R&D activities on sCO_2 in Europe

ISOP project – Innovation in Supercritical CO_2 Power generation systems

Eighth episode – 13 February 2025

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 [1/2]

Moderators

Introduction

- David Sánchez (University of Seville)

Q&A session moderators

- Giovanny López Muñoz (University of Seville)
- Mohammed Alnajjar (City University of London)

Webinar content & speakers [2/2]

Speakers

WP1: System integration

- Giacomo Persico (Politecnico di Milano)

WP2: System operation, transient performance and control

- Lorenzo Cosi (Baker Hughes)

WP3: Component innovations, turbomachinery, and heat exchangers

- Abdulnaser Sayma (Brunel University)

WP4: Materials and manufacturing

- Fátima Montemor (Instituto Superior Técnico)


Active poll
57
What area of technology needs the most research?
Component innovations, turbomachinery and heat exchangers
42%
System operation, transient performance and control
37%
Materials and manufacturing
12%
System integration
7%
Other
2%

Project overview

David Sánchez

University of Seville

R&D funding – Horizon Europe

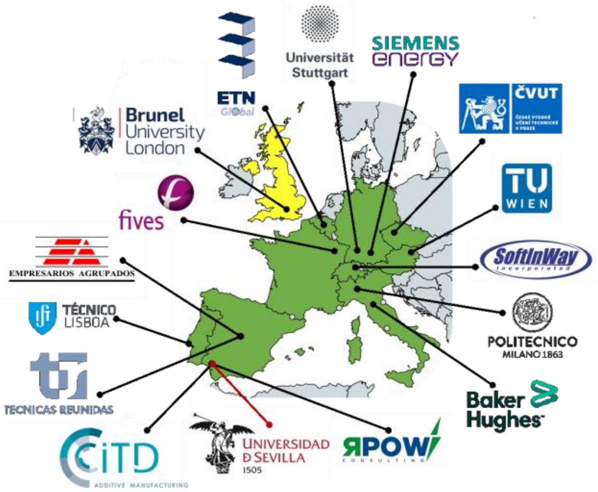
€25B (TRL<4-5) €53.5B (TRL<7) €13.6B (High TRL)

€3.4B

Facts & figures

Optimal integration of sCO2 power cycles components

- Funded in 2022
- 6+1 Academic + 9 Industrial partners
- 6 Associates
- 10 countries involved
- 4.4 M€ (3.85 EU + 0.55 UKRI)
- 17 research topics in 4 WPs
- 5 years: January 1st 2023 – December 31st 2027



Consortium

Universidad de Sevilla 1505
Politecnico Milano 1863
Universität Stuttgart
Brunel University London
ČVUT České vysoké učení technické v Praze
Técnico Lisboa
TU Wien

Academia (7)

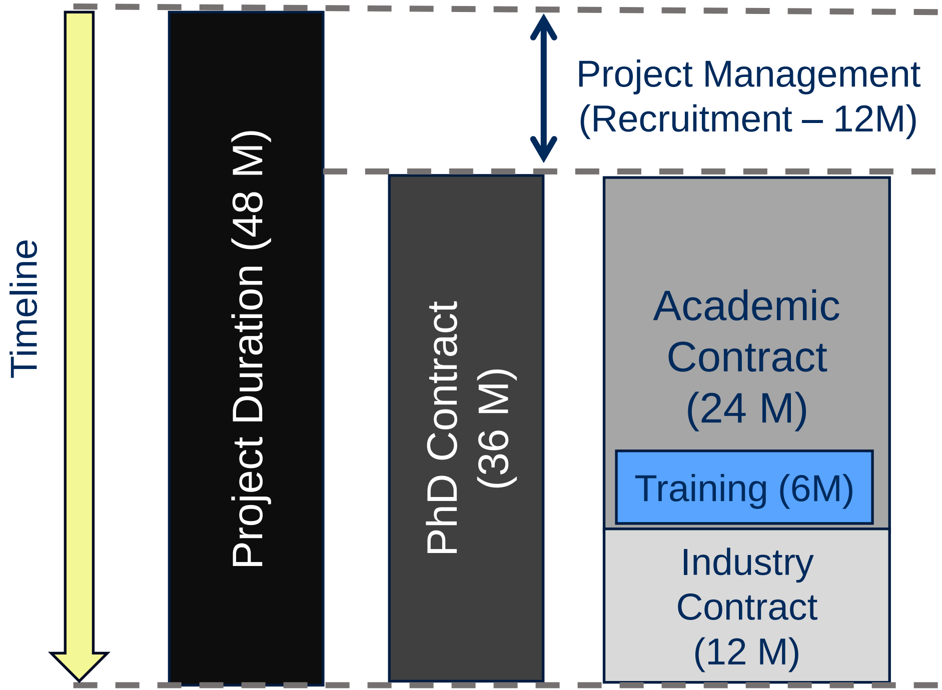
Baker Hughes
Empresarios Agrupados
Tecnicas Reunidas
Siemens energy
fives
ETN Global
CiTD Additive Manufacturing
RPOW Consulting
SoftInWay incorporated

Industry (9)

Aalborg CSP - Changing Energy
Easy Energy Consulting & Technology
AzzeroCO2 climate in our hands
Doosan Doosan Škoda Power
Rosswag engineering
Inerco

Associates (6)

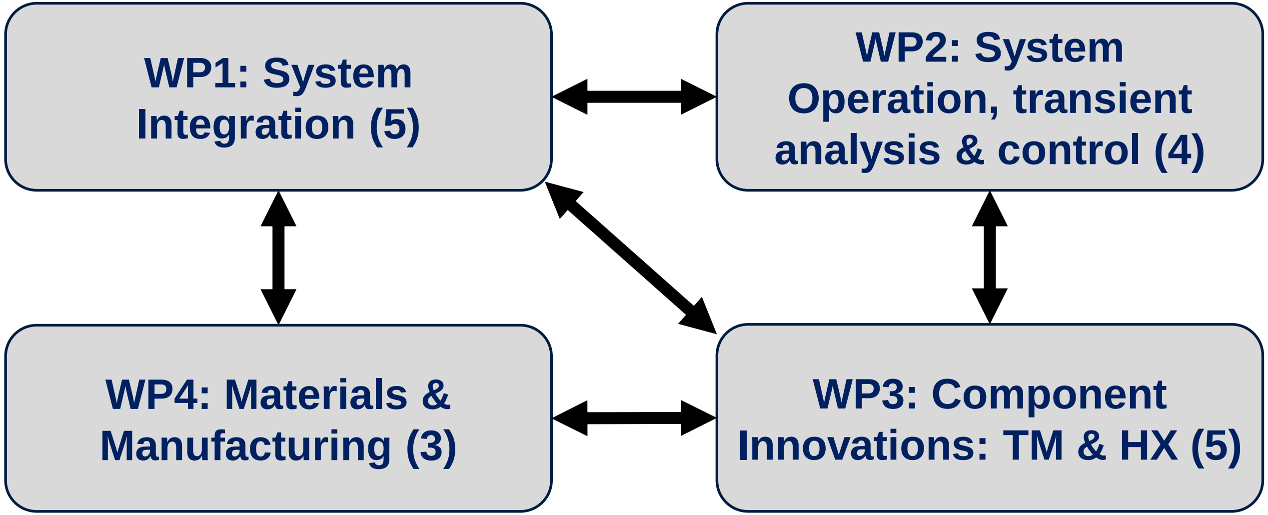
Organization of work



- 24M at University
- (6M training in industry)
- 12M contract with industry
- 50% split R&D/industry

x17

Work program



POLITECNICO MILANO 1863

Baker Hughes

TÉCNICO LISBOA

University of Stuttgart

Integral approach

Two hosts (R&D/Ind)

		WP1: System Integration					WP2: Operation, Performance, Control				WP3: Component Innovations					WP4: Materials, Manufacturing		
	Doctoral Candidates	DC1	DC2	DC3	DC4	DC16	DC5	DC6	DC7	DC8	DC9	DC10	DC17	DC11	DC12	DC13	DC14	DC15
	Hosts	POLIMI EAI	USE ETN	CVUT EAI	TUW EAI	POLIMI RPOW	CVUT BH	TUW BH	USE SIW	BUL	BUL	POLIMI BH	USE SIEMENS	USTUTT TR	USTUTT FIVES	IST CITD	IST CITD	USTUTT CITD
	Secondments	System Integration	LCA/Env, Market	System Integration	Energy Storage	sCO2 Mixtures	Operation - direct	Operation - indirect	Transient Perfo.	System Control	Compress.	Expansion - Off-design	Expansion - Flexibility	Heat Exch. - Condenser	Hext Exch. - Recuperat.	Materials - Polymeric	Materials - Corrosion	Additive Manuf.
WP1	DC1 (TR)																	
	DC2 (ACO2)																	
	DC3 (INERCO)																	
	DC4 (ETN)																	
	DC16 (AAL)																	
WP2	DC5 (DSPW)																	
	DC6 (SIW)																	
	DC7 (DSPW)																	
	DC8																	
WP3	DC9																	
	DC10 (EASY)																	
	DC17 (SIW)																	
	DC11 (FIVE)																	
	DC12 (TR)																	
WP4	DC13 (BH)																	
	DC14 (ROSS)																	
	DC15 (ROSS)																	

Type of Interaction:

Share cycle parameters	Share models and validation data	Share material properties
Secondments	Share component characteristics	Share manufacturing limitations
Share design parameters	Market and cost limitations	Share transient behaviour

Additional industrial training

Teamwork

Training program

	Theme(s) and main programme	Organiser	Location
WSH1	Introduction to sCO_2 power systems	POLIMI/BH	Milan
WSC1	Introduction to material coatings, manufacturing techniques and fundamental modelling of heat transfer	USTUTT/FIVES	Stuttgart
WSH2	Commercialisation: IPR management, economics, policy and regulations	USE/EAI/RPOW	Seville
WSC2	Advancements on materials for energy	IST/CITD	Lisbon
WSH3	Modelling Power Systems	TUW/SIW	Vienna
WSH4	sCO_2 system component design and analysis	CVUT/SIEMENS	Prague
WSC3	Energy Cultures	BUL/BH	London
ISC	sCO_2 in the future power systems mix	ETN/BH/USE	Brussels

Proof of life

Thank you!

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www.

LinkedIn

Work package 1
System Integration

Giacomo Persico

Politecnico di Milano

WP1 Objectives

Optimal integration of sCO_2 power cycles components

- Training & research targeted to optimal integration of sCO_2-based energy systems for CSP, WHR, nuclear, energy storage, CCS
- Diversity of applications and technologies: exploitations of synergies and sharing of experiences to advance knowledge, develop methods and models, to understand similarities and differences between applications
- Developing advanced models and design tools, also making use of AI, that enable optimal integration of sCO_2 power systems and components

WP1 Challenges

- The need of simplified though reliable models of main components (heat exchangers, turbomachinery, air separation unit) to be integrated into cycle calculation to enable proper system optimization

- Extending the components models to enable off-design simulations of the systems, considering the thermodynamic properties of CO_2 and CO_2 mixtures

- The need of more reliable models and tools to support the commercial exploitation of sCO_2 energy systems

Who’s who

Combination of Academic and Industrial Hosts, 5 doctoral students

Phd student	Topic	Academic Host	Industrial Host
 Giovanny López Muñoz (DC1)	Integration of power systems based on directly-fired oxycombustion sCO_2 power cycles	University of Seville	Empresarios Agrupados Internacional
 Amgad Khamis (DC2)	Market uptake of sCO_2 power systems to enable carbon-neutrality by 2050	University of Seville	Energy and Turbomachinery Network
 Babras Khan (DC3)	Integration of power systems based on indirect sCO_2 power cycles	Czech Technical University in Prague	Empresarios Agrupados Internacional
 Sukhrob Shakirov (DC4)	Large Scale Energy Storage based on sCO_2 systems	Technische Universitaet Wien	Empresarios Agrupados Internacional
 Matyas Junek (DC16)	Utilisation of CO_2 mixtures to enhance the performance of sCO_2 power systems	Politecnico di Milano	RPOW Consulting

WP1 management

Timeline, Deliverable, Milestones

- **Timeline**
  - all WP1 projects started between October 2023 and February 2024
  - WP1 activities will end at the beginning of 2027 – still two years of research!
- **Deliverables**
  - System Configuration for sCO_2, released in July 2024 and publicly available
  - Market potential of sCO_2 power generation system, to be released in 2026
- **Milestones**
  - Experimental validation data is collected (end of 2024)
  - Market data collected (beginning of 2025)

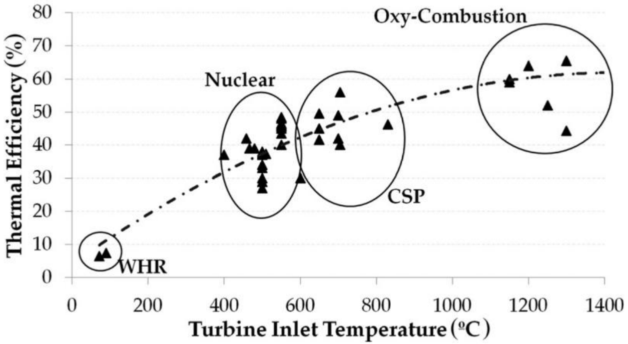
Topics

Topic 1: Directly-fired sCO_2 systems

Integration of power systems based on directly-fired oxycombustion sCO_2 power cycles

- **Background & motivation**
  - High-efficiency, zero-emission power generation with CCS
  - Integration into transitioning and decarbonized energy systems
  - Technology of high interest, need of EU research on the topic

- **Gaps & challenges**
  - Lack of systematic comparison of directly-fired sCO_2 cycles.
  - Discrepancies on ASU power consumption reported in literature, affecting the assessment of the integrated systems.
  - Limited studies on the impact of ASU integration on sCO_2 cycle performance.

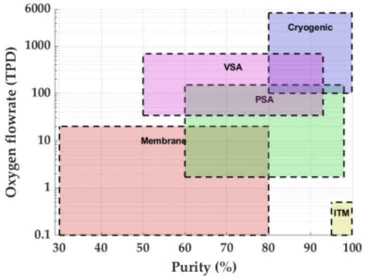


Crespi, F.M. et al, 2018. Analysis of the Thermodynamic Potential of Supercritical Carbon Dioxide Cycles: A Systematic Approach. Journal of Engineering for Gas Turbines and Power, 140 (5), 051701-.

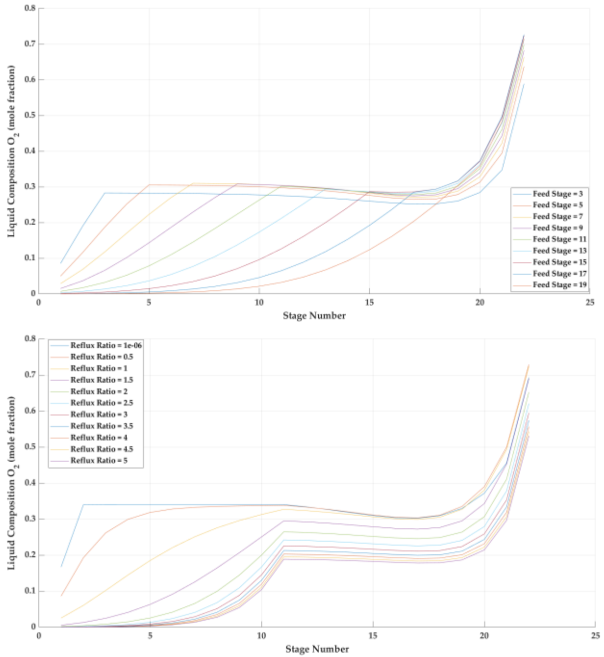
Topic 1: Directly-fired sCO_2 systems

Integration of power systems based on directly-fired oxycombustion sCO2 power cycles

- **Approach & first results**
  - Development of a systematic methodology to compare different power cycles under defined boundaries
  - Implementation of a detailed model of the ASU to set-up optimization strategies.
  - Investigate alternative thermal integration schemes for the ASU and the power cycles.



Most suitable Air Separation Technology according to required flow rate and purity



Influence of Feed Location and Reflux Ratio on O2 Composition

Topic 2: Market of sCO_2 power systems

Market uptake of sCO_2 power systems to enable carbon-neutrality by 2050

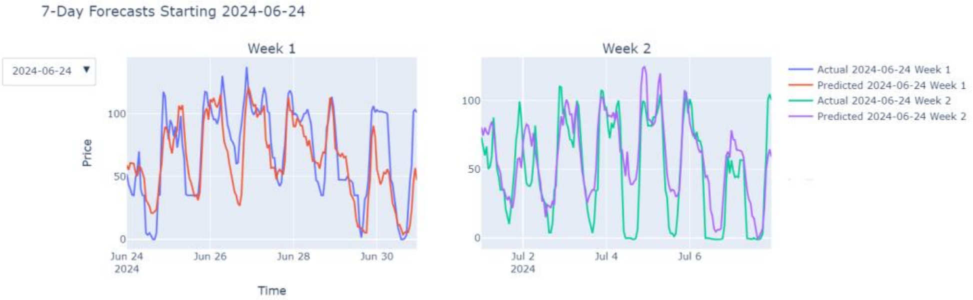
- **Background & motivation**
  - Need of a roadmap towards the commercialization of direct sCO_2 systems
  - Evaluation of the roles of different thermal energy sources in the carbon-neutral energy transition
  - Definition of relevant business cases for the sCO_2 technology and the associated costs of energy

- **Gaps & challenges**
  - Critical technology and supply chain gaps for the market deployment of sCO_2 power systems
  - Handling Market Volatility: The models struggle to capture extreme fluctuations in electricity prices
  - Forecast Gap at Initial Prediction: A significant difference between the first forecasted hour and the last observed value creates a discontinuity, reducing forecast credibility.

Topic 2: Market of sCO_2 power systems

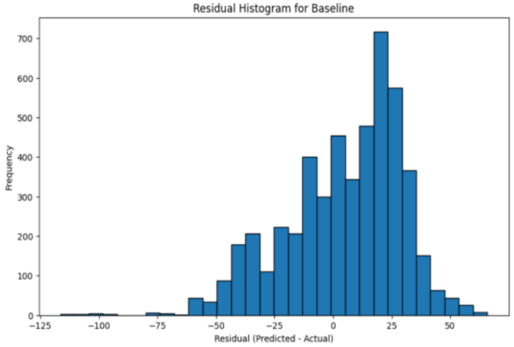
Market uptake of sCO_2 power systems to enable carbon-neutrality by 2050

- **Approach & first results**



- Introduce external market indicators (fuel prices or weather conditions).
- Employ probabilistic forecasting techniques to model uncertainty and extreme price variations.
- Integrate the forecasting tool with trading tool to determine when to buy and sell electricity.
- Boosting revenues by using sCO_2 power cycles in secondary market

- The model captures well the trend of the price in week 1, but for week 2 it is not always the case.
- The residual histogram give an idea on error distribution.
- Next step: understanding source of errors

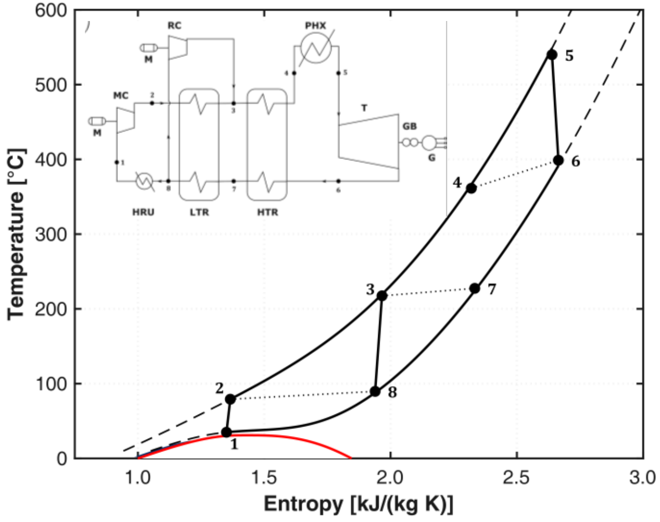


Topic 3: Indirect sCO_2 power systems

Integration of power systems based on indirect sCO_2 power cycles

- **Background & motivation**
  - Need for improved modeling of Heat Exchangers and Axial Turbines integrated with a sCO_2 Cycle
  - Development of optimal solution for cycle efficiency, with focus on nuclear plants in arid climates.
  - Addressing critical temperature variations at the gas cooler end

- **Gaps & challenges**
  - Lack of Standardized Framework for optimizing the integration of indirect sCO_2 power cycles and critical components
  - Limited Experimental Validation of full systems at real-scale (but pilot plant data are coming in the next years)

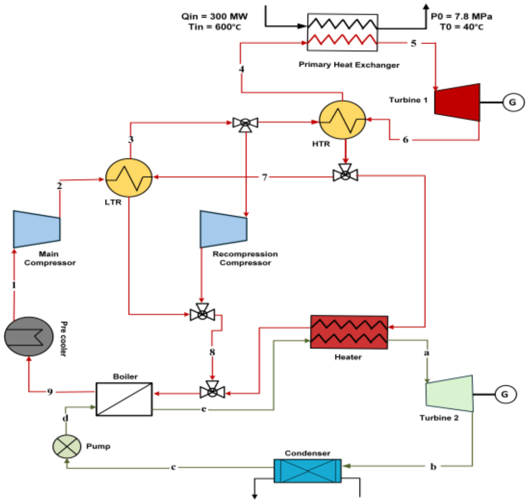


Romei et al., Journal of Turbomachinery 2020

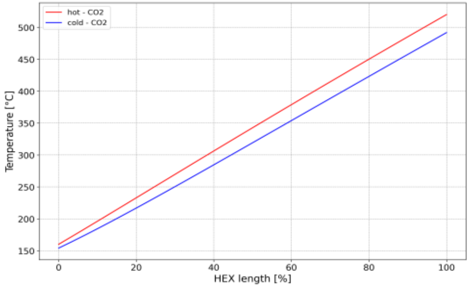
Topic 3: Indirect sCO_2 power systems

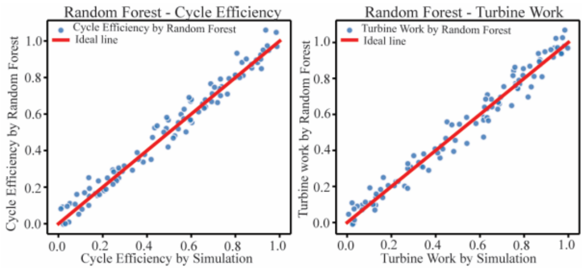
Integration of power systems based on indirect sCO_2 power cycles

- **Approach & first results**
  - Selection of the most suitable cycle layout (recompressed cycle)
  - Development of a two-dimensional numerical model to simulate multi-pass heat exchanger tailored to sCO_2 applications, to address critical temperatures
  - Formulation of a generalized cycle optimization strategy, featuring advanced heat exchangers and turbine models, based on AI



High Temperature Recuperator



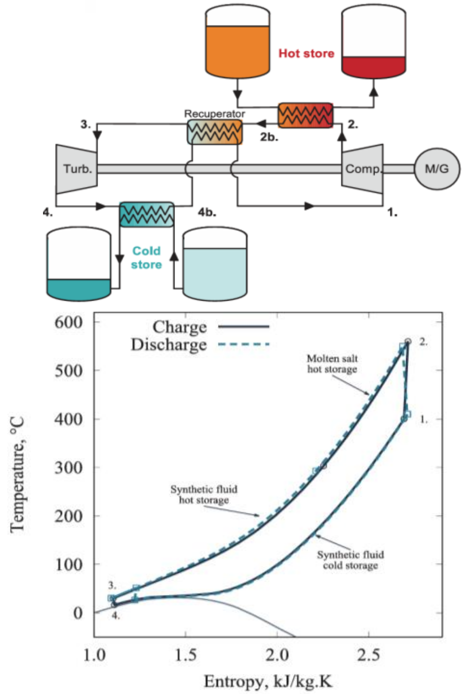


Topic 4: sCO_2-based Carnot batteries

Large Scale Energy Storage based on sCO_2 systems

- **Background & motivation**
  - A Carnot battery is an energy storage system that converts electrical energy into thermal energy and then back into electricity
  - Composed by a combination of discharge (power system) and charge (high-temperature heat pump) cycles
  - sCO_2 -based Carnot Battery may offer round-trip efficiency advantages

- **Gaps & challenges**
  - Heat exchanger with CO_2-TES is critical, detailed models needed to avoid pinch point within the heat exchanger
  - Research still in its infancy on sCO_2 Carnot Battery, and on TES materials

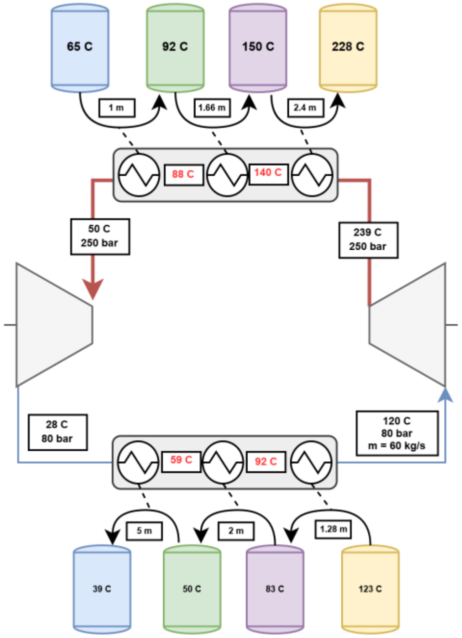


McTigue et al, 2019. Pumped thermal electricity storage with supercritical CO2 cycles and solar heat input," AIP Conference Proceedings

Topic 4: sCO_2-based Carnot batteries

Large Scale Energy Storage based on sCO_2 systems

- **Approach & first results**
  - Steady state sCO_2 cycles are modeled featuring heat exchangers calculations, combined with optimization
  - Transcritical and supercritical Brayton sCO_2 PTES modelled and validated
  - The impact of extraction/inclusion of HOT/COLD energy studied through modelling and optimization.
  - High-temperature recuperators for the Brayton cycle under investigation
  - Multiple storage media considered, particularly solid-based thermal storage systems.



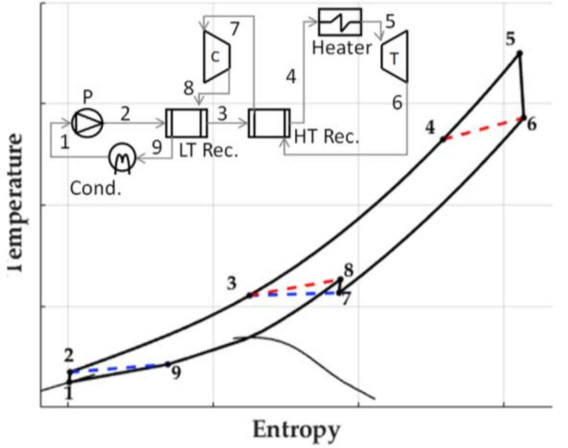
Charge Cycle		
	T [C]	P [bar]
1	120	80
2	239	250
3	50	250
4	28	80
Discharge Cycle		
CIT	35	100
TIT	650	250
SR	0.59	
RT = 59 %		

Topic 16: Power cycles with CO_2 mixture

Utilisation of CO_2 mixtures to enhance the performance of sCO_2 systems

- **Background & motivation**
  - Need to improve the performance of CO_2 systems in hot environments
  - CO_2 mixtures, such as blends of CO_2 and SO_2/$TiCl_4$, can enhance the critical point temperature
  - Technology conceived for CSP can be extended to other applications

- **Gaps & challenges**
  - Availability of precise data on thermodynamic properties of the mixtures
  - Knowledge on mixtures effect on health, environment and safety
  - Assessment off-design performance of cycles based on CO_2 mixtures

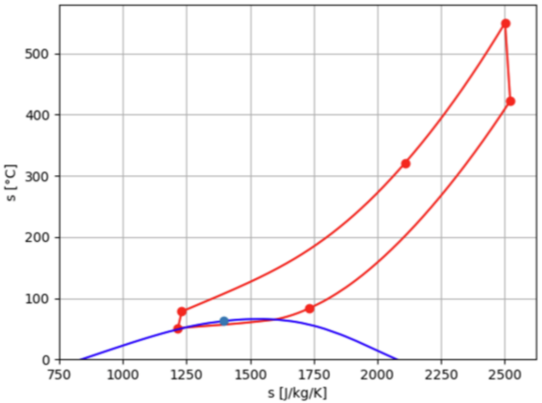


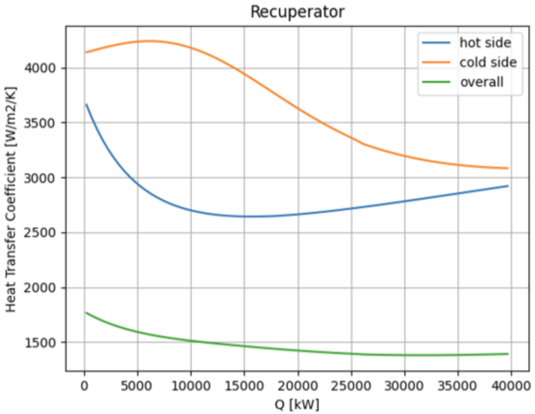
Crespi et al., Energy 2020

Topic 16: Power cycles with CO_2 mixture

Utilisation of CO_2 mixtures to enhance the performance of sCO_2 systems

- **Approach & first results**
  - Optimization leads to trans-critical cycle, with temperature change across the condensation (zeotropic mixture)
  - 1D modeling of recuperator: heat transfer coefficient shows how much the working fluid properties change near the critical point
  - Set-up of off-design models of heat exchangers and other components and first simulations performed





Collaborations

INTRA-WP AND INTER-WP BRIDGES

- **INTRA WP (WP level):**
  - Topic 2 → all Topics: sharing information on market opportunities, limitations, and main components CAPEX
  - Topic 3 → Topic 4: sharing information on power cycle and heat exchanger modeling (similar direct cycle)

- **INTER WP (Project level):**
  - Topics 1, 3, 16 → WP2: benchmarking cycle calculations at steady-state level, sharing information on off-design operation, start-up / shut down, transients
  - All Topics → WP3: sharing information and comparing models of heat exchangers (crucial for Topics 3, 4), receiving information on turbomachine sizing, performance, maps
  - Topic 2 → WP4: sharing information on manufacturing limitations and selected materials, to identify potential supply chain or market issues

WP1 publications

- “High Temperature Nuclear Cogeneration Utilizing Supercritical CO_2 for Enhanced Thermal Efficiency”, European Conference on Supercritical CO_2 for Energy Systems, Delft, The Netherlands, April 2025

- “Unconstrained Optimisation of Combined Gas Turbine & Supercritical Carbon Dioxide Cycles for Off-shore Applications”, ASME Turbo Expo 2025, Memphis, Usa, June 2025

- “Hybrid sCO2 and ORC Integration for Enhanced Waste Heat Recovery and Power Generation Efficiency”, ASME Turbo Expo 2025, Memphis, USA, June 2025

- “Exploring the Potential of Directly Fired Supercritical Carbon Dioxide Power Cycles: A Comparative Thermodynamic Approach”, 8th International Seminar On ORC Power Systems, Lappeenranta, Finland, Sept. 2025

Thank you!

giacomo.persico@polimi.it

Work package 2
System Operability

Lorenzo Cosi

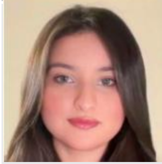
Nuovo Pignone

Work Package Objectives

sCO2 Power cycles operability

- Define the **operational strategies** of indirect (i.e. externally heated) and directly-fired supercritical sCO2 power systems
- **Assess the constraints** set by the operational strategies on the design specifications of major equipment for each energy source considered
- Define the **control operating procedures** of indirect and directly-fired sCO2 power cycles: start-up, shutdown, emergency shutdown

Topics and Partners involved

Leading Researcher		Topic	Academic Host	Industrial Host
	**Matěj Jeřábek**	**Operation of indirectly heated sCO2 cycles**	CVUT (Prague)	Baker Hughes
	**Ihtishamul Haq**	**Operation of directly-fired sCO2 cycles**	TUW (Wien)	Baker Hughes
	**Leonard Muke**	**Dynamic operation of sCO2 power generation systems under variable load and variable energy input**	USE (Seville)	SoftInWay
	**Reem Ahmed**	**Control Strategies and Optimization of sCO2 Power Generation Systems for Direct and Indirect Heating Configurations**	BUL (London)	BUL (London)

Topics Overview

Topic 1: Operation of power systems based on indirect sCO2 power cycles

Objectives

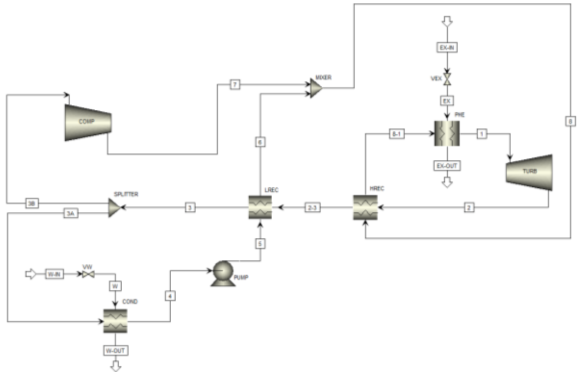
- Define the operational strategies of **externally heated cycles** in off-design and high partial loads

Identified gaps

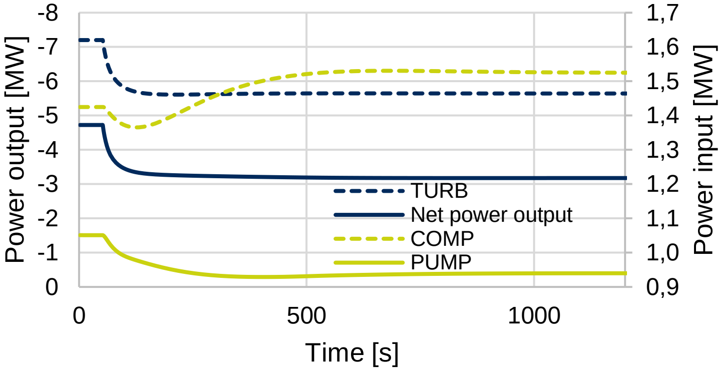
- **Limited literature** on operational strategies and relevant plant configuration features (e.g. inventory, by-pass valves, major control scenario)

Topic 1 Status and Plan

- Trans-critical Rankine cycle and Supercritical Brayton cycle selected for the analysis
- Literature review completed
- Blended (SO2-CO2) Rankine cycle transient response under assessment
- Next Steps:
  - WHR Brayton cycle dynamic simulation
  - CSP Rankine cycle dynamic simulation



Blended Rankine cycle model



Heat source temperature step change (300°C)

Topic 2: Operation of directly-fired sCO2 power systems

Objectives

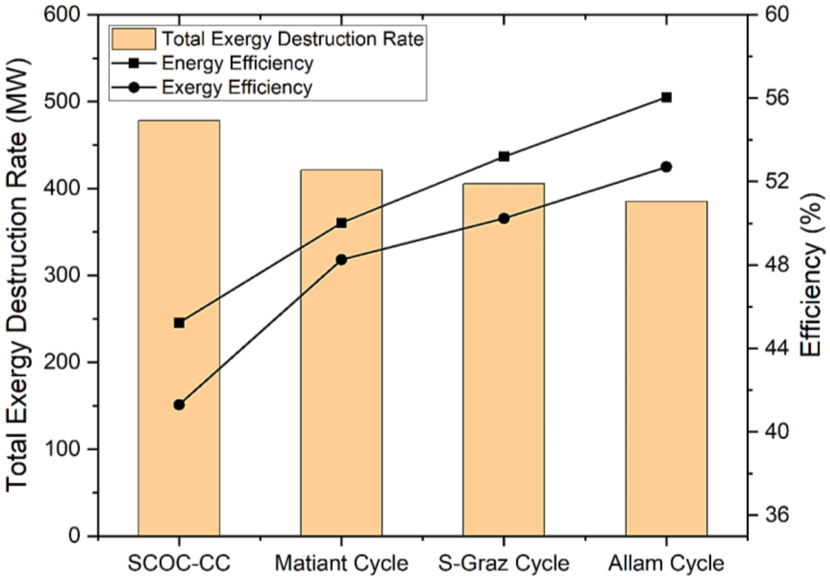
- Define the operational strategies for directly-fired sCO2 power systems.
- Assess the constraints set by the operational strategies on the design specifications of major equipment (including the Air Separation Unit)
- Define the exceptional operating procedures of directly-fired sCO2 power.

Identified gaps

- Significant literature with steady state performance assessment of different directly fired cycles (Allam, Matiant, SCOC-CC, S-Graz). **Limited insight into off design** system behavior.
- Some ASU integration strategies have been assessed but many options not yet explored

Topic 2 Status and Plan

- Literature review completed
- Allam cycle selected as the most promising among directly fired cycles available in literature
- **Focusing** operational strategy definition on **Allam cycle**



Cycles Comparison

Topic 3: Dynamic operation of sCO_2 power generation systems under variable load and variable energy input

Objectives

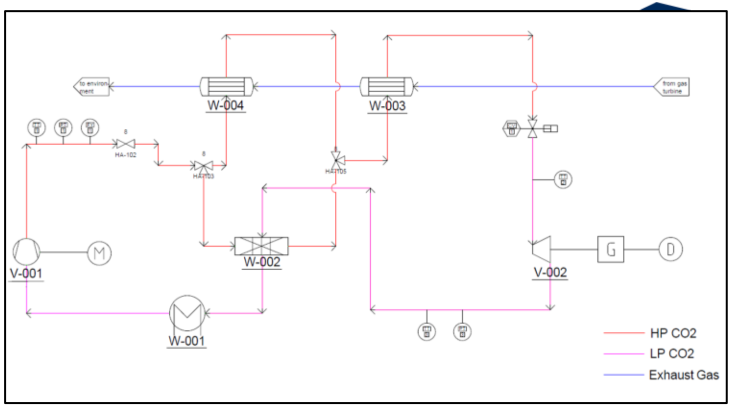
- **Develop dynamic model** to simulate transient operation of the sCO_2 cycle
- Validate the developed dynamic model with available experimental data
- Evaluate the **robustness** of sCO_2 power systems at the megawatt scale in responding to **load variations and emergency trips**
- **Assess the impact** of transient operation **on** the mechanical integrity of **critical components.**

Identified gaps

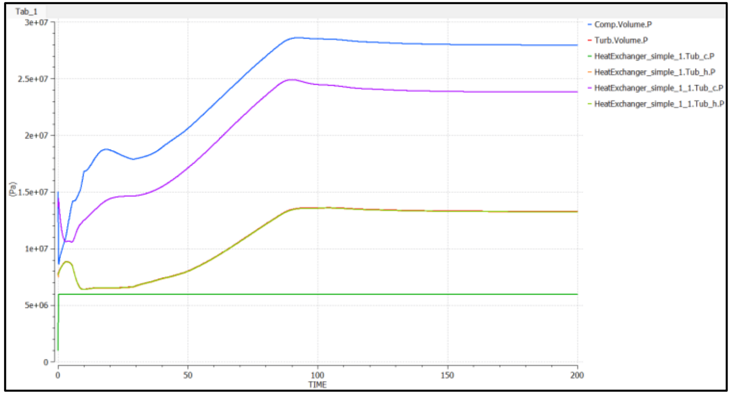
- Control Strategies for Startup, Shutdown, Load Following
- Heat Exchangers (both S&T and PCHE) dynamic modelling
- sCO_2 turbomachinery dynamic modeling
- Grid interaction of sCO_2 cycle
- Comprehensive validation with experimental data

Topic 3 Status and Plan

- Steady state investigation of GT exhaust recovery cycle completed
- Development of dynamic model ongoing, Control logic developed
- Planned component development:
  - Compressor surge model
  - Dynamic PCHE model
  - Thermal modelling of turbine



Preheating Brayton Cycle



Turbomachinery loading in hot condition

Topic 4: Control Strategies and Optimization of sCO_2 Power Generation Systems for Direct and Indirect Heating Configurations

Objectives

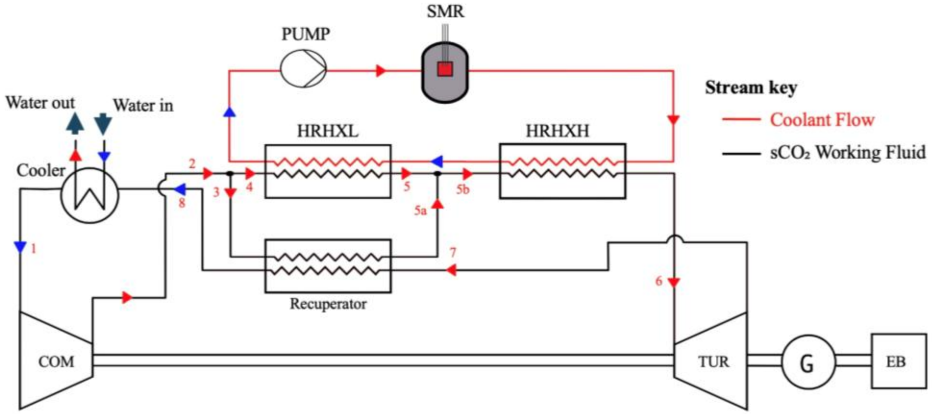
- Develop a robust dynamic simulation tool for the control systems of sCO_2 power cycles.
- Model and optimize sCO_2 system performance under varying control strategies.
- Evaluate system operability under critical conditions such as start-up, rapid load change, and fluctuating energy inputs from renewable sources.

Identified gaps

- Limited data about sCO_2 power system control (e.g. part load management)
- Lack of validation
- Advanced control methodology potential not exploited

Topic 4 Status and Plan

- 30 MWe split reheater sCO2 power cycle in SMR application selected for control strategy optimization
- Steady state model completed and validated
- Off-design model developed
- Next Steps:
  - Simulate varying operational conditions
  - Implement standard and advanced control strategy



Next Publications

Title	Conference / Journal
Thermodynamic benchmarking of sCO_2 Allam cycle against alternative oxy-fuel cycles: A comparative analysis	6th Edition of the European Conference on Supercritical CO_2 (sCO_2) for Energy Systems
Unconstrained Optimisation of Combined Cycle Gas Turbine & Supercritical Carbon Dioxide Cycles for Offshore Applications	ASME Turbo Expo 2025 Turbomachinery Technical Conference and Exposition
Dynamic Modelling and Control of a supercritical CO_2 Power Cycle for Waste Heat Recovery	8th International Seminar on ORC Power Systems 2025
Dynamic analysis of CO_2-SO_2 recompression Rankine cycle using waste heat	6th Edition of the European Conference on Supercritical CO_2 (sCO_2) for Energy Systems
Supercritical CO_2 power cycle control strategies: A Review	Applied Thermal Engineering (Elseviewer)

Collaborations

- **With WP2** researchers: **Test control strategy** on a different externally heated cycle configuration and on direct firing cycle configuration
- **With WP3** researchers: Heat Exchanger dynamic modeling and Turbomachinery modeling
- **With WP1** researchers: Optimal cycle definition

Conclusions

- Identified significant **literature gaps** in this area
- Proposed research **covers the major sCO2 power cycles** concepts
- Initial results will be **published this year**
- Relevant **collaborations** within WP2 team members and with WP1 and WP3 reseachers

Thank you!

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Work package 3 Component Innovations, Turbomachinery and Heat Exchangers.

Abdulnaser Sayma

Brunel University of London

WP3 Objectives

Component Innovations, Turbomachinery and Heat Exchangers.

- Improve sCO_2 Compressor Off-Design Performance.
- Optimise sCO_2 Turbine Flow Paths – Enhance off-design and transient performance
- Advance sCO_2 Heat Exchanger Design.

WP3 Challenges

- The need to develop suitable design and analysis tools for large scale sCO_2 turbomachinery
- Modelling flow and heat transfer phenomena close to critical point including two phase flow
- Understanding the implications of extreme transient and stationery conditions on Gas dynamic, thermal and mechanical behaviour

WP3 Expected Outcomes

- Advanced-validated design and analysis tools for key system components: Compressors, Turbines, Heat Exchangers
- Improved understanding of the off-design and transient behaviour of sCO_2 turbomachinery for large scale power plants
- Improved understanding of the flow behaviour and design requirements for sCO_2 heat exchangers

Who’s who

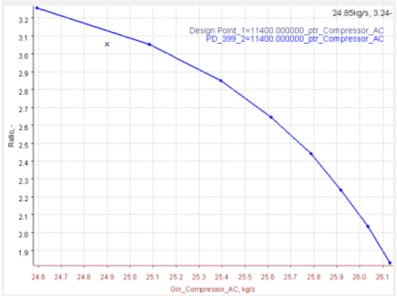
Combination of Academic and Industrial Hosts, 5 students

Phd student		Topic	Academic Host	Industrial Host
	Mohammed Alnajjar (DC9)	Fundamental studies to enhance off-design performance of megawatt scale sCO_2 compressors	Brunel University of London	SoftInWay (collaboration)
	Muhammad Nouman Saleem (DC10)	Megawatt scale axial sCO_2 Turbine flow path enhancement to improve Off-Design Performance	Politecnico di Milano	Baker Hughes
	Adonis Constantinidis Brevi (DC17)	Turbine designs for enhance flexibility of MW scale axial sCO_2 turbines	University of Seville	Siemens Energy
	Davide Dioguardi (DC11)	Fundamental study of pseudo-condensation in supercritical CO_2	University of Stuttgart	Tecnicas Reunidas SA
	Ahmad Ali Awais (DC12)	Numerical Investigation of the Mixing process in the headers of sCO_2 heat exchangers	University of Stuttgart	Fives Cryo

DC work programmes

DC9 – Mohammed Alnajjar – Brunel University of London

Research Topic: Fundamental studies to enhance off-design performance of megawatt scale sCO2 compressors

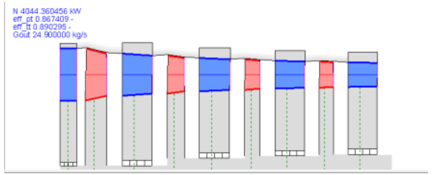


Motivation and Objectives:

- Develop and validate sCO2 compressor off-design performance models
- To investigate strategies to enhance off-design performance

Identified Research gaps:

- Limited experimental data.
- Modelling and Simulation Challenges particularly at off-design

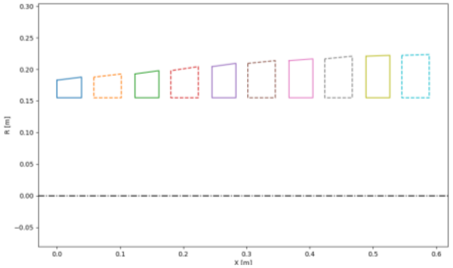


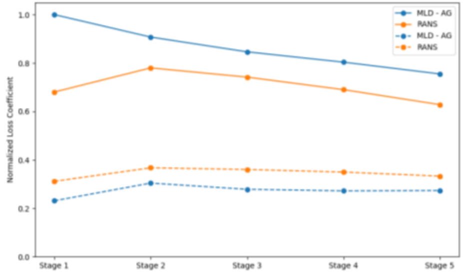
Status and progress:

- Preliminary designs and Compressor performance maps using AxSTREAM
- Ongoing Development of a novel streamline curvature throughflow model for sCO2 axial flow compressors

DC10 – Nouman Saleem - Politecnico Di Milano

Research Topic: Megawatt scale axial sCO_2 Turbine flow path enhancement to improve Off-Design Performance





Motivation and Objectives:

- Optimisation of the turbine flow path to maximise performance
- Assess and quantify secondary flow losses in low aspect ratio sCO2 turbines
- To produce off-design performance maps for the optimised flow path

Identified Research gaps:

- Compact machine, aspect ratio <1.0 (10 x smaller than conventional steam turbines)
- Lack of experimental data for sCO_2 turbines for validation

Status and progress:

- Comparison of sCO_2 turbine gas dynamic losses usinflow and high-fidelity modelling techniques
- Investigation of secondary flows in low aspect ratio axial flow sCO_2 turbine
- Design of seals to reduce leakage flow across axial flow sCO_2 turbine blade

DC17 – Adonis Constantinidis Brevi – University of Sevil

Research Topic: Innovative turbine designs for enhanced flexibility of megawatt scale axial sCO2 turbines

Motivation and Objectives:

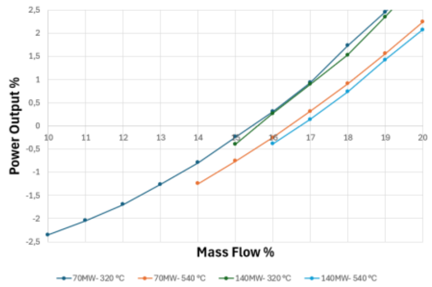
- To investigate innovative turbine designs that enhance the dynamic performance of sCO2 turbines.
- To analyse flow path configurations that improve the turndown capability of sCO2 turbines.

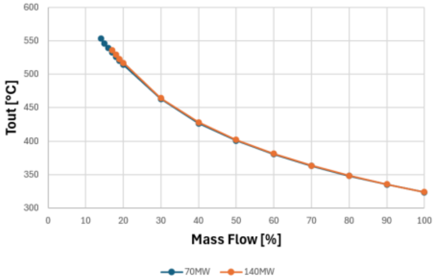
Identified Research gaps:

- Increased need for a more flexible network, resulting in a need for improved off-design operation to support flexibility.
- Lack of knowledge in part-load phenomena in sCO_2 turbines such as windage effect and its consequences

Status and progress:

- Turbine mean-line code and validation (KARAWAL)
- Windage effect review and analyses.





DC11 – Davide Dioguardi - UNIVERSITY OF STUTTGART

Research Topic: Fundamental study of pseudo-condensation in supercritical CO_2

Motivation and Objectives:

- Empirical investigation of sCO_2 pseudo-condensation
- Optimal heat exchangers design

Identified Research gaps:

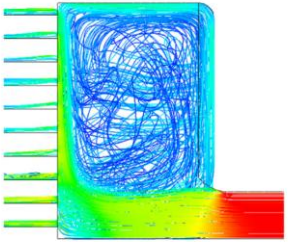
- Experiments showed incomplete condensation (pipe surrounded by cold water flow)
- Improve knowledge about presence of stratification, and how to avoid it
- Need to identify optimal parameters for heat exchangers design

Intended work:

- Perform experiments using the SCARLETT facility
- Test setup to analyse pseudo-condensation
- Obtain High quality data on pseudo-condensation

DC12 – Ahmad Ali Awais- UNIVERSITY OF STUTTGART

Research Topic: Numerical Investigation of the Mixing proce headers of sCO_2 heat exchangers



Motivation and Objectives:

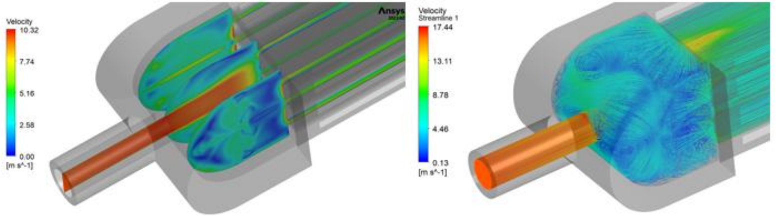
- Numerical investigation of mixing inside the headers
- Derive design recommendations and test conceptual header design
- Thermal stress and fatigue analysis to predict failure in heat exchangers

Identified Research gaps:

- Inefficient distributor header design can cause severe flow maldistribution across the channels of the heat exchanger.
- This causes local hotspots and thermal stresses in heat exchangers and should be addressed.

Intended work:

- Optimise the distributor header design for uniform flow distribution
- Test different header profiles and shapes
- Test header design under varying operating conditions
- Fatigue testing to predict failure in heat exchanger



Thank you!

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Work package 4
Materials and Manufacturing

M. Fátima Montemor
Técnico – Lisboa

WP Objectives

To develop advanced modelling and experimental methods to support selection and development of materials, coatings and manufacturing techniques that would enable reliable and safer operation of key components in sCO_2 power cycles

- Advance modelling techniques
- Test and create knowledge on materials (Metals and coatings) durability for sCO_2 facilities
- Support materials selection for sCO_2 applications
- Propose new manufacturing techniques for advancing materials durability (e.g. Additive manufacturing)
- Understand the degradation of polymers in sCO_2 facilities

WP Challenges

- Wide range of operating temperatures (25 to 700+) and pressures (0.1 to 250 bar)
- Different exposure media: oxygen, cold + hot water, steam, HCl, H_2S, CO_2, sCO_2…
- Many different materials can be used
- Require combination of different materials in very harsh conditions

WP outcomes (fill the gap)

- Performance of materials in medium to high temperature ranges
- Corrosion rates, exfoliation, and their mechanisms
- Formation of oxide scales: when and how?
- Effect of contaminants in the media
- Understand onset of corrosion and other ageing mechanisms
- Develop coatings and fillers to mitigate sCO2 uptake
- Understand coatings and polymers failure (initiation and growth)
- Monitoring techniques
- Use of materials fabricated by AM
- Guidelines regarding materials for different ranges of P and T

Who’s who

3 Doctoral Candidates on materials solutions for sCO_2 technologies

Leading Researcher		Topic	Academic Host	Industrial Host
	**Mayra Akhtar (DC13)**	**Coatings** Advancing the durability of polymeric parts and coated components in sCO_2 power systems	Técnico Lisboa	CiTD
	**Jules Aeby (DC14)**	**Metals and alloys** Advancing the durability of corrosion resistant alloys for sCO_2 power systems	Técnico Lisboa	CiTD
	**Mohamed Khaled (DC15)**	**Heat Exchangers** Additive manufacturing technologies of heat exchangers	University of Stuttgart	CiTD

WP management

Timeline, Deliverable, Milestones

- Timeline

 - Start-up of DCs: September – December 2023

 - End of PhD programs: September – December 2026

- Deliverables

D4.1: Advance materials and super alloys, (month 38)

D4.2: Additive manufacturing for next generation of energy (month 32)

DC working programs

DC13 – Mayra Akhtar

Advancing the durability of polymeric, metallic parts and coated components in sCO2 power systems

- Background and motivation
  - Materials durability is critical in sCO2 applications.
  - High temperature and high pressures, in the presence of moisture and contaminants, induces corrosion.
  - Corrosion is the major cause of equipment and structures failure.
  - Materials for sCO2 range from metals and alloys to coatings, polymers and sealants.

- Rationale, objectives & outcomes
  - Mechanism of degradation of polymer chemistries (Polyolefin, PTFE, urethanes) in sCO2 conditions.
  - Self-healing polymer to minimize mechanical damage and formation of voids & cracks.
  - Non-destructive evaluation (NDE) techniques and applicability evaluation.
  - Additive manufacturing technologies with corrosion resistance.

DC13 – Mayra Akhtar

Advancing the durability of polymeric, metallic parts and coated components in sCO2 power systems

- Status of the research and main results
  - Selection of polysilazane for environments simulating sCO2 conditions for carbon steel.
  - Inhibitor particles optimization for polysilazane coating.
  - Testing and optimizing polysilazane coating for different temperature ranges of 200˚C - 800˚C.
  - A novel system carrying self-healing matrix cerium loaded modified hydroxyapatite particles for corrosion protection.

- Expected scientific outcomes
  - Presented the poster at CQE event Coimbra university and Técnico PhD Open Days.
  - To attend European sCO2 Conference for Energy Systems 2026, EUROCORR 2026 and International Conference on High-Temperature Materials and Processes (ICHTMP) to share insights and gain feedback.

DC14 – Jules Thibault Aeby

Advancing the durability of corrosion resistant alloys for sCO2 power systems

- Background and motivation
  - High pressures and temperatures, in supercritical state and over 450°C, alongside the reactivity of CO_2, require careful material selection and advanced component and system fabrication techniques to ensure safe operation.
  - Typical corrosion in these environments is rapid oxidation coupled with carburization, leading in the long term to breakaway failures.
- Rationale, objectives & outcomes
  - To understand the implications of extreme operating conditions on the material requirements of components in sCO2 power systems.
  - To develop advanced modelling and experimental methods that enable selection and development of materials.

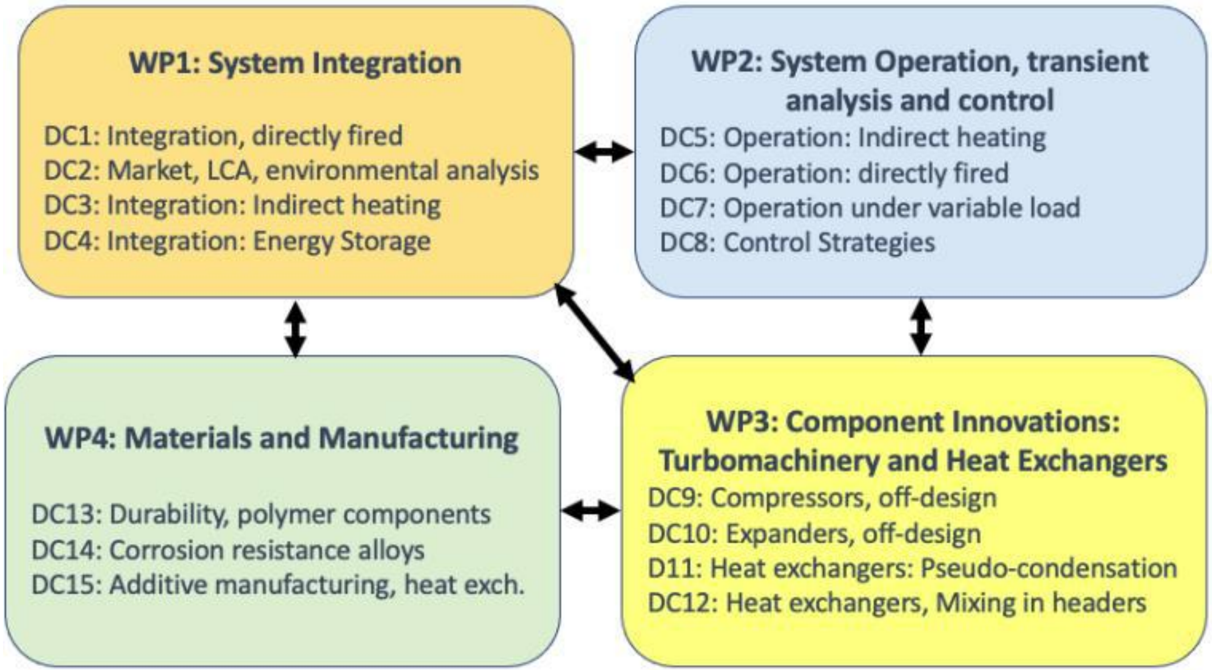
DC 15 – Mohamed Khaled

Additive Manufacturing Technologies for Heat Exchanger Applications in sCO2 Power System:

- Evaluate design methodologies and geometry optimization through simulations for enhancing HX applications in sCO2 power systems.
- Investigate different alloys for its processability through additive manufacturing technologies.
- Analyze the optimum AM process parameters for desired application.
- Characterize the material: thermo-mechanical and chemical properties as well as microstructure.
- Investigate post processing steps, including thermal treatments, surface finishing, weldability, etc.
- Evaluate the best AM technology for producing the targeted components and geometries through representative samples.
- Investigate on non destructive evaluation techniques for highly complex geometries validation.
- Investigate the functional capacity of HX demonstrators with special focus on sCO2 power systems.
- Print a small-scale prototype with additive manufacturing (AM) technologies.
- Derive recommendation for designers and manufacturers.

Collaborations

INTRA- AND INTER-WP BRIDGES



Thank you!

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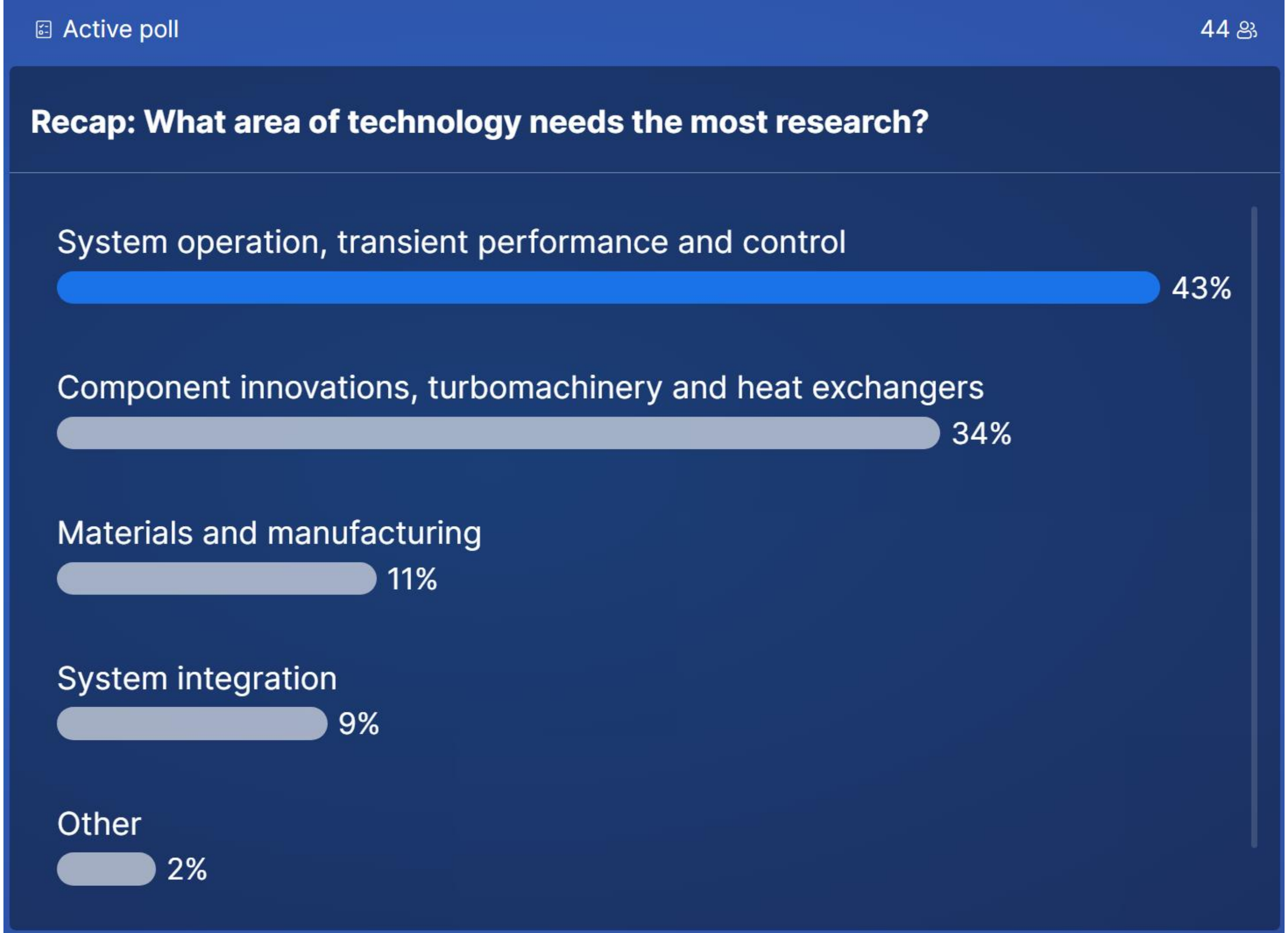
Active poll
44
Recap: What area of technology needs the most research?
System operation, transient performance and control
43%
Component innovations, turbomachinery and heat exchangers
34%
Materials and manufacturing
11%
System integration
9%
Other
2%

Thank you and see you next time!

Question / comments?

js@etn.global