sCO2 Power Cycles Symposium – San Antonio

Baker Hughes

sCO2 Axial Expanders Development

International Panel Session

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February 2024

Axial Expanders for sCO2 Externally Heated Power Cycles

DeSOLination

- Started in **2021**. **Ongoing**
- **Prototype in 2025.**
- **2.5 MW** (~2MW$_e$).
- **550ºC-200 bar** at inlet.
- 93 bar at exhaust.
- Mixture CO_2- SO_2.
- 17000 rpm, 5 stages.
- Transcritical cycle (CSP).

sCO2flex

- Started **2018**. **Completed**
- No prototype built**.**
- ~**40 MW** (25 MW$_e$).
- **620ºC-245 bar** at inlet.
- 81 bar at exhaust.
- Pure CO_2.
- 9000 rpm, 5 stages.
- Supercritical cycle (coal fueled).

SCARABEUS

- BH joined in **2020**. **Completed**
- No prototype built**.**
- ~**130 MW** (100 MW$_e$).
- **700ºC-240 bar** at inlet.
- 81 bar at exhaust.
- Mixture CO_2- SO_2.
- 3000 rpm, 14 stages.
- Transcritical cycle (CSP).

The projects sCO2flex, and Scarabeus and Desolination have received funding from the European Union's Horizon 2020 research and innovation programme

Desolination Project Consortium

Consortium of 21 partners

- 13 Universities
- 2 Research centre
- 2 Large Industries
- 4 SME

Duration: 64 months

Start Date: 01 Jun 2021

Estimated Project Cost: M€13.8

Requested EU Contribution: M€10

The projects sCO2Flex, sCO2OLHEAT, CO2OLHEAT and DESOLINATION have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreements N° 764690, No 952953, 101022831 and 101022686

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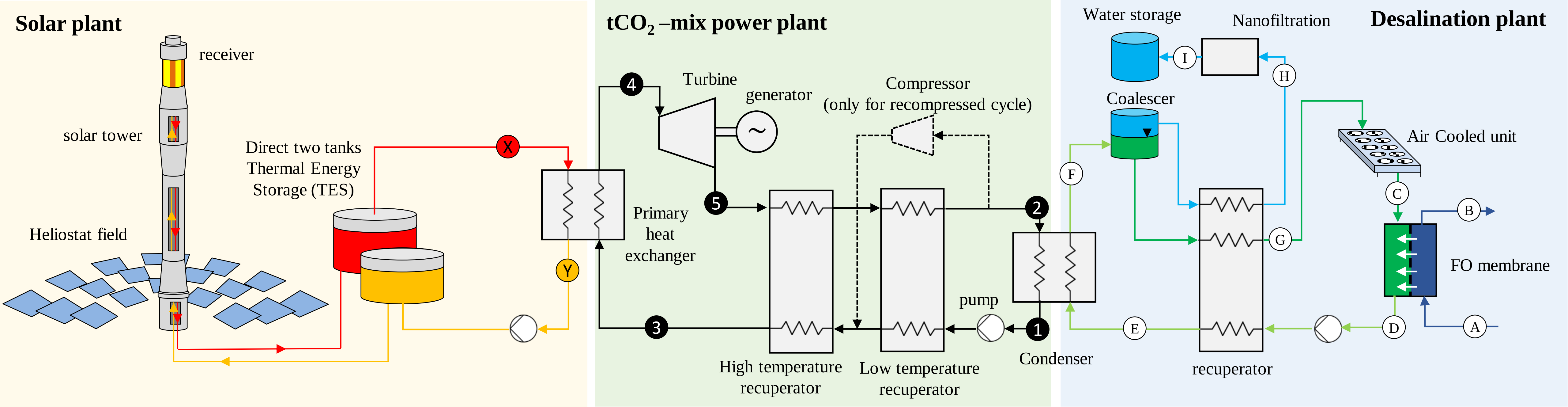
Plant Concept



CSP plant	Power cycle	Forward Osmosis plant
• Central tower receiver (max T=565°C) • Direct storage with solar salts	• Transcritical cycle • CO_2+SO_2 as working fluid	• PAGB2000 as working fluid • Regeneration Temp. = 75 °C

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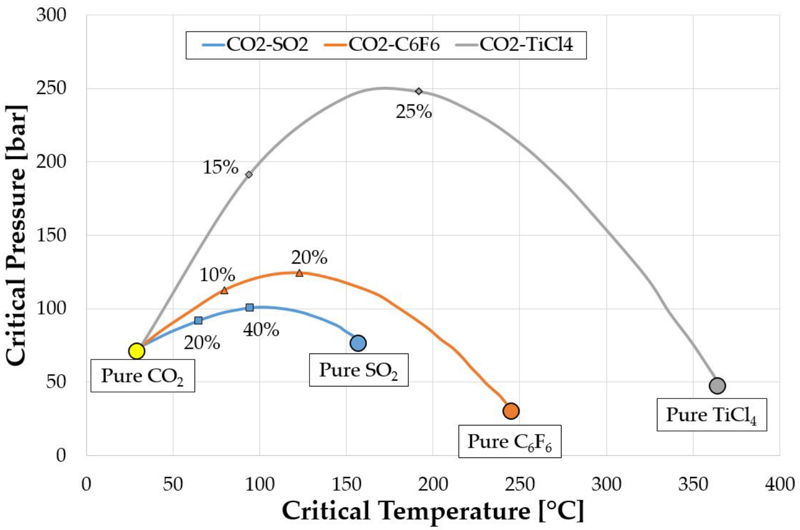
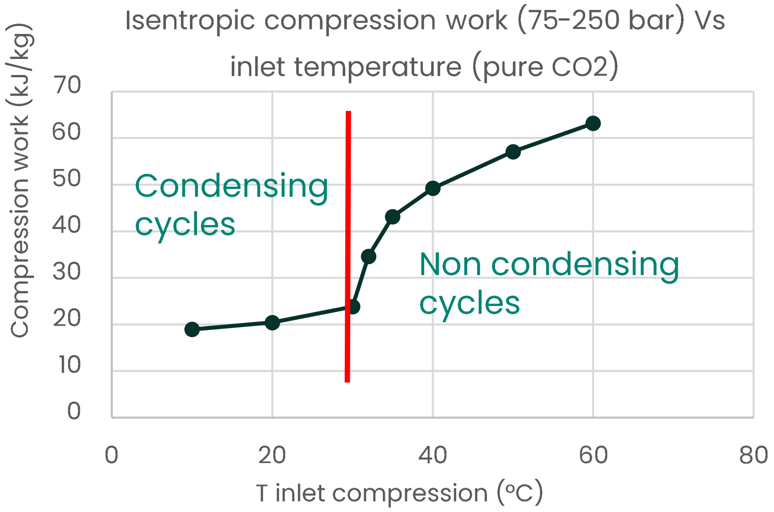
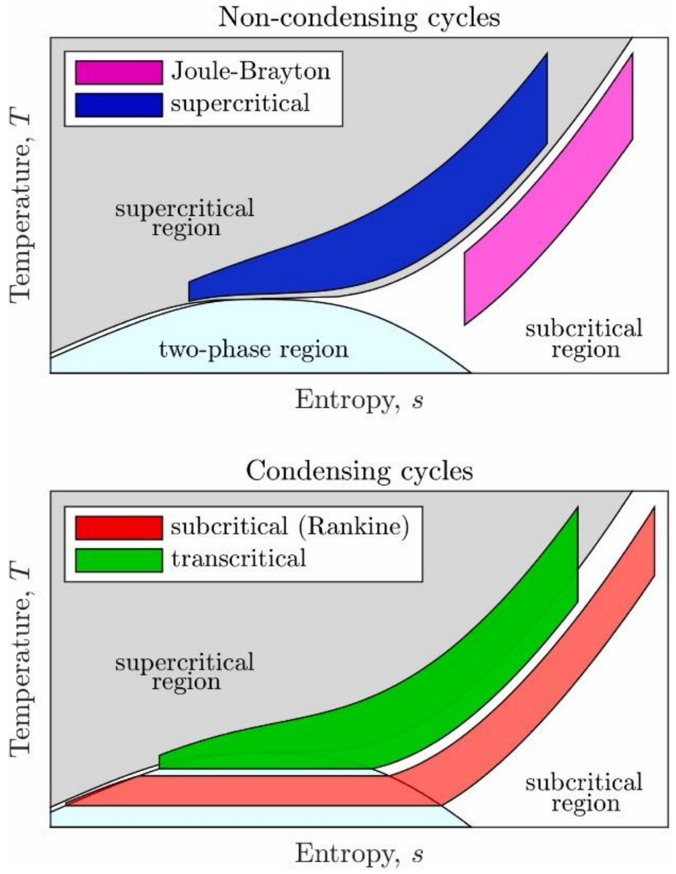
Transcritical Condensing (Rankine) Cycle

- **Transcritical cycles** attractive to **reduce the compression work and enable high ambient temperature** application (CO_2 critical Temp. 31°C)
- **82% CO2-18% SO2 (molar basis) Mixture** selected resulting in a critical temperature higher than pure CO_2 (**60-65°C**)







Source: M.T. White, G. Bianchi, L. Chai et al., Review of supercritical CO2 technologies and systems for power generation, Applied Thermal Engineering (2023)

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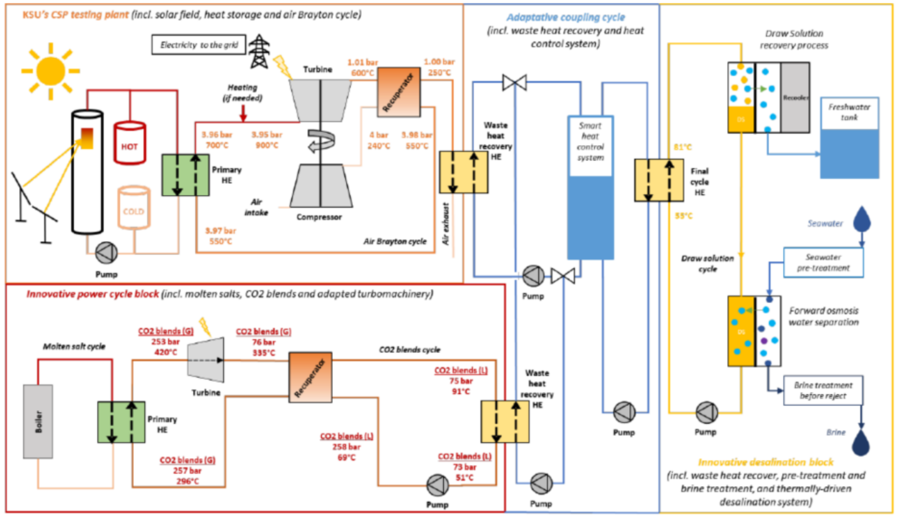
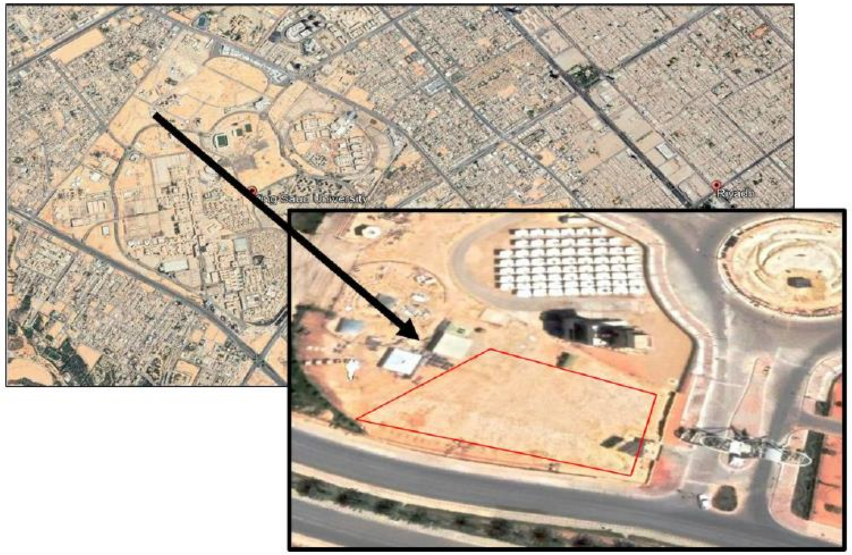
Demonstrator Plant Overview

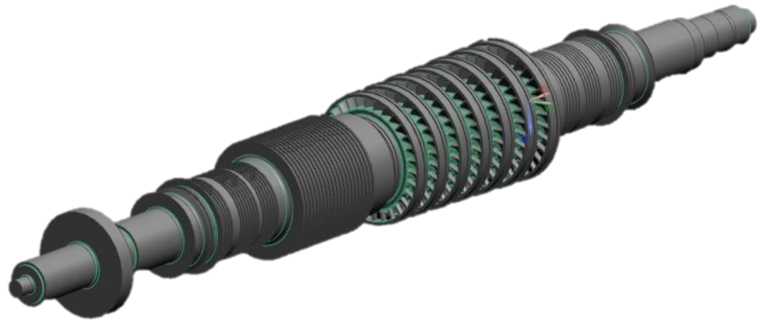
- Demonstrate the optimized coupling of an existing CSP plant at **King Saud University** and of an innovative **supercritical CO_2 power cycle** with an advanced **desalination system.**
- **Containerized** plant design exception made for the molten salt heater => Limited foundation work required
- **3000 hours test** planned
- Desalination plant commissioning Q1 2025
- Power Cycle commissioning Q4 2025





Desolination main design features

- **200 bar** and **550°C** at inlet
- **135 kg/m_3** inlet density
- **93 bar** at exhaust
- **17000 rpm, 5 stages**
- Rotor hub diameter: **130 mm**
- Rotor bearing span: ~ **1m**
- Rotating **blades integral with rotor**
- External casing **barrel** type.



Integral rotor design

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Expander Main Technology and Industrial development focus

Dry Gas Seal technology and cooling system: DGS required to minimize shaft end leakage. Existing DGS technology (limited at ~250ºC) not compatible with expander conditions=> dedicated cooling system required.

Rotordynamics: high fluid density leads to strong destabilization effects

Performance: low volume flow, low cycle pressure ratio, EOS Modeling, Standard Testing procedure development (ASME PTC Type)

Materials compatibility: nickel-based alloy (Inco type) required to resist carburization above a certain temperature. CO_2+ SO_2 requires specific Inconel type. Long term effect characterization is required

Manufacturability: required alloys manufacturing process not consolidated for the expander commercial scale size. Optimizing manufacturing process as a function of size

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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!
- 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.
- **Primary vent management**

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.

Dry Gas Seals Validation

- **sCO2-Flex** DGS tested at Flowserve: housing equipped with **heating rods** to simulate heat flux external to the DGS.
- Developed a **segregated conjugated heat transfer model** with University of Florence: 1D fluid solver is calibrated with CFD results.
- **Further component validation** planned on Desolination program
- **Demonstrator plant test will be crucial** to observe DGS behavior in all operating conditions

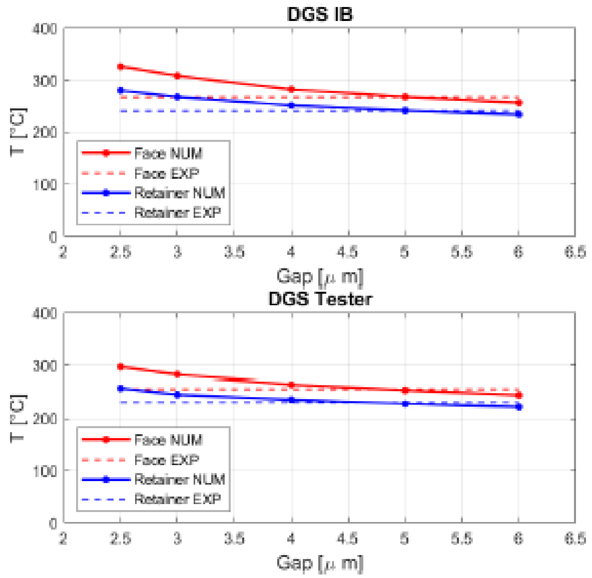

FIGURE 7: Gap sensitivity on (a) DGS IB and (b) DGS Tester at OP3.1 (baseline) (**© 2023 Baker Hughes Company - All rights reserved)**

Picture 2: Tester set-up for hot sCO2

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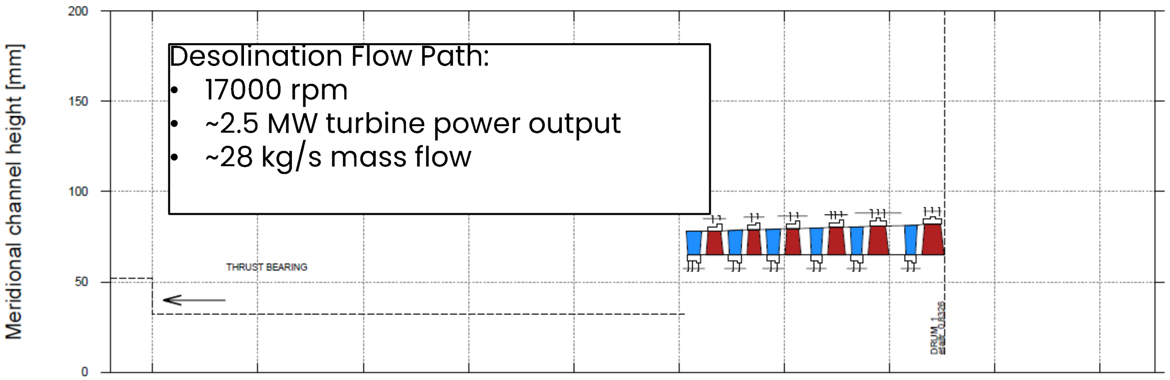
Performance – Low volume flow

- Initial **Desolination** cycle conditions established an inlet volume flow of ~ 0.08 m^3/s that was judged not feasible for axial turbine technology
- Cycle adapted (increased mass flow) to increase volume flow up to ~ 0.2 m^3/s still leading to **15 mm first nozzle airfoil height** and 130 mm rotor hub diameter (rotor weight ~80 kg)
- Detailed understanding of secondary losses (aspect ratio and leakage) is critical to scale the results to production units size



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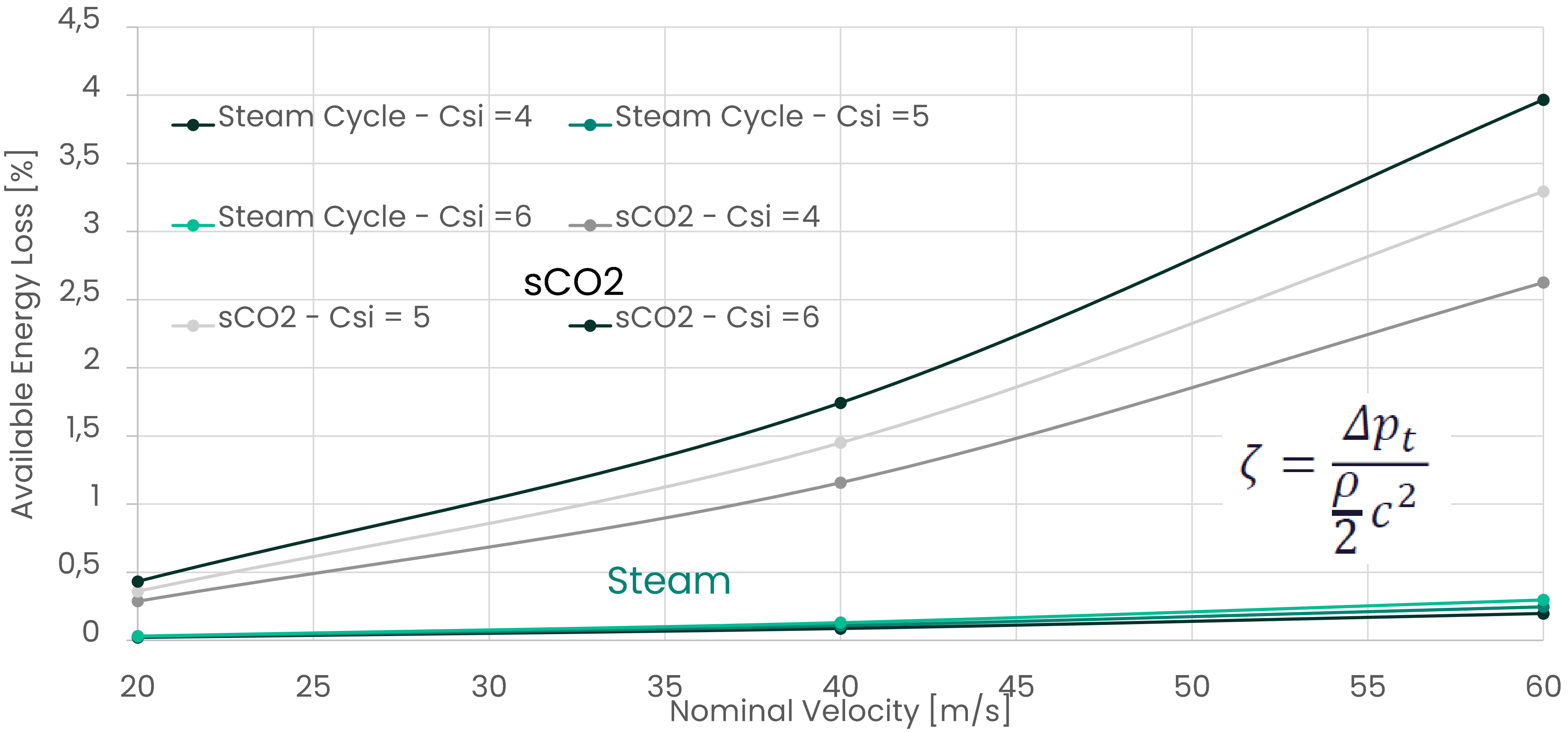
Inlet Pressure losses sensitivity



Available Energy:

sCO2 Cycle = ~ 150 - 200 KJ/kg

Steam Cycle = ~ 1200 – 1400 KJ/kg

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Materials Characterization and Manufacturing Industrialization

Materials Selection and Characterization

- **Carburization** limits application of 12Cr Steel at **400°-500°C**
- Nichel-Chromium based alloy required (**bulk or surface protection)**
- CO2-SO2 mixture poses further constraints on material selection
- Environment effect on critical material properties (LCF, FCG) under assessment

Manufcaturing Process Industrialization

- Nichel based alloys **large forging and large casting** (commercial scale) size goes beyong existing qualified process
- Procurement of qualification trials started (5 tons shaft forging)
- Main components **manufacturing process optimization** as a function of size (rotor, external casings, blades, valves)

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Conclusions

- **EU and DOE projects** have set the foundations of sCO2 technology now the industry has to continue the development

- Turbomachinery components risks are reduced with detailed analysis and specific experiments but **system level and cycle operability validation requires demonstrator plants experience**

- Raw materials and components manufacturing process industrial development crucial for **cost and lead time optimization**

- Some development of International standard (**PTC Code, ASTM material listing**) could contribute to build a common ground for the industry

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