Recovery through sCO2 cycles in Resource and Energy Intensive Industries.

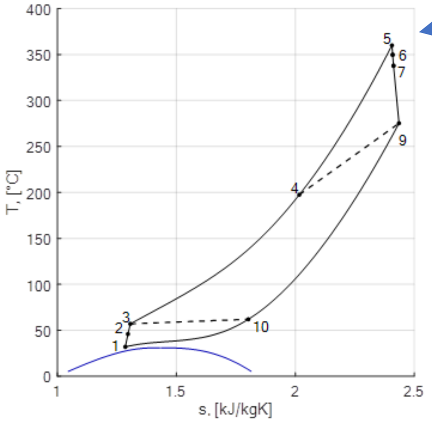
Target: development and demonstration of a 2MW highly flexible sCO2 WH2P power block with a heat source T>400˚C and efficiency η>23%



(a) (b)

Figure 12 – Dynamic simulation of sCO2 temperature at the Primary Heat Exchanger outlet (a) non-controlled system ; (b) controlled system.





TIT<400°C

Turbine boundary conditions are in the mild-range, allowing the use of low grade steel material. Pressures are anyway in the supercritical region.

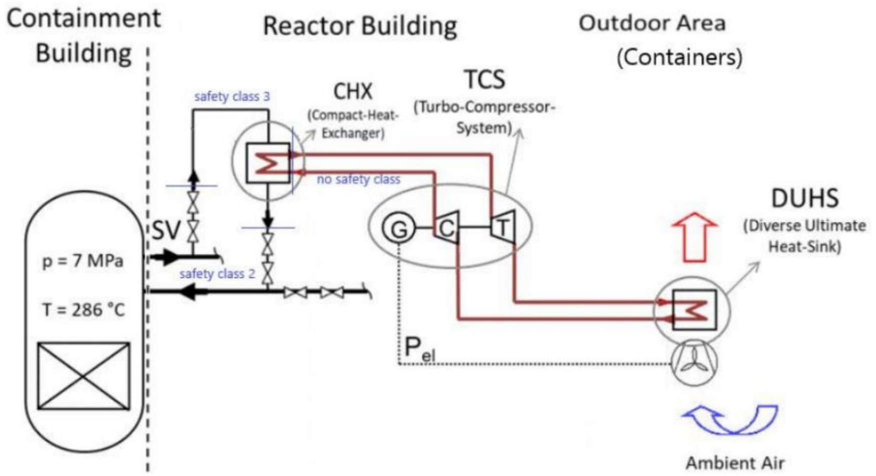
https://co2olheat-h2020.eu/wp-content/uploads/2022/03/D5.1.pdf

Alfani et al., Proceedings of the 5th sCO2-EU

Nuclear

The sCO2-4-NPP project in EU (Innovative sCO2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants)

The project focuses safety of Nuclear Power Plants (NPP), targeting the development of a sCO2 backup cooling system, attached to the principal steam-based cooling system, to considerably delay or eliminate the need for human intervention (>72 hours) in case of accidents such as station blackouts.



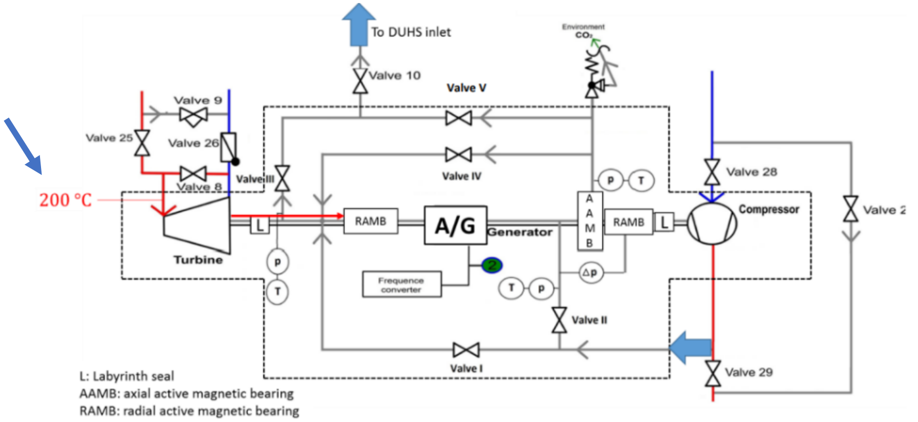
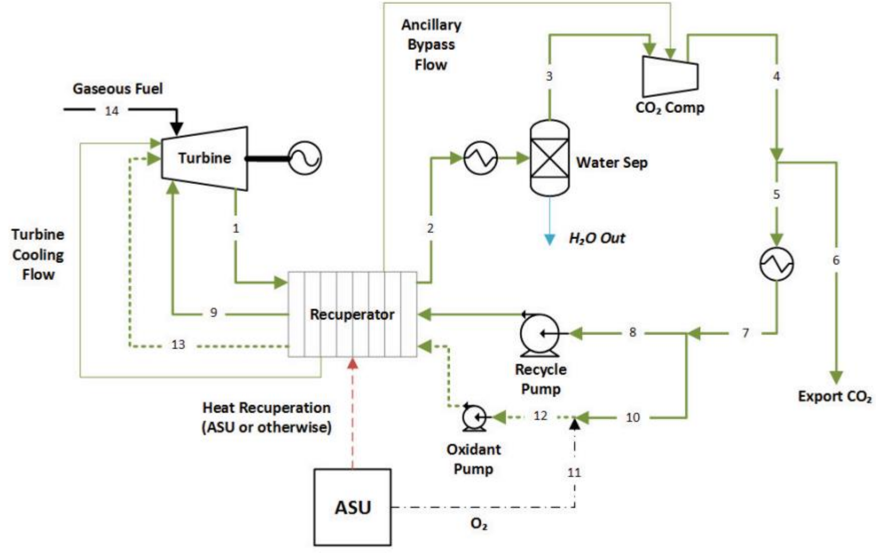


Figure 27: P&ID diagram of the additional cooling system

https://www.sco2-4-npp.eu/wp-content/uploads/sCO2-4-NPP_D4.3_Conceptual_Design_of_sCO2_4_NPP_Turbomachine_R1.0.pdf

Outlier: the ALLAM cycle by NET power

The Allam cycle is an oxy-fuel combustion cycle that utilizes hydrocarbon fuels while inherently capturing approximately 100% of atmospheric emissions, including CO2



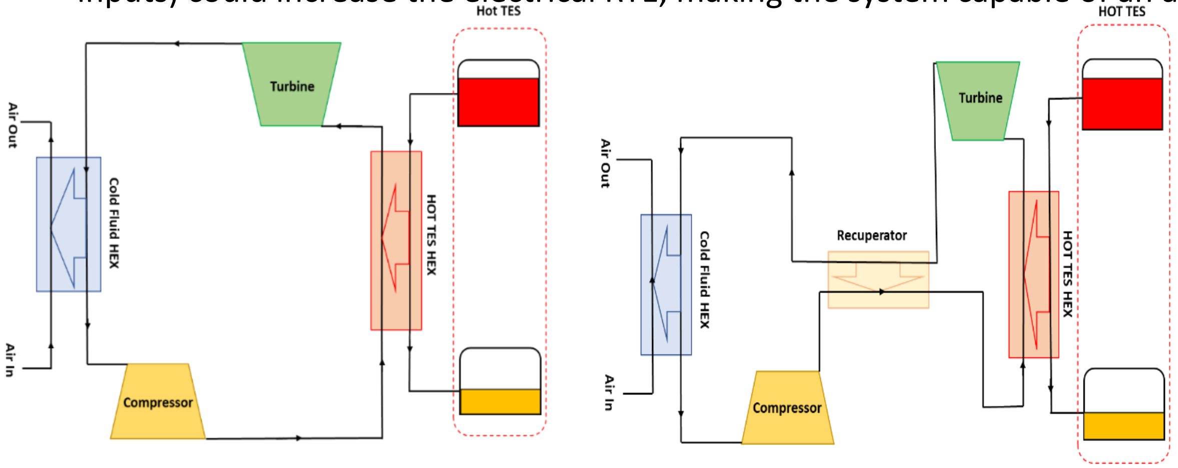
The cycle operates with a single turbine that has an inlet pressure of approximately **300 bar** and a pressure ratio of 10.

Inlet temperature 1150°C
Outlet temperature >700°C

Recuperator role is key in achieving the target performance

The Carnot-Battery concept based on sCO2 cycles

sCO2 heat pumps and power cycles could reduce PTES concept CAPEX, particularly via reversible and flexible machines. Furthermore, the possibility to exploit freely available heat sources (such as waste heat and/or CSP inputs) could increase the electrical RTE, making the system capable of an apparent RTE > 100%



TIT<450°C

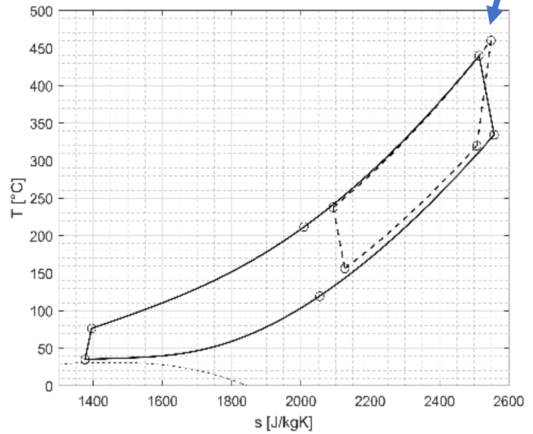
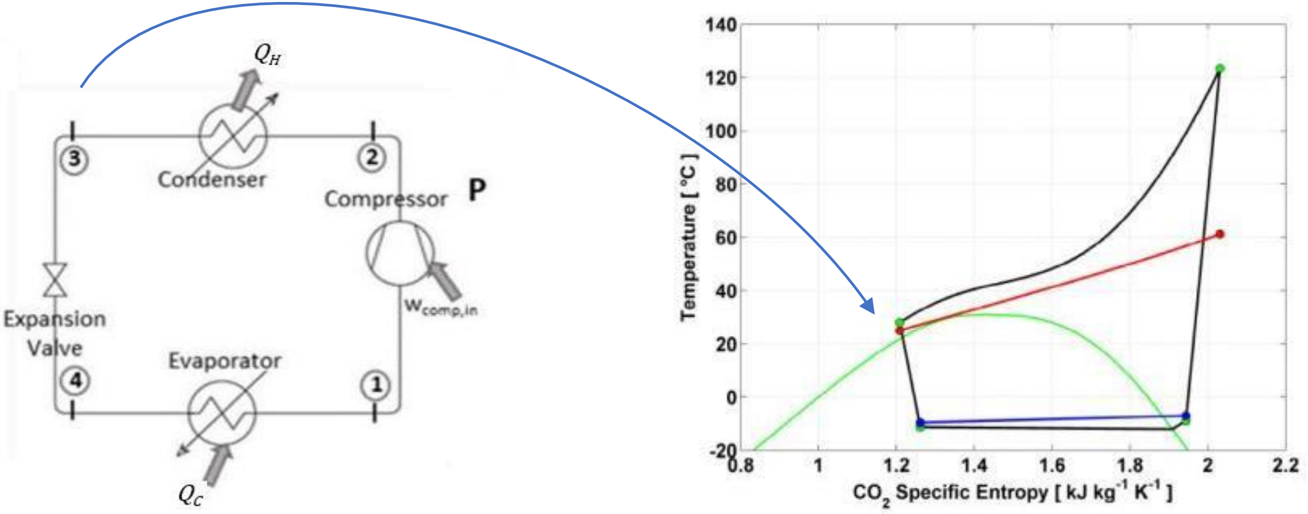


Figure 3. Discharging cycle configurations: (**a**) simple discharge cycle and (**b**) recuperated discharging cycle.

S. Barberis, S. Maccarini, S.S.M. Shamsi, A. Traverso, 2023, "Untapping Industrial Flexibility via Waste Heat-Driven Pumped Thermal Energy Storage Systems", Energies, Vol. 16(17), pp. 6249.

CO2 two-phase nozzles modelling

Two-phase CO2 nozzles, starting supercritical, are currently being used in CO2-based chillers and heat pumps



Example of thermodynamic cycle of a CO2-based heat pump (trans-critical).

External heat sources are highlighted with red and blue lines. An ejector or turboexpander could be placed at point (3).

CO2 two-phase nozzles modelling

The speed of sound in two-phase flows is much lower than in single-phase flows.

A convergent-divergent nozzle must be used to achieve high speeds. ***They are used in ejectors and two-phase turbine!***

Phenomena related to two-phase fluids make modeling these nozzles complex.

The phenomena to be considered for modeling are mainly three:

- ***slip***: speed difference between phases.
- ***friction***: Use of complex experimental correlations to determine friction.
- ***metastability***: rapid expansion can result in a metastable phase that modify the evolution of the pressure profile.

M. de Lorenzo, Ph. Lafon, J. M. Seynhaeve, and Y. Bartosiewicz, "Benchmark of Delayed Equilibrium Model (DEM) and classic two-phase critical flow models against experimental data," International Journal of Multiphase Flow, vol. 92, pp. 112–130, 2017.

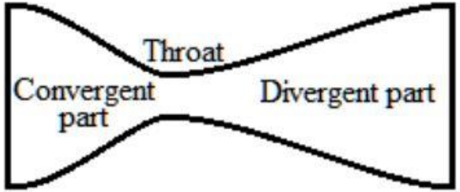
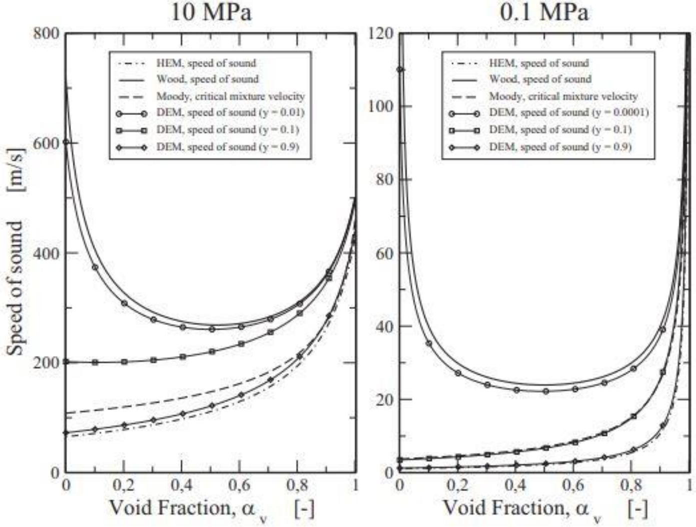


Figure 4: convergent-divergent nozzle.



Speed of sound in two-phase conditions with different modeling approaches.

New correlation for critical CO2 flow rates

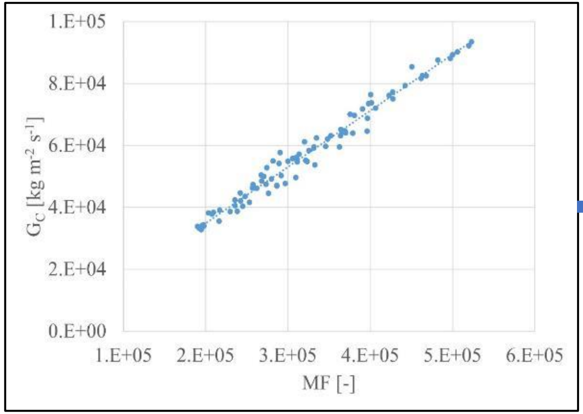


Figure 10: relation between MF and critical mass flux Gc.

$$MF = \left(\frac{\Delta T_{SAT-ISO}}{T_{crit}}\right)^a \left(\frac{\Delta P_{SAT-ISO}}{P_{crit}}\right)^b \left(\frac{F}{P_{crit}}\right)^c \left(\frac{E \cdot \mu_{crit}}{P_{crit}}\right)^d$$

$$G_C = n \cdot MF + G_{C\_0}$$

Coverage factor: 95%

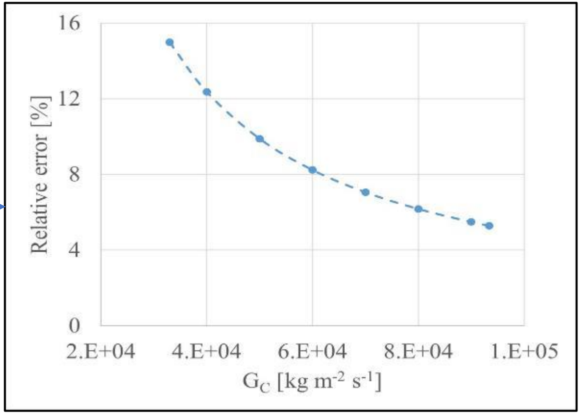


Figure 11: relative error of Gc.

- The linear regression between MF and G_C must not only be as accurate as possible but also meet the assumptions of ***homoscedasticity and normality***. Maximum accuracy was sought by maximizing the value of R^2 regression parameter.
- ***In the validation range, the error is in the range ±15%*** *(higher the lower the flow rate, i.e. the closer to the liquid saturation line)*

Table 1: correlation values after the optimization.

Parameter	Value	Unit
a	-0.301532	[-]
b	0.371195	[-]
c	0.147544	[-]
d	-0.411644	[-]
n	0.181921791	[kg m^{-2} s^{-1}]
G_{C_0}	-1564.972	[kg m^{-2} s^{-1}]

M. Ferrando, A. Traverso, V. Sishtla, 2023, "A new statistical approach to identify critical mass flow rate in CO2 nozzles near saturation conditions", International Journal of Refrigeration, Vol. 149, pp. 181-191.

4. Summary conclusions

- sCO2 cycles for **power production** require high performance turbines (**up to 715°C and 250bar**)
- **WHR applications or Carnot-battery** cycles require mild performance turbines (up to **450°C and 200bar**)
- Nuclear applications are in the low temperature range (**<300°C**)

- For fossil fuel oxy-combustion, a semi-closed cycle has been proposed (Allam cycle) involving a cooled turbine with inlet conditions in the order of **1150°C and 300bar.**

- CO2 in supercritical or transcritical cycles are nowadays in commercial use for **refrigeration cycles** in mid-to-large applications (e.g. supermarkets), requiring detailed engineering for **two-phase flow** management in ejectors or expanders.

- **Boundary conditions for sCO2 turbines** are much more **application-dependent** than sCO2 compressor boundary conditions

Thank you!

Università
di Genova

Expander stage of an sCO_2 Compander for 2 MW output power

Markus Sauerborn
Aerodynamics & Process Development
Atlas Copco Gas and Process, Germany

This is the Atlas Copco Group

- Customers in more than **180** countries
- **49 000** employees in **70** countries
- Established in **1873** Stockholm, Sweden
- Turnover of **141** BSEK/ **13** BEUR*
- Operating margin of **21.4%**

*Based on the average exchange rate in 2022.

Atlas Copco Gas & Process

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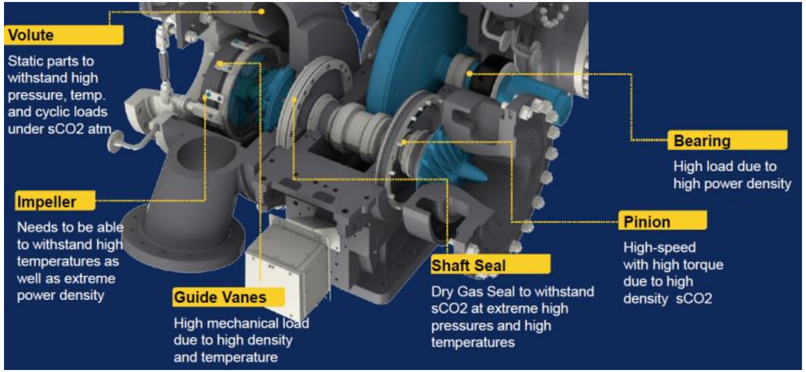
sCO2 Component Challenge

Leveraging decades of experience in CO2 handling for the next phase of sCO2 turbomachinery evolution



Volute

Static parts to withstand high pressure, temp. and cyclic loads under sCO2 atm.

Impeller

Needs to be able to withstand high temperatures as well as extreme power density

Guide Vanes

High mechanical load due to high density and temperature

Shaft Seal

Dry Gas Seal to withstand sCO2 at extreme high pressures and high temperatures

Pinion

High-speed with high torque due to high density sCO2

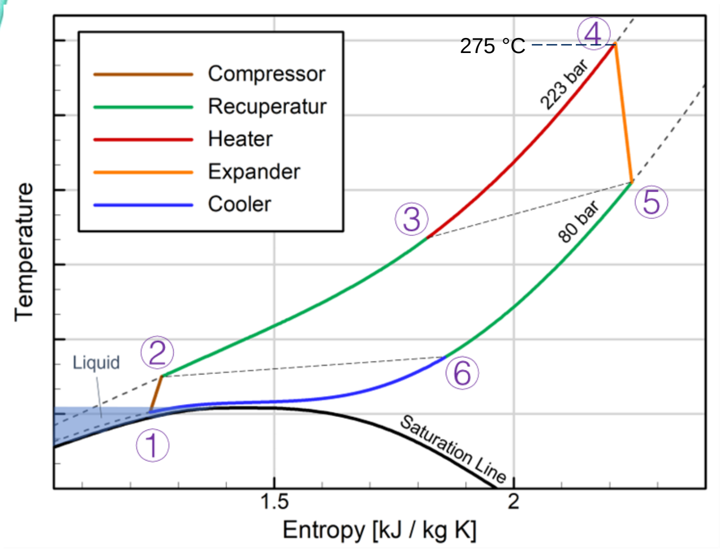
Bearing

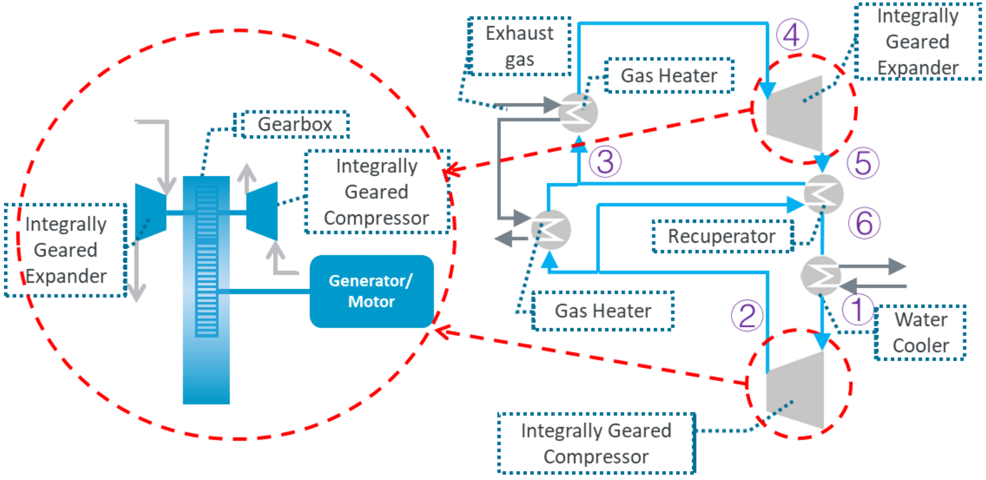
High load due to high power density

Year Ordered	Compressor Type	Q'ty	Gas Handled	Volume m^3/h	t1 °C	P1 bar(a)	P2 bar(a)	Speed Rotors rpm	Driver Power kW	Driver Speed rpm
2013	GT040T8S1	2	CO_2	21 999	45	1,06	202	18 034 32 461 36 068 37 455	5 150	2 960

sCO2 Compander (2018)

Waste heat recovery cycle and machine design

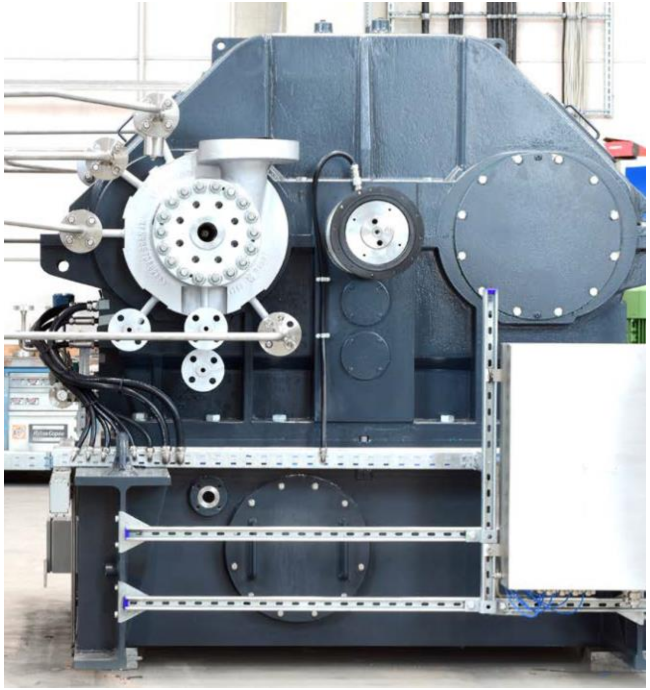




sCO2 Compander

Integrally geared design

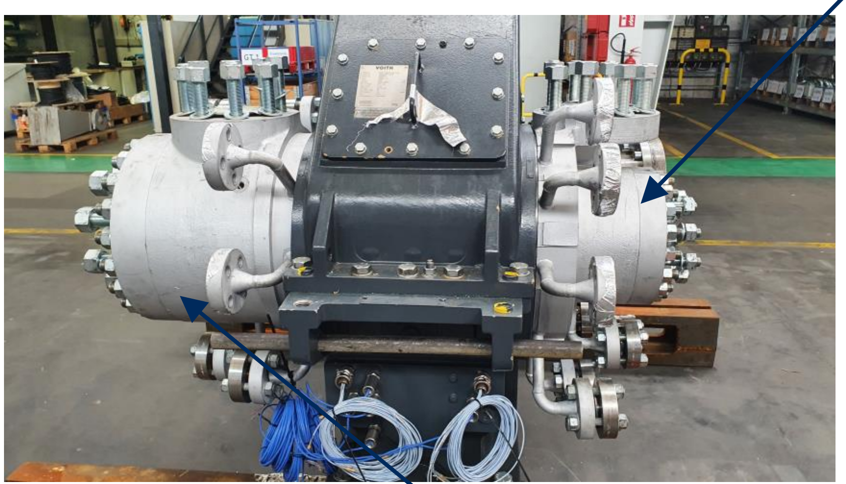
Expander stage

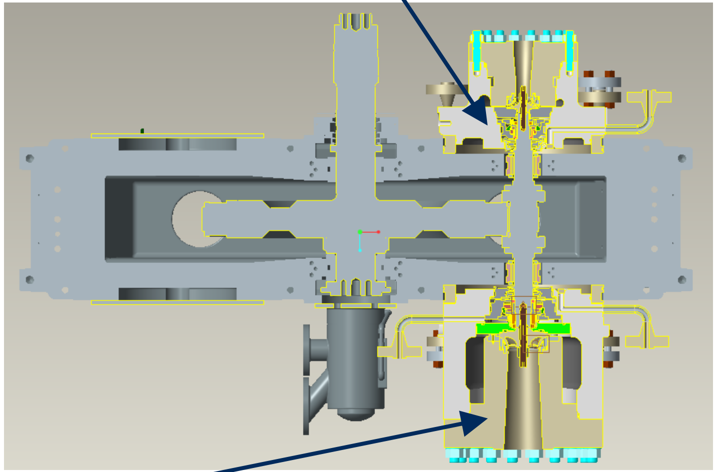


Compressor stage

sCO2 Compander

single pinion back-to-back arrangement



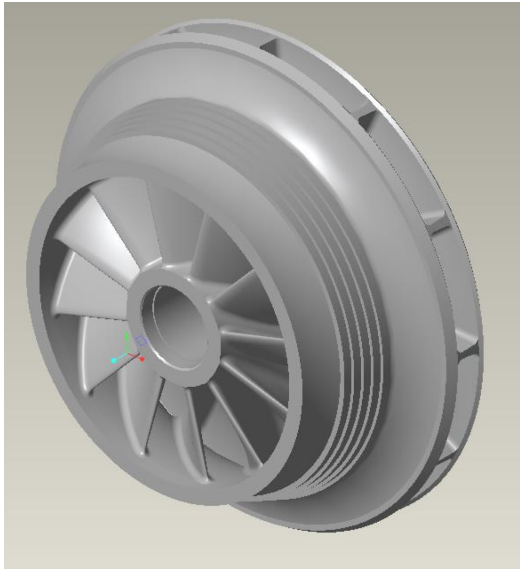


Compressor

Expander

sCO2 Expander stage

Aerodynamic design parameters

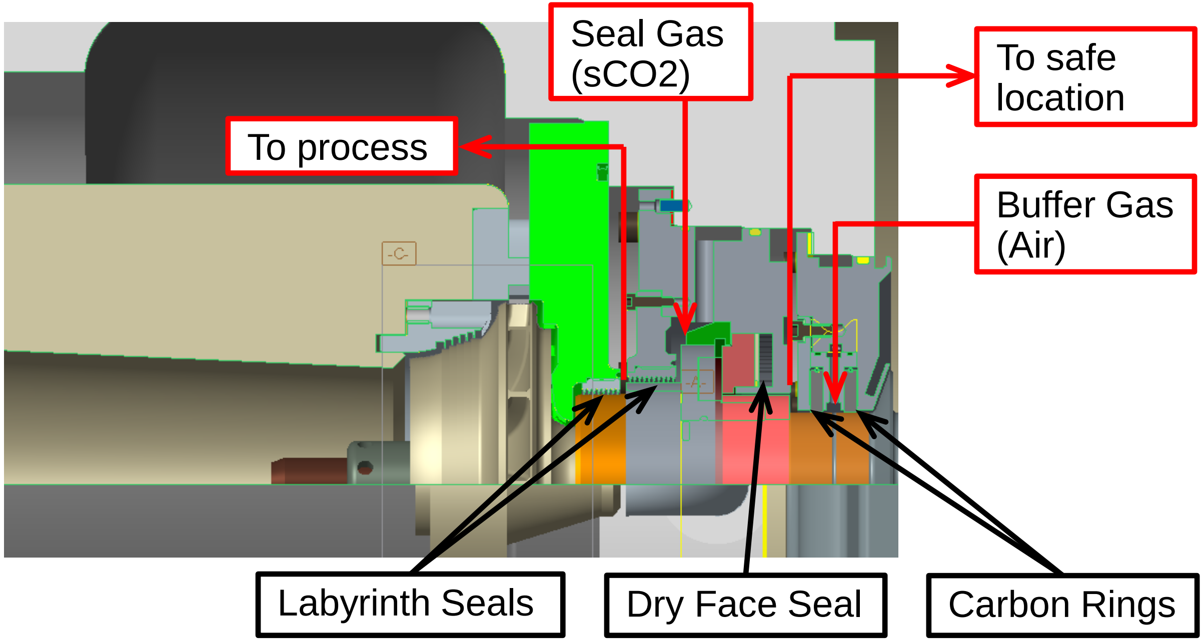


Impeller type		**centrifugal, shrouded**
Shaft sealing		labyrinth, dry face seal, carbon rings
Impeller outer diameter	mm	150
Speed	rpm	38000
Mass flow	kg/h	174600
Inlet pressure	bar	220
Inlet temperature	°C	275
Outlet pressure	bar	82
Expander power	kW	3528

- Gas property package: NIST/Refprop

Shaft sealing

Labyrinth - Dry Face Seal – Carbon ring



Seal Gas (sCO2)

To process

To safe location

Buffer Gas (Air)

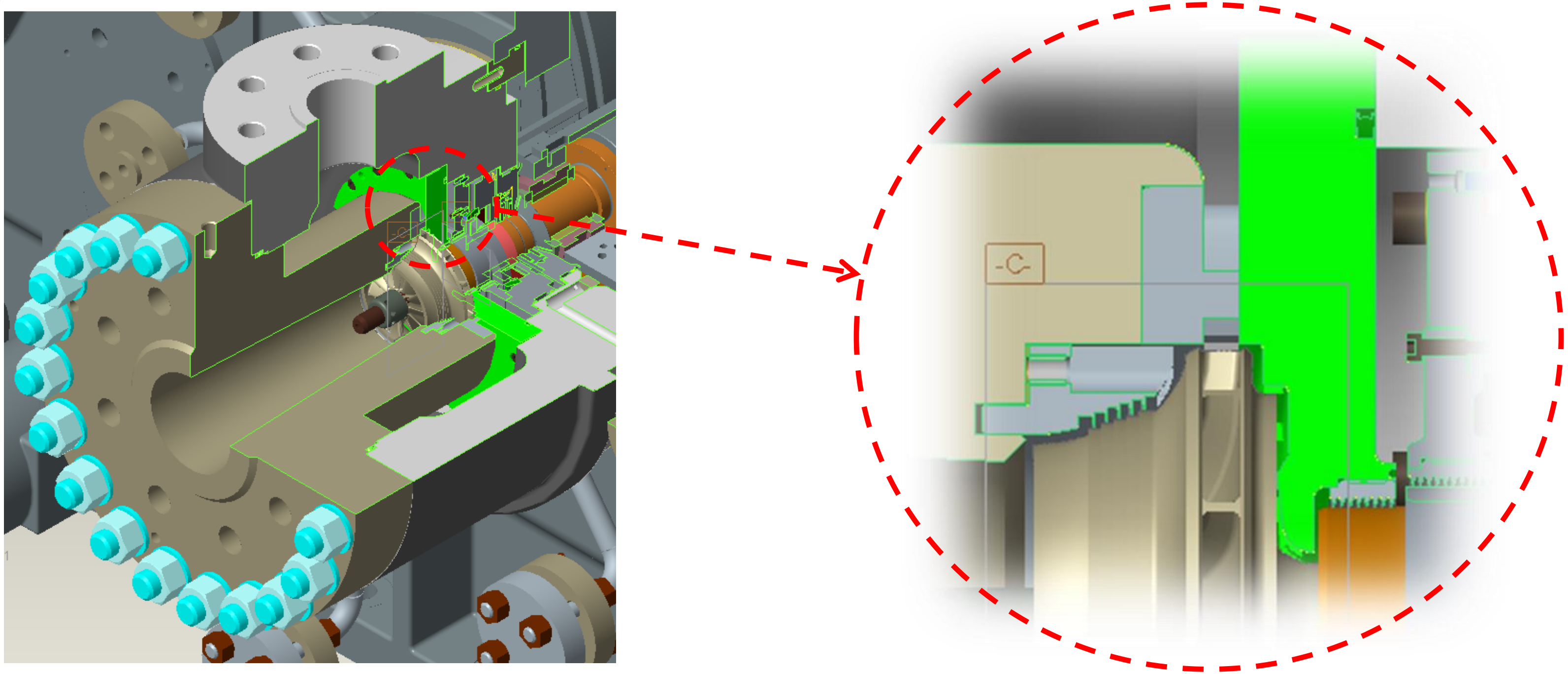
Labyrinth Seals

Dry Face Seal

Carbon Rings

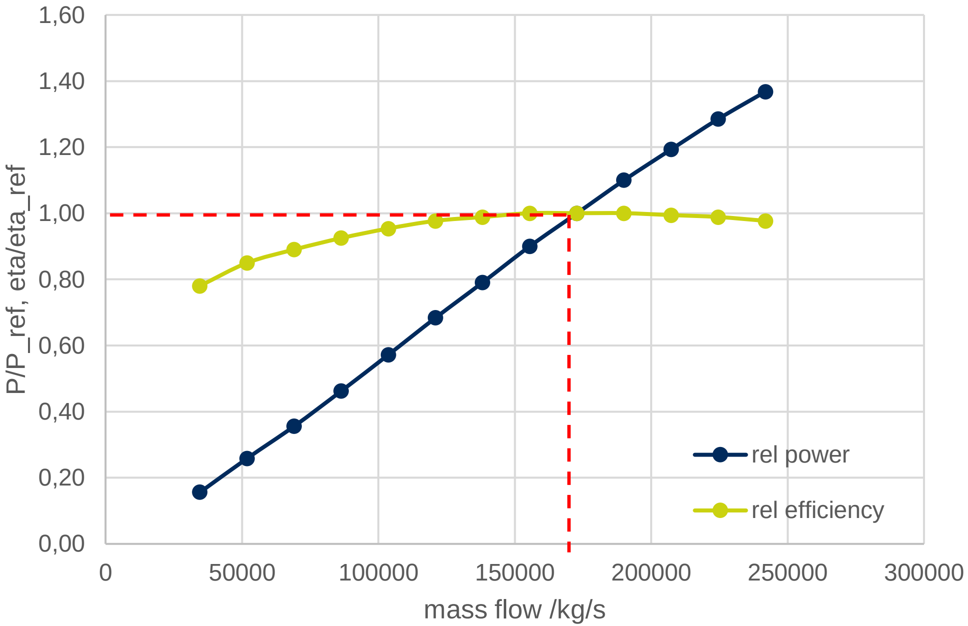
Nozzle ring (IGV)

fixed design - optional adjustable design for flow control



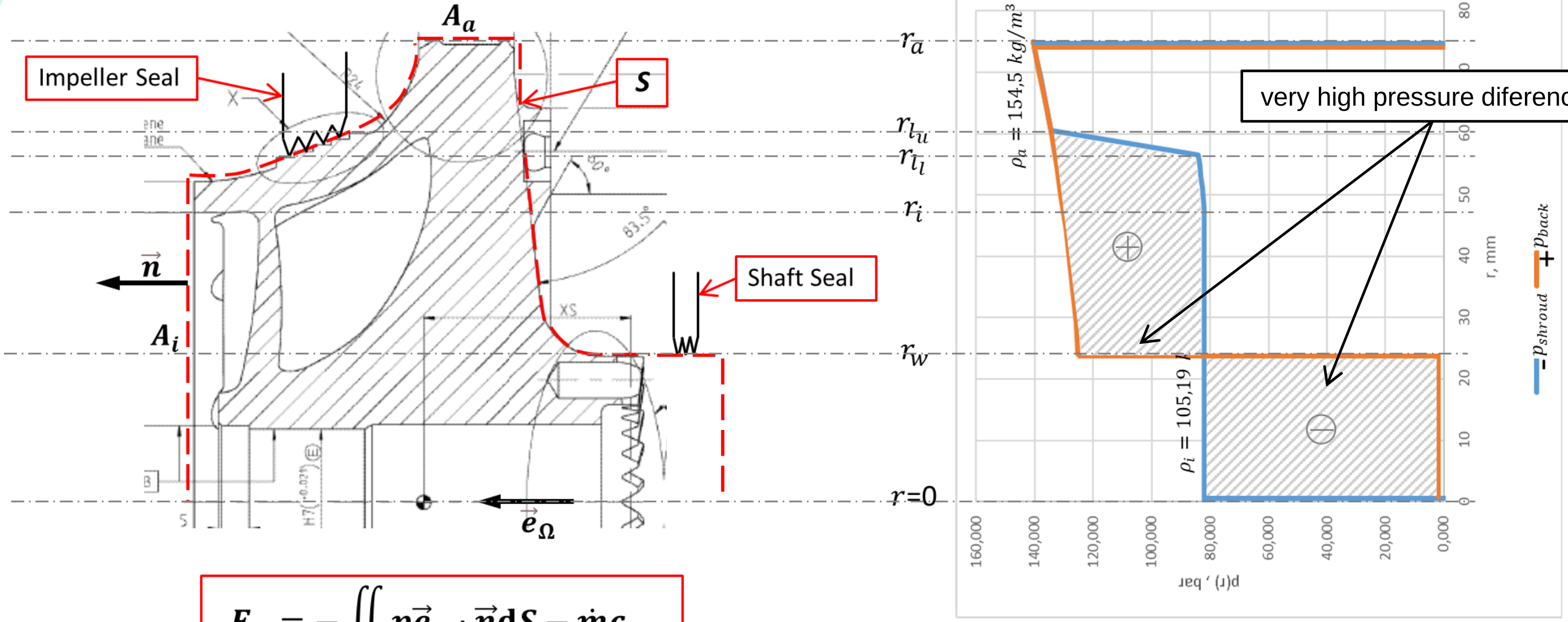
Flow control – adjustable nozzles

expander performance @adjustable IGV



Axial thrust

pressure distribution shrouded impeller

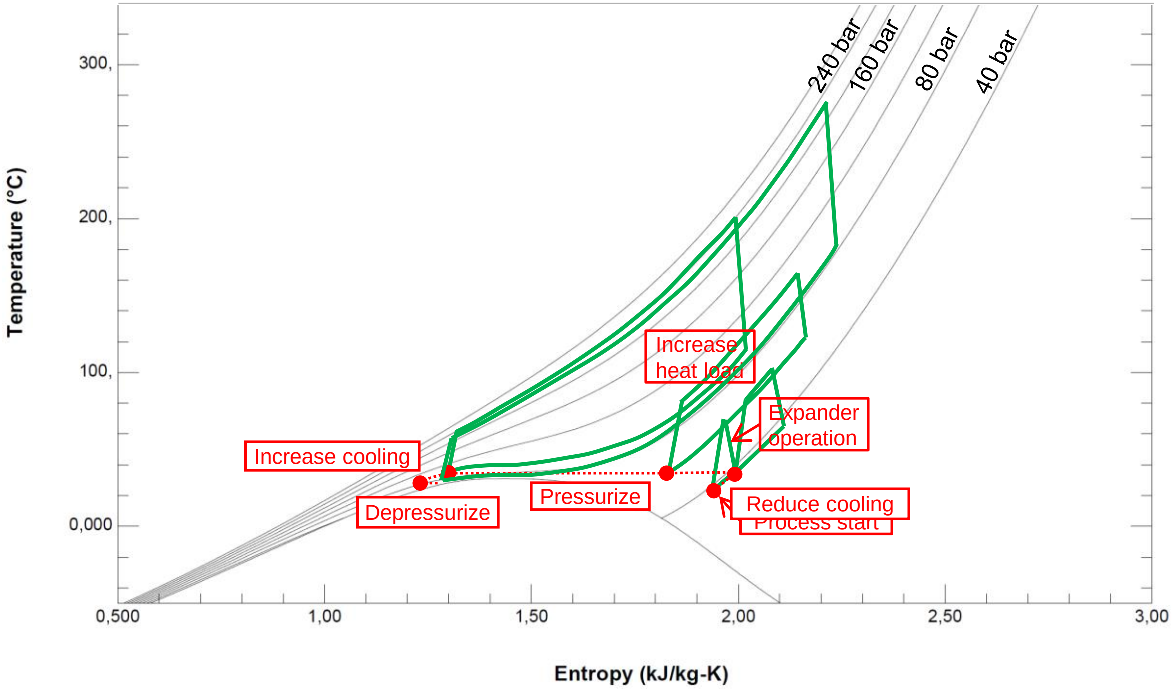


very high pressure diference!

$$F_\Omega = -\iint_S p\vec{e}_\Omega \cdot \vec{n}\,\mathrm{d}S - \dot{m}c_{\Omega i}$$

Start-up and controls

from gaseous to supercritical



Summary & Conclusion

- Long term experience in CO2 handling allows for the next phase of sCO2 turbomachinery evolution
- sCO2 expander as part of a compander for 2 MW output power developed and order awarded in 2018
- Challenges and solutions in regards to aerodynamics, shaft sealing, axial thrust and process controls presented
- First in the commercial market machine delivered.

Thank you!

Markus Sauerborn

markus.sauerborn@atlascopco.com

Benefits and design challenges of axial sCO_2 turbines

Stefan Glos

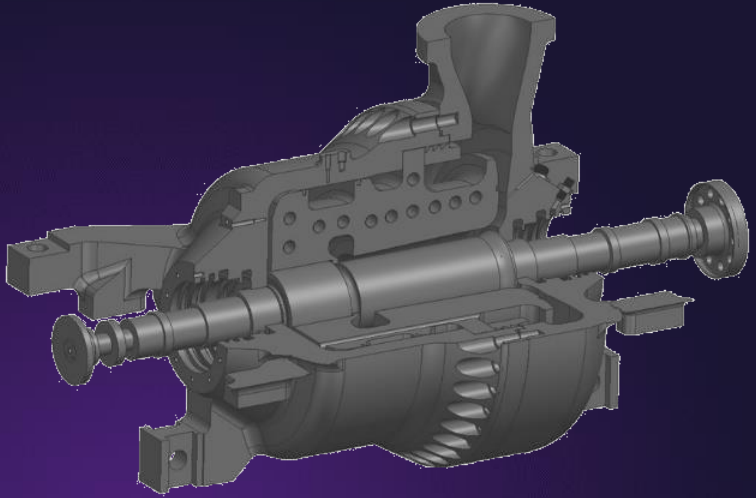
Siemens-Energy, Germany

Agenda

- **Basic Considerations**
  - **Why sCO_2 ?**
  - **Basic working priciples and impact on turbine design**
    - Impact of pressure losses & windage heating
  - **Application range for (axial) sCO2 turbines**

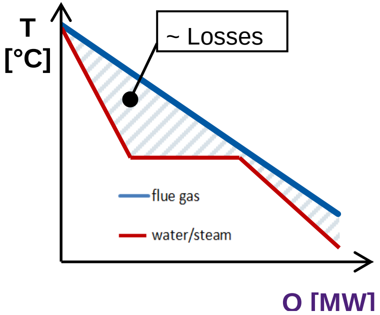
- **2 MW turbine design for a demo plant**
  - **Design study**
    - Mechanics
    - Optimization of inlet aerodynamics
    - Sealing integration

- **Summary**

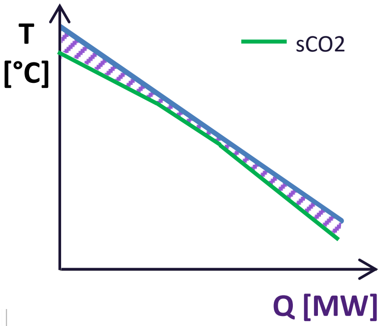


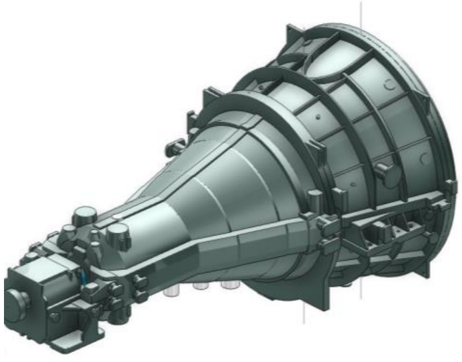
Why sCO2 ?

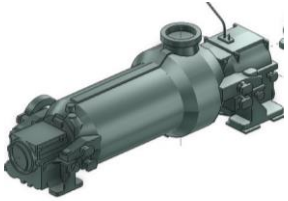
Water/Steam



sCO_2





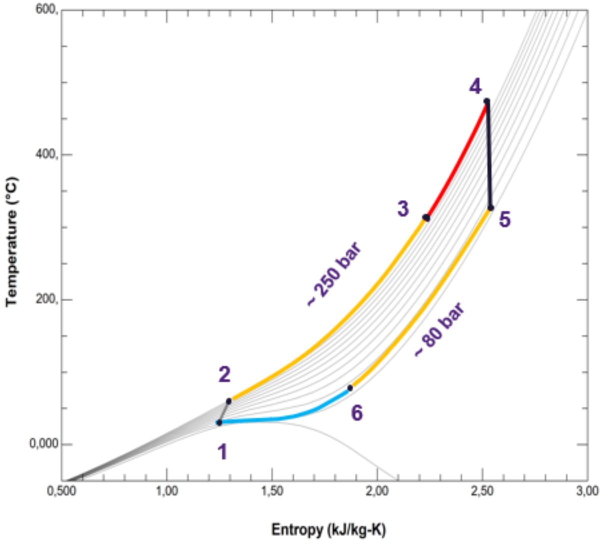


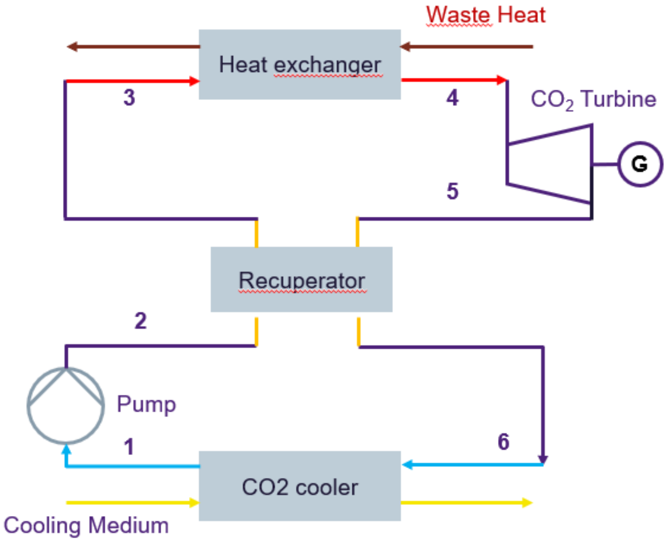
36 MWel WHR solution developed within CARBOSOLA project

Potential Benefits

- Higher efficiency compared to water/steam
  - → Depending on heat source, power output and heat sink temperature
- High energy density leads to smaller turbines & footprint
- Lower LCOE compared to water/steam
  - → Depending on heat source, power output and heat sink temperature
- Non-hazardous fluid (not flammable/explosive/toxic)

sCO2 working principles
Impact on turbine design

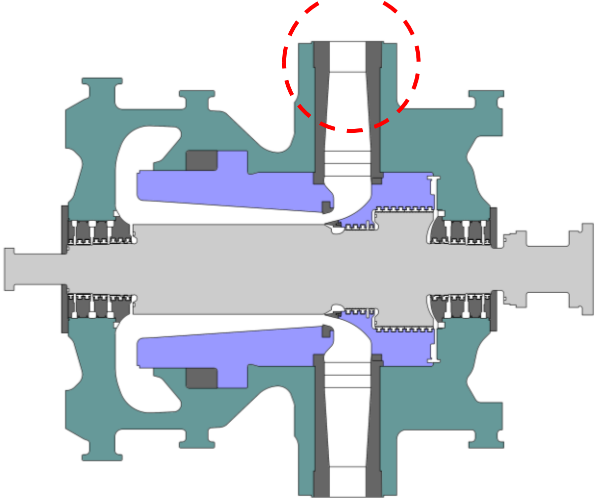


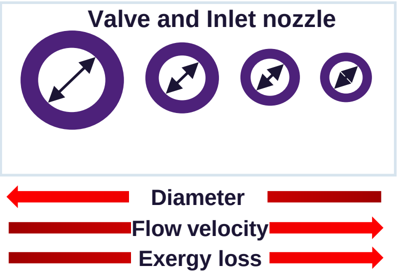


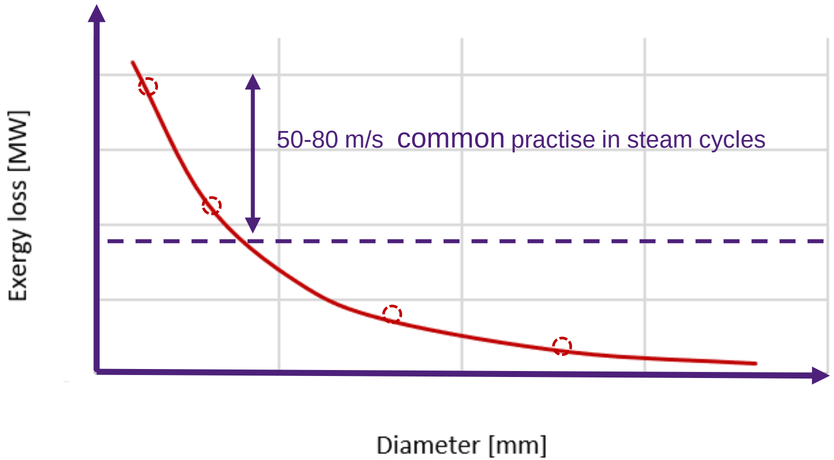
- High pressure level (~250-300bar) → Turbine topology, mechanical design
- Backpressure turbine (~ 60-90 bar) → Operational concept (start-up, low load,…), sealing technology
- Low Δh but high Δp → High mass flow, few stages, robust air foils, internal leakages..
- High fluid density → Aerodynamics, rotormechanic &-dynamics

Impact of pressure losses

Inlet flow optimization





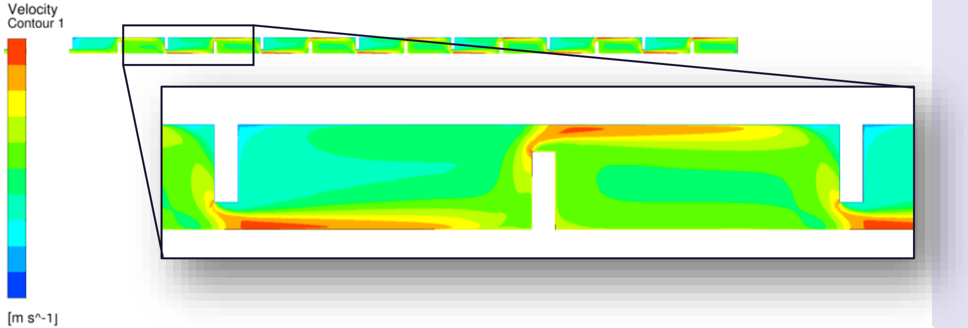


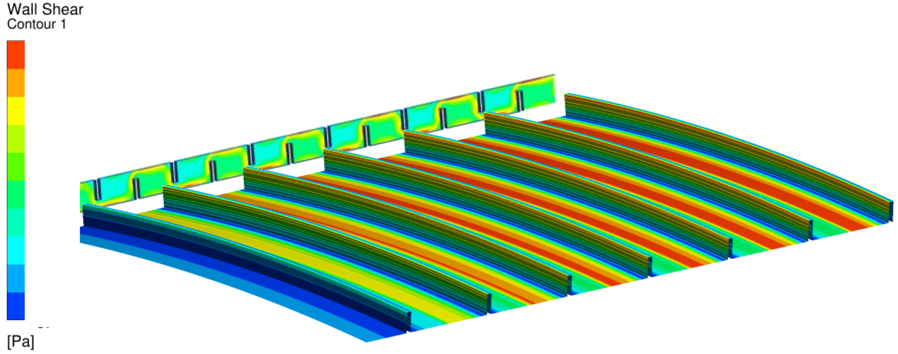
→Performance sensitive to pressure losses

→Thermo-economic optimization will lead to larger flow diameters than known from conventional steam cycles

Leakage and windage heating effects

Labyrinth seal flow physics



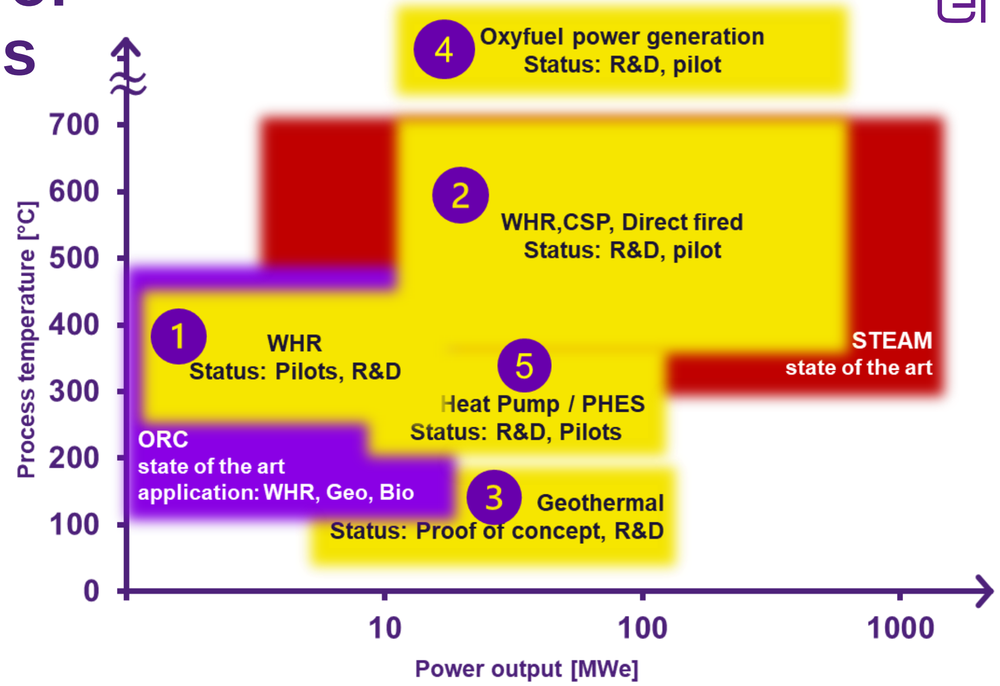


- Pressure difference and density drives mass flow $\dot{m}$
- Circumferential wall shear τ at rotating shaft is reason for fluid heat up Δh_t

$$\boldsymbol{\tau} = \text{Const.} \cdot \text{Re}^{-0.2} \times 0{,}5\, \boldsymbol{\rho}\, \boldsymbol{w}^2$$

- Temperature increase in labyrinth seals to be considered in mechanical design
- Especially important for high temperature applications

Application range of axial sCO_2 turbines

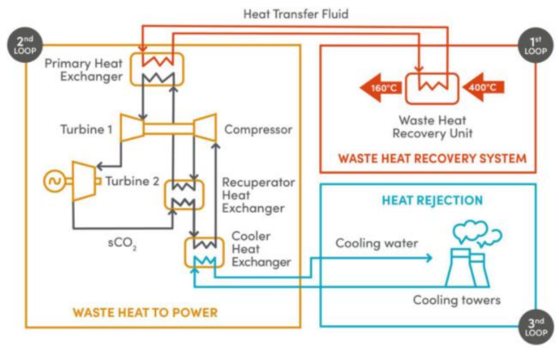


Turbine Type	Radial turbines		
		Axial turbines	
Speed [rpm] / di [mm]	~ 10000 / 160	~ 3000/ 400	~ 3000/ 700

2

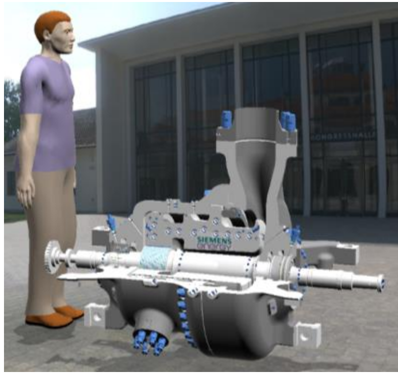
Unit Scaling
2-100 MW

Turbine Performance
Up to 92%

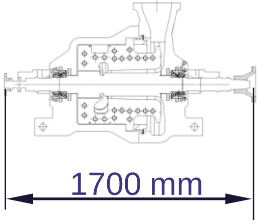


Large-Scale Industrial Waste Heat Recuperation with axial sCO$_2$ Turbine

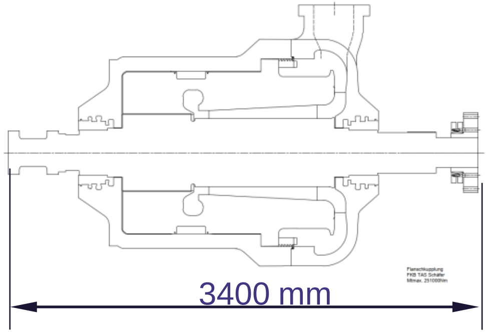
- **Adapting barrel-type turbine design** for high temperatures and pressures, i.e. **high efficiencies**
- Realization and validation of **2 MW demo application** within EU funded project **CO2OLHEAT** *)
- Design **scalable to large power output** for different types of applications



2 MW Demo sCO$_2$ turbine



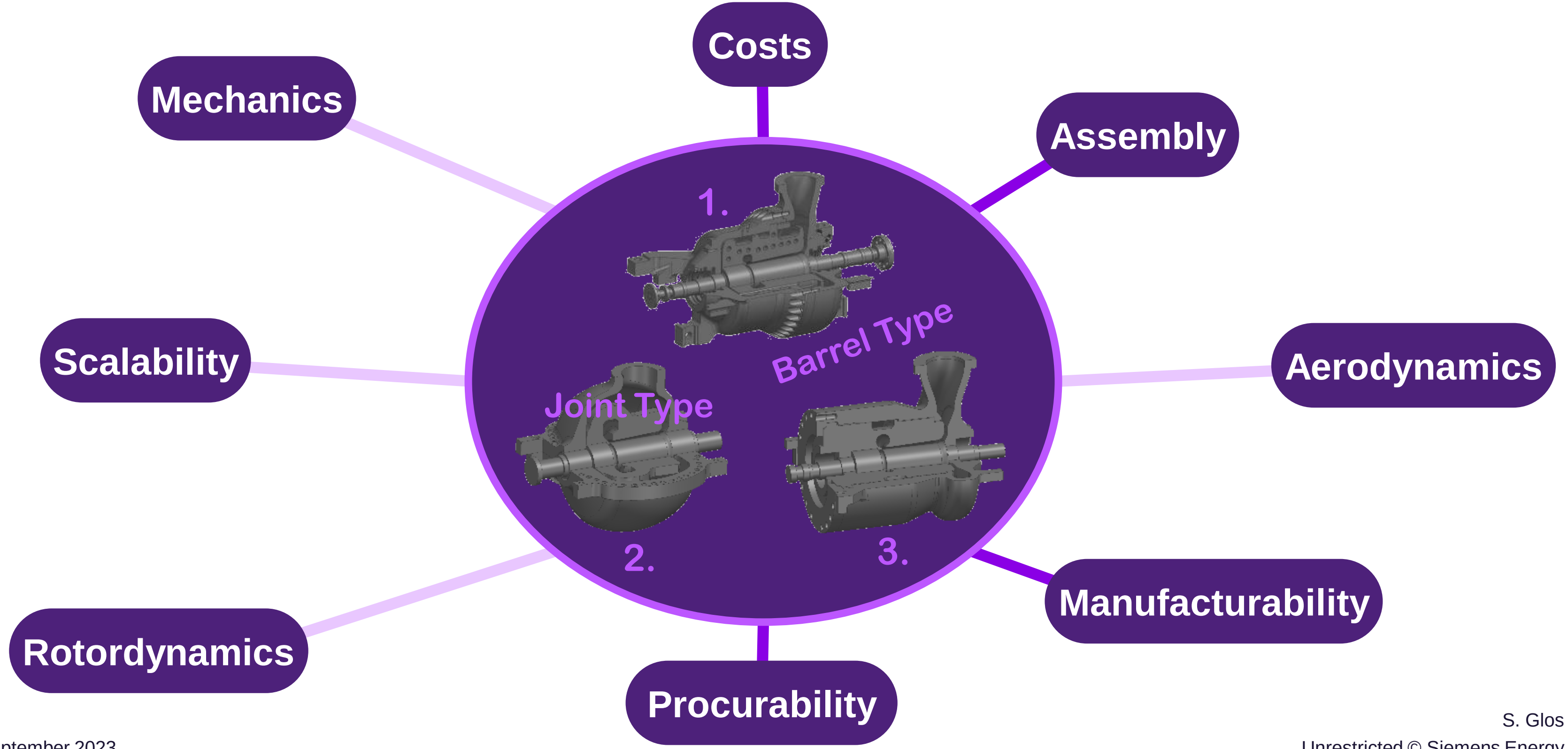
Upscaled 50 MW sCO$_2$



*) This project has received funding from the European Union’s Horizon 2020 research and innovation programme under GA n. 101022831

Turbine Design

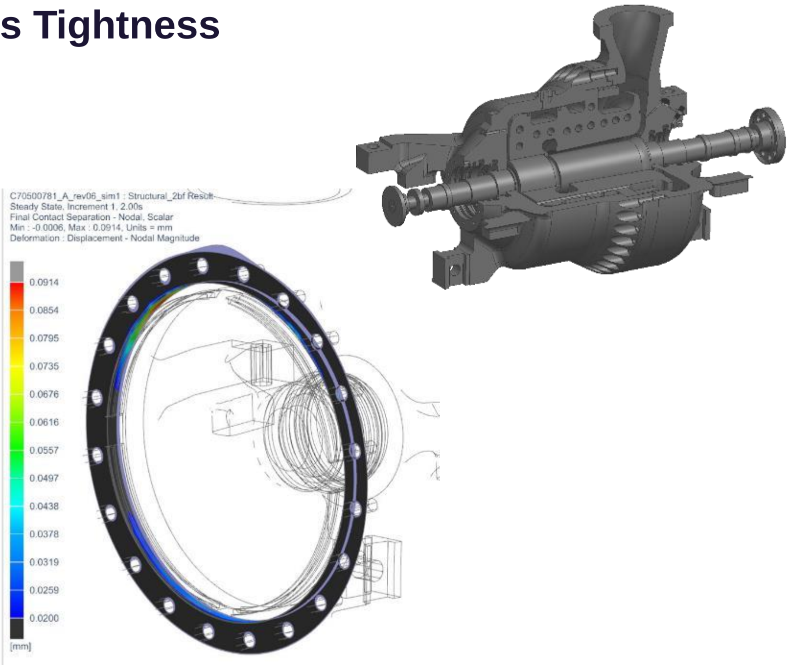
Decision Criteria

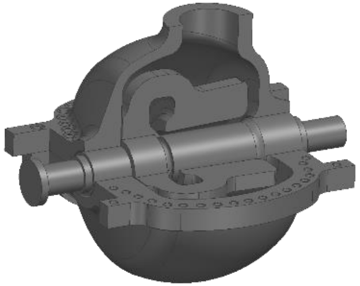


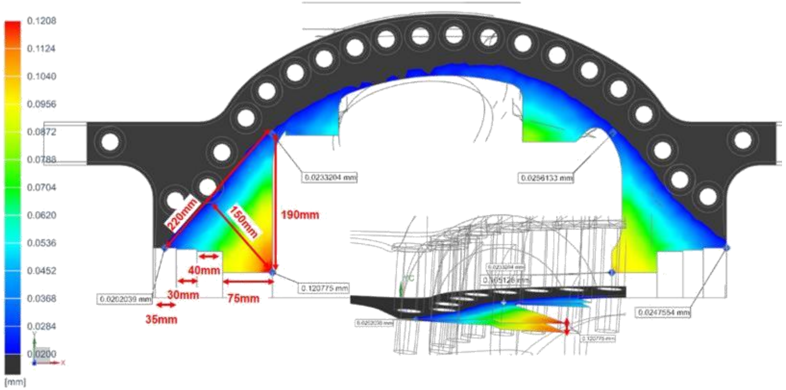
Turbine Design

Mechanical – Casing Deformation

Gas Tightness



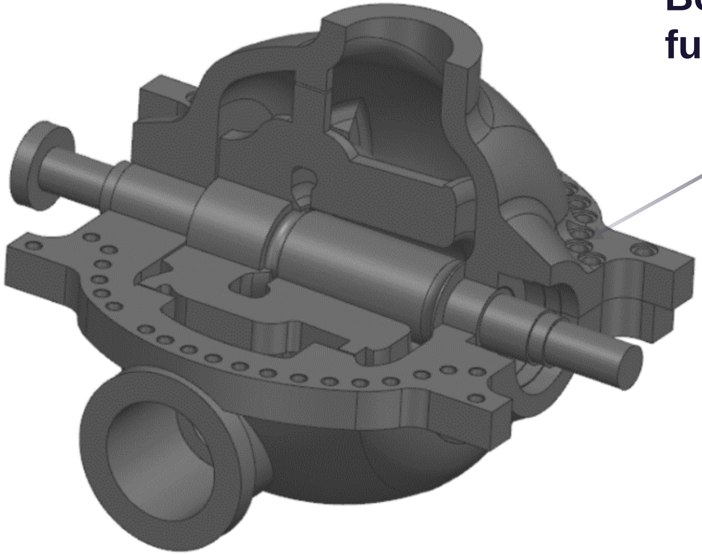




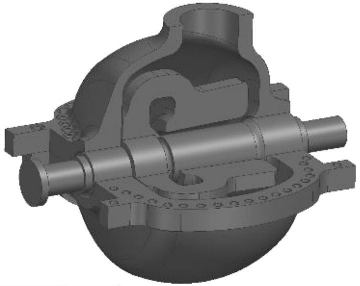
Half Joint leaking for joint type, due to high pressure (90 bar) and large dry gas seals

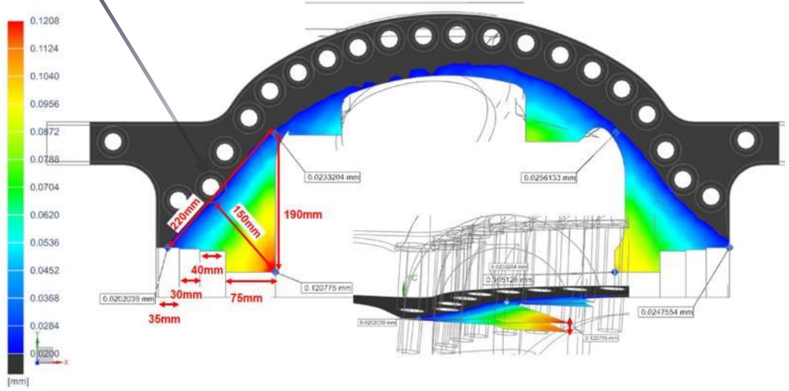
Turbine Design
Mechanical – Casing Deformation

Steam Tightness



Bolts cannot be moved further inside

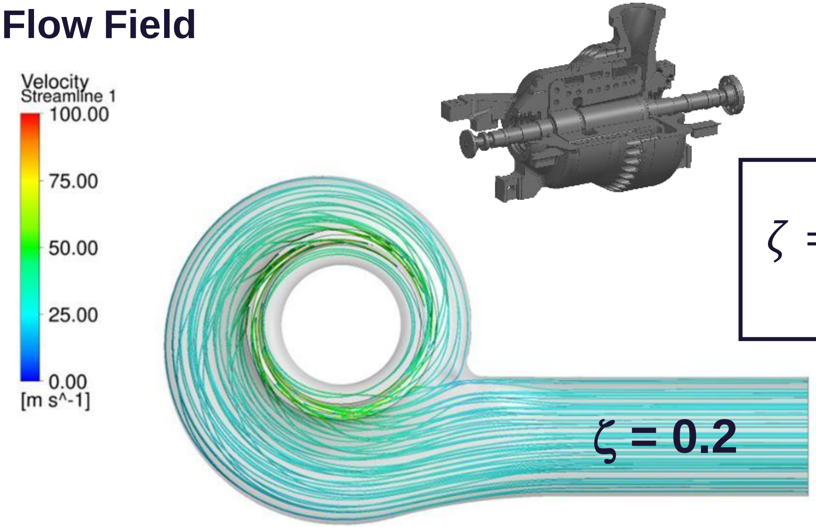




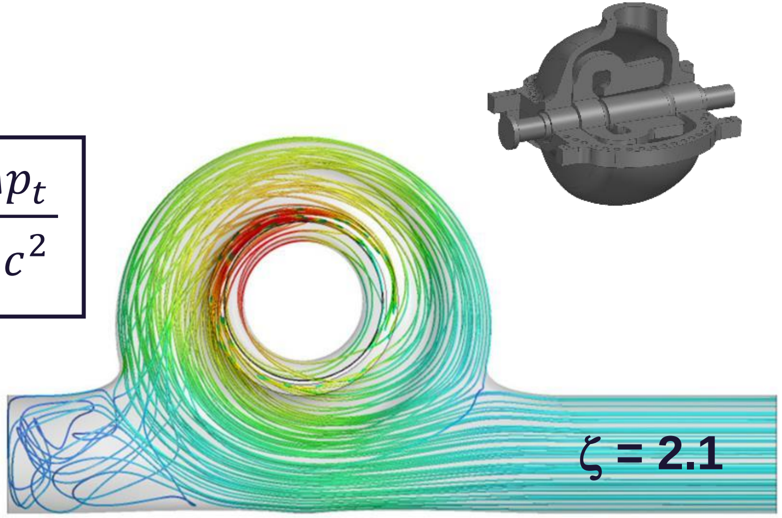
Half Joint leaking for joint type, due to high pressure (90 bar) and large dry gas seals

Turbine Design
Aerodynamics Part 1 – Inlet Flow

Flow Field



$$\zeta = \frac{\Delta p_t}{\frac{\rho}{2} c^2}$$



- Very homogeneous flow velocities

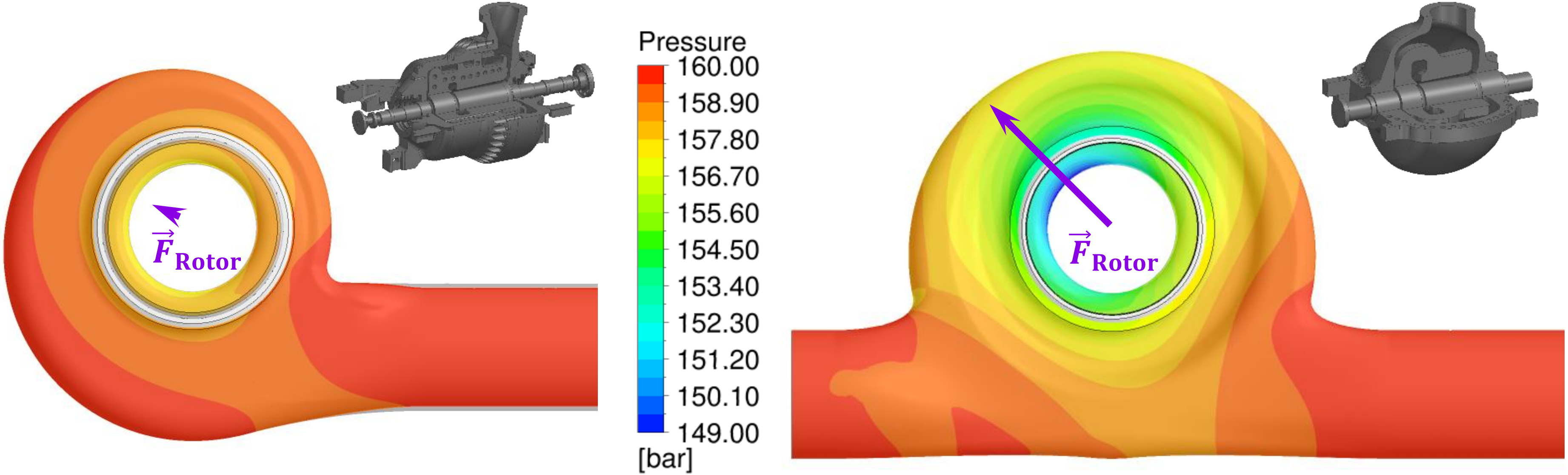
⇒ **low pressure losses**

- Locally very high flow velocities
- Large variation around circumference

⇒ **raised pressure losses**

Turbine Design

Aerodynamics Part 1 – Inlet Flow



- Little pressure variation

⇒ **small resulting force on rotor**

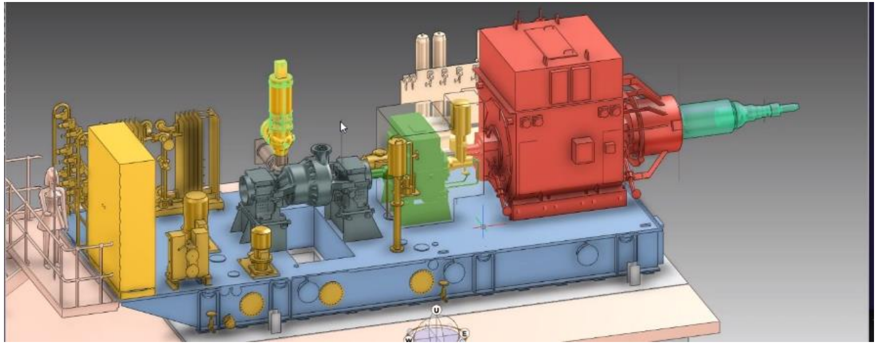
- Large pressure variation

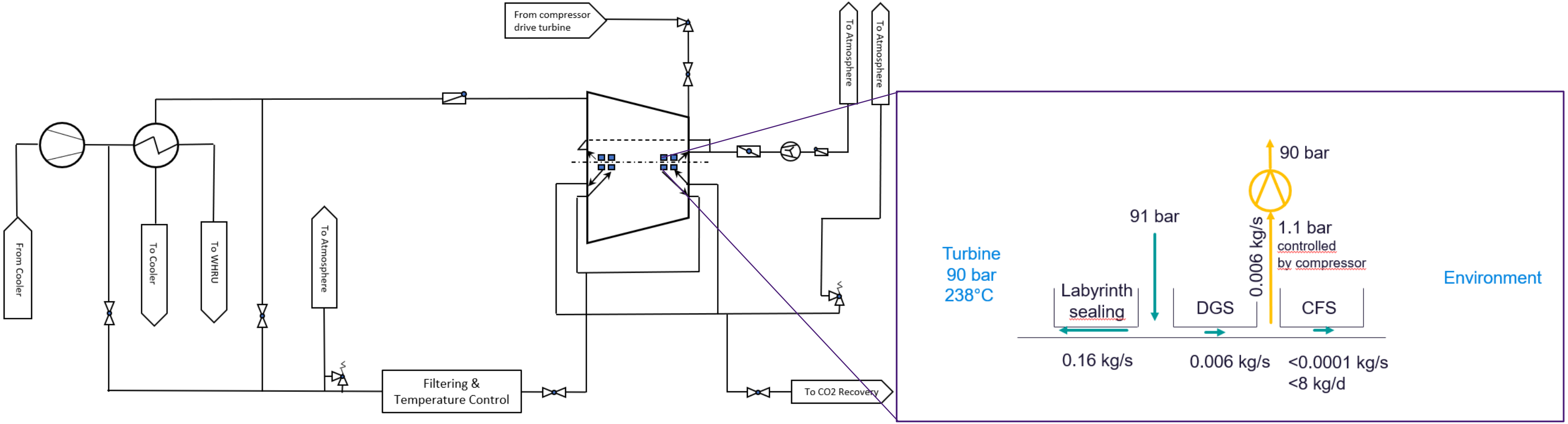
⇒ **reasonable resulting force on rotor**

Joint type turbine mechanically, aerodynamically and rotordynamically disadventageous

Dry Gas Seals Implementation

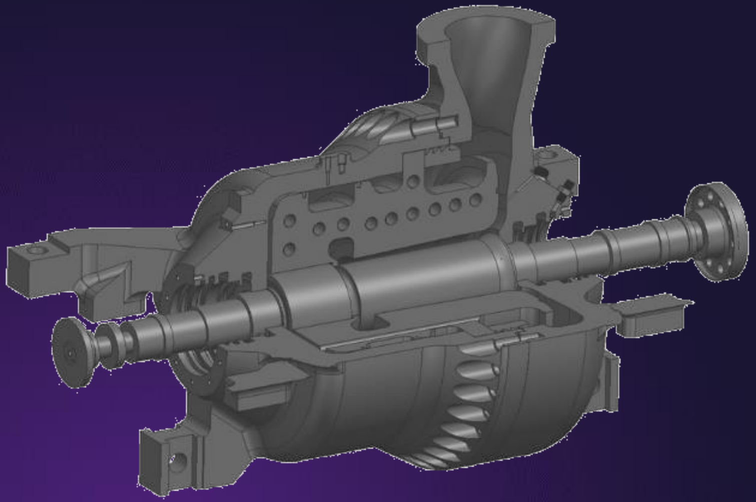
- DGS seal gas supply from system (downstream comp.)
- Backup-system necessary
- Recovery of leakage flow mandatory
- Minor remaining lekages need to be refilled
- Temperature limits of DGS to be considered
- Max. diam. of DGS may limit turbine sizing





Summary

- sCO2 turbines provide benefits in terms of performance & compactness
- Design challanges coming from the high energy density, pressure levels and specfic fluid properties require must be considered
- Proven barrel type turbine concept very suitable
- Validation and comercialization remains the main challange



March 2023

Thank you!

Baker Hughes Design Experience with unfired Expanders

Andrea Paggini

Baker Hughes, Italy

We take energy forward—making it safer, cleaner, and more efficient for people and the planet

120+
countries

~55,000
employees

$21.2B
revenue 2022

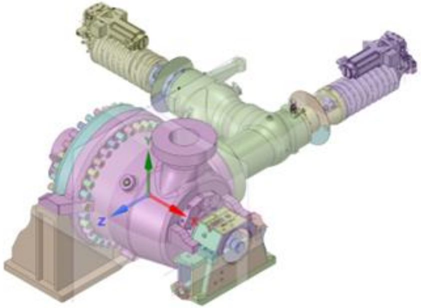
217
HSE Perfect Days in 2022

$556M
in research and development

2,200
patents granted

BH experience with sCO2 Axial Expanders

Three projects employing axial expanders carried out in the framework of Horizon 2020.



sCO_2-Flex*

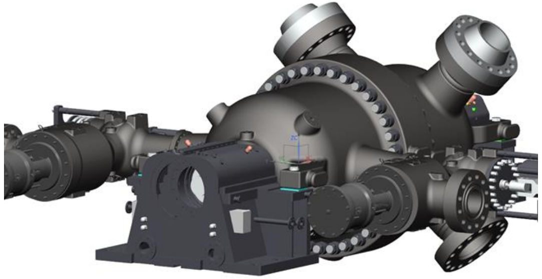
- ~40 MW (25 MW_e).
- 620°C-245 bar at inlet.
- 81 bar at exhaust.
- Pure CO_2.
- 9000 rpm, 5 stages.
- Supercritical cycle (coal fueled).
- No prototype.

*The sCO2-Flex project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 764690

Desolination**

- 2.5 MW (~2MW_e).
- 550°C-200 bar at inlet.
- 93 bar at exhaust.
- Mixture CO_2- SO_2.
- 17000 rpm, 5 stages.
- Transcritical cycle (CSP).
- Prototype in 2025.

**The DESOLINATION project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101022686



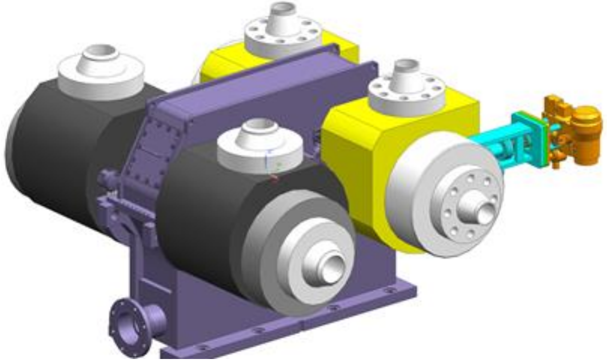
Scarabeus***

- ~130 MW (100 MW_e).
- 700°C-240 bar at inlet.
- 81 bar at exhaust.
- Mixture CO_2- SO_2.
- 3000 rpm, 14 stages.
- Transcritical cycle (CSP).
- No prototype.

***The SCARABEUS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 814985

Both pure and blended sCO2 applications. Most of technical challenges are common, few are peculiar of the CO_2 blended application.

BH experience with sCO2 Radial Expanders



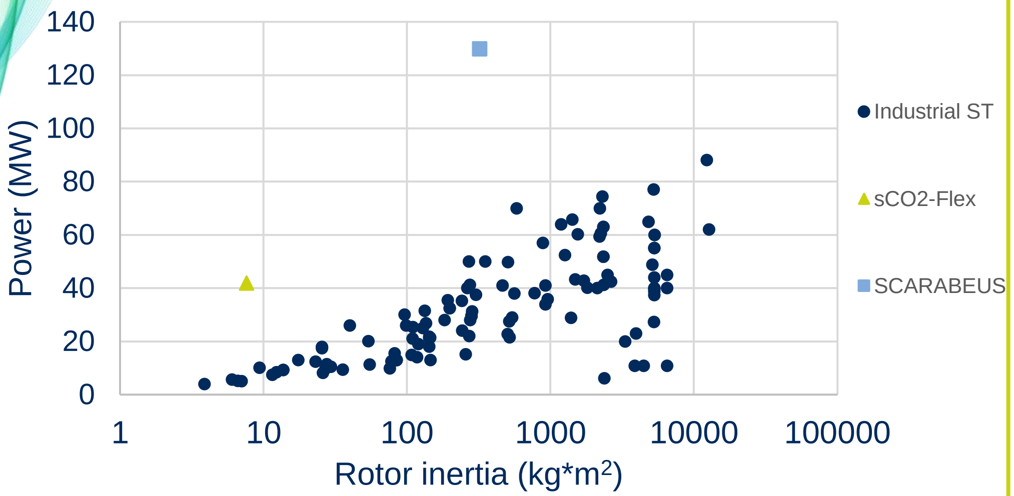
- Shrouded wheels much more efficient: +3.5% with respect to open wheels.
- Performance very much affected by non-scalable geometrical parameters (due to the small wheels size).
- Advanced manufacturing processes to minimize the surface roughness.

CO2OLHEAT†

- Integrally geared compressor-expander.
- ~2 MW.
- Supercritical cycle (WHR).
- 360°C-210 bar at inlet.
- 85 bar at exhaust.
- Pure CO_2.
- Expansion:
  - 2 radial inflow impellers (back-to-back arrangement).
  - 12500 rpm.
  - Wheel diameter: 160 mm.
- Compression:
  - 2 radial outflow impellers.
  - 20000 rpm.
  - First phase with IGVs.

†The CO2OLHEAT project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101022831

Design Challenges (1): extreme Power Density



SCARABEUS 1st rotoric blade (AR~1.2)

- ➢**Huge power-to-inertia ratio** establishes challenging requirements for **trip system responsiveness** and **rotor overspeed capability**.
- ➢**Rotor-dynamic stability** very much sensitive to **destabilizing** forces (Alford effect and interstage cross-coupled stiffnesses): **validated models for accurate predictions are crucial**.
- ➢Fluid forces drive big chords for airfoils: **aspect ratio** AR (height-to-chord ratio) of the blades tendentially **low**.

Technical challenges: BLENDED CO_2 ~ PURE CO_2

Design Challenges (2): Dry Gas Seals

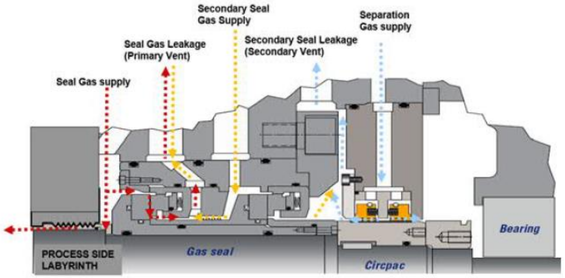
PURE CO_2

- ➢ DGS are essential to avoid unaffordable quantities of CO_2 released into the atmosphere: gain with respect to labyrinths is some orders of magnitude!
- ➢ Conventional labyrinths are suitable for ST since the minimum pressure of the cycle is much lower (even sub-atmospheric Vs. > 80 bar for sCO_2): leakages from the HP machine can be recovered into IP and LP sections.
- ➢ Recompressing a leakage through labyrinth seals, although possible, would heavily impact the CO_2 cycle efficiency: **DGS** are **unavoidable** for sCO_2 cycles.
- ➢ DGS technology is currently available for low temperatures (**~250°C**): a dedicated **cooling** system is necessary. Tradeoff between cooling effectiveness and thermal stresses minimization in hot components is a tricky task.
- ➢ DGS are limited in size: this limits the **torque transmission capability**.

BLENDED CO_2

- ➢ Even a minimal release of process mixture into the atmosphere is to be avoided (owing to the nature of all the possible dopants): necessary a **buffer** with **pure CO_2**. To minimize the buffer flow entering the loop (and diluting the mixture), a peculiar (more complex) DGS arrangement is necessary.

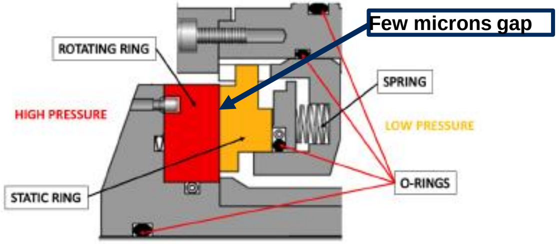
TANDEM DGS ARRANGEMENT



REPRODUCED BY

D. Steinmann et al, «Dry Gas Seals for Centrifugal Compressors in Supercritical CO_2 Application», 7th International sCO_2 Power Cycles Symposium (2022).

SINGLE DGS DETAIL



Technical challenges: BLENDED CO_2 > PURE CO_2

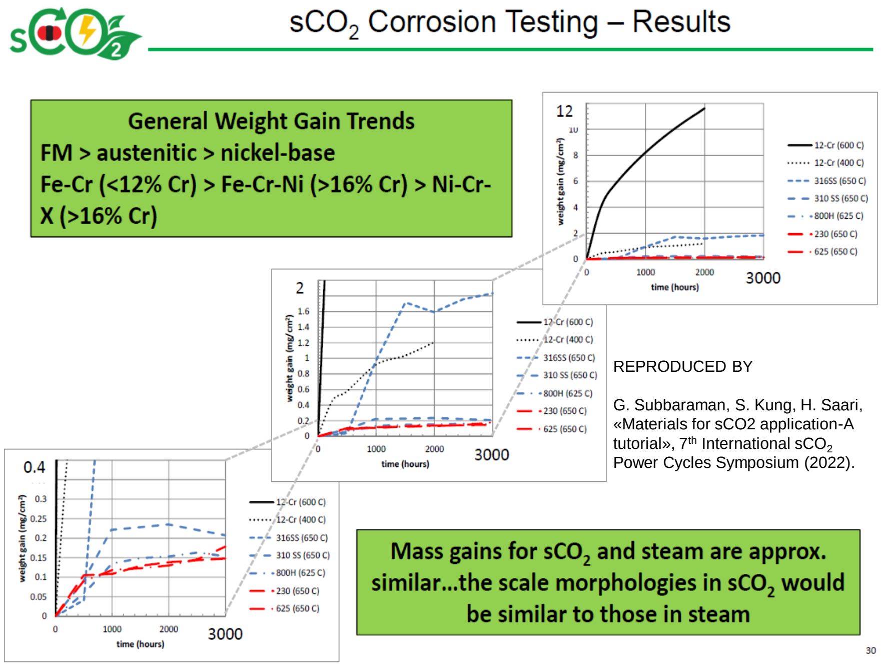
Design Challenges (3): Materials

PURE CO_2

- ➢Martensitic steel 12%Cr (common in ST up to >600ºC), are prone to **oxidation** and **carburization** in CO_2 environment. **Ni-based** alloys experience, in general, much lower interaction with CO_2 at high temperature.
- ➢Considerable amount of data available in the literature but mechanical properties degradation requires further assessments.

BLENDED CO_2

- ➢Experimental data still scarce for the dopants of interest ($TiCl_4$, C_6F_6, SO_2,…): compatibility data gathered after **2000 hours** of **exposure** (tests carried out for Desolination at University of Brescia) have shown that, depending on the dopant, even certain Ni-based alloys can be totally inadequate.
- ➢Material compatibility and manufacturability constraints increase a lot the complexity of the expander design.



sCO_2 Corrosion Testing – Results

General Weight Gain Trends
FM > austenitic > nickel-base
Fe-Cr (<12% Cr) > Fe-Cr-Ni (>16% Cr) > Ni-Cr-X (>16% Cr)

Mass gains for sCO_2 and steam are approx. similar…the scale morphologies in sCO_2 would be similar to those in steam

REPRODUCED BY

G. Subbaraman, S. Kung, H. Saari, «Materials for sCO2 application-A tutorial», 7th International sCO_2 Power Cycles Symposium (2022).

Technical challenges: BLENDED CO_2 >> PURE CO_2

Conclusions

- Apart from materials, the technical criticalities of expanders for carbon dioxide mixtures are comparable to the case of pure CO_2.
- Addressing **materials** and **manufacturing processes** more in details is the most crucial aspect, primarily for **blended CO_2** expanders, to fully exploit the advantages claimed by the sCO_2 technology.
- Despite the technical challenges highlighted, the turbomachinery design is able to achieve the technical objectives addressed by the sCO_2 technology in terms of **efficiency**, **compactness** and **operability** requirements.
- The development of a **demonstration** plant is a key enabler for the success of the technology.

Thank you for listening!

Andrea Paggini

andrea.paggini@bakerhughes.com

www.bakerhughes.com

@bakerhughesco

@bakerhughesco

Baker Hughes

Concluding Slido question

Are there any remaining challenges for sCO2 expanders needing to be addressed and if so, which ones? (1-2 words)

Corrosion at HT

Cooling (Allam)

DGS

System overall cost

Testing

full scale

System integration

Dry gas seal

Lcf

Materials

Lower outlet pressure

Validation

Efficiency

Batch operation

validation results

Material compatibility

Thank you and see you next time!

Question / comments?

js@etn.global