SUPERCRITICAL CARBON DIOXIDE/ALTERNATIVE FLUID BLENDS FOR EFFICIENCY UPGRADE OF SOLAR POWER PLANT

3rd European supercritical CO_2 Conference

September 19-20, 2019, Paris, France

Presentation Outline

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

Introduction

Blending rationale

Preliminary results

Integration in CSP plant

The SCARABEUS project

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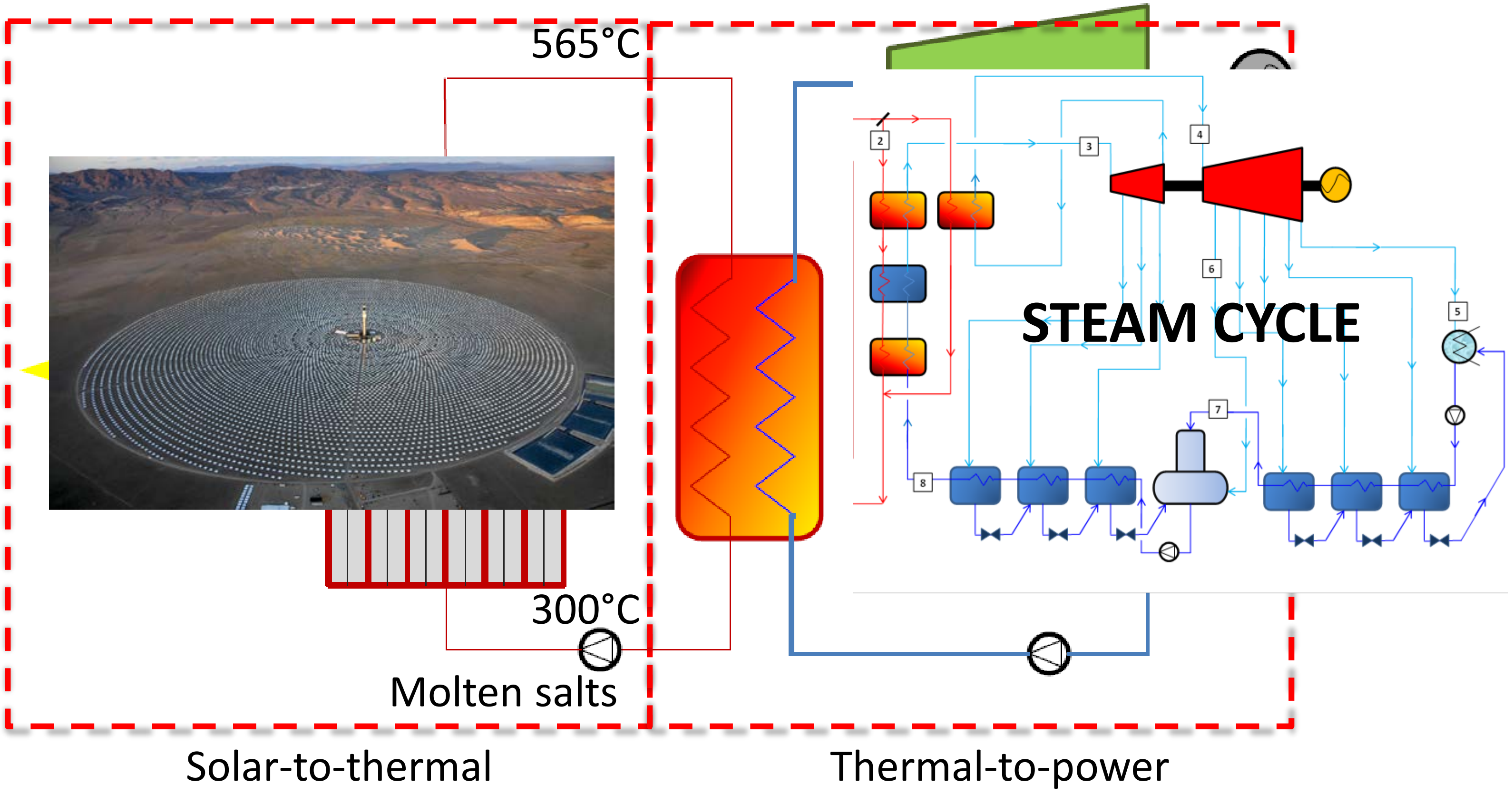
Solar Energy → Thermal power → Electricity



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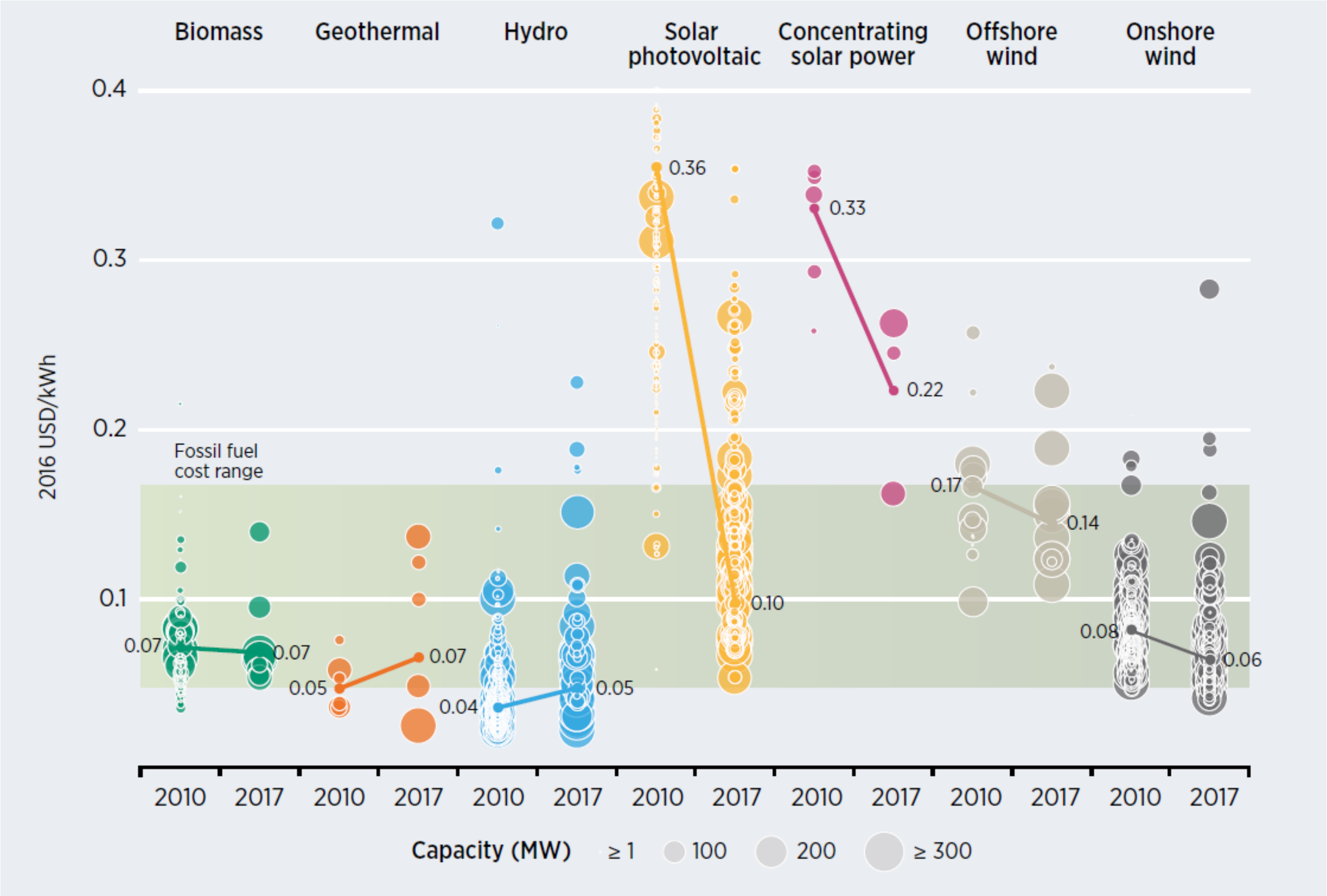

	Investment Cost ($/kW)		Capacity Factor		LCOE ($/MWh)	
	2015	2025	2015	2025	2015	2025
PTC	5550	3700	41%	45%	150-190	90-120
ST	5700	3600	46%	49%	150-190	80-110

Source: IRENA Cost database

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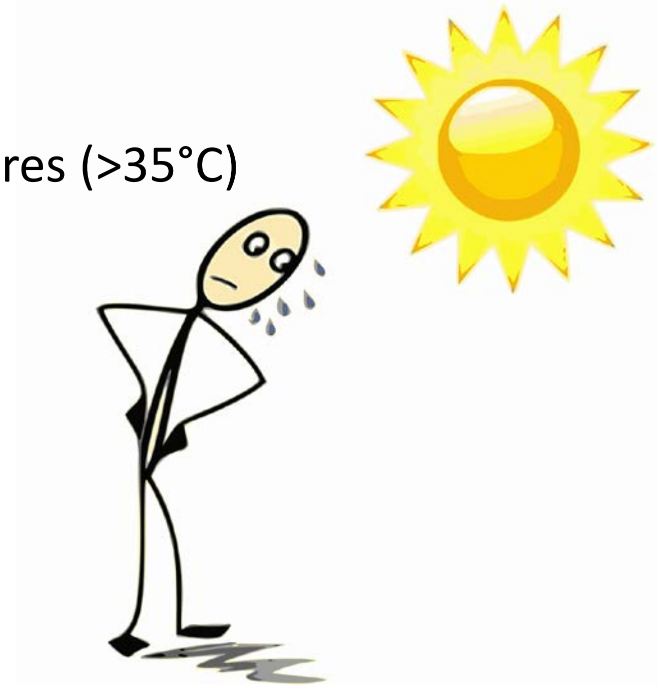
Main issues:
High overall specific capital costs (>5000 €/kW)
Low operating hours (around 4500 h/y)
Adoption of steam cycle with limited power output (50 to 150 MW)
Low conversion efficiency mostly because of the power cycle size and operating temperatures (max 565°C)

Can sCO2 solve the problem?

CSP site characteristics:
High ambient temperatures (>35°C)
Absence of water



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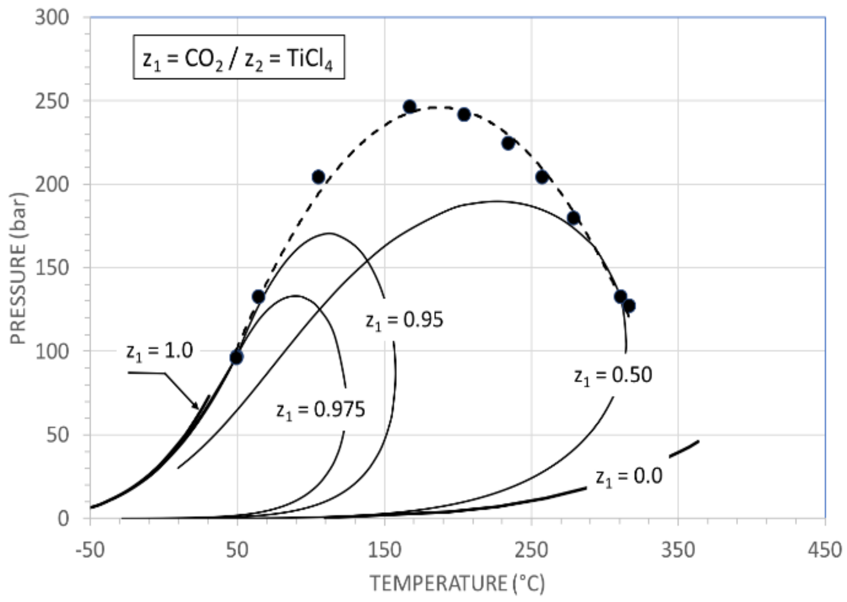
CO_2 blending aims at modifying the critical properties (temperature and pressure) of the working fluid.



Research Institute	Years	Fluid	Temperature Range
SANDIA	2011-2013	Binary mixtures of carbon dioxide and Sulphur Hexafluoride (SF6) and different hydrocarbons.	50 °C to 160 °C
KAIST	2011	Binary mixture of $CO_2$and: argon, xenon, nitrogen, oxygen.	580 °C
UNIBS	2012-2014	Mixtures of CO_2 and hydrocarbons: benzene and toluene	400 °C
UNIBS – POLIMI	2016-2018	Binary mixtures of CO_2 with Di-Nitrogen Tetroxide (N_2O_4) and Titanium Tetracholride ($TiCl_4$)	400 °C to 700°C
UNIBS	2017	Mixtures of carbon dioxide and n-butane, sulphur hexafluoride, toluene	<350 °C
Czech TU in Prague	2016-2017	Binary mixture of CO_2 and: He, O_2, N_2, Ar, CH_4 (methane), H_2S (Hydrogen Sulfide), CO	550°C
Xian Jaotong University	2018	Binary mixture of CO_2 and hydrocarbons/organic fluids	<330°C

Preliminary analysis

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Assessment performed on some blends: $TiCl_4$, N_2O_4
Calculation performed with ASPEN PLUS V9.0
Thermodynamic properties determined using PENG-ROBINSON equation of state
PENG-ROBINSON calibrated on available experimental data taken from literature

Assumptions:
Dry condenser
Minimum cycle temperature 51°C
Simple regenerative cycle
Assumed polytropic efficiency of the turbomachinery
Economic assessment based on commercial software (Thermoflex) and a work available in literautre (Ho, Carlson, J. Sol. Energy Eng. 138 (2016) 51004. doi:10.1115/1.4033573)

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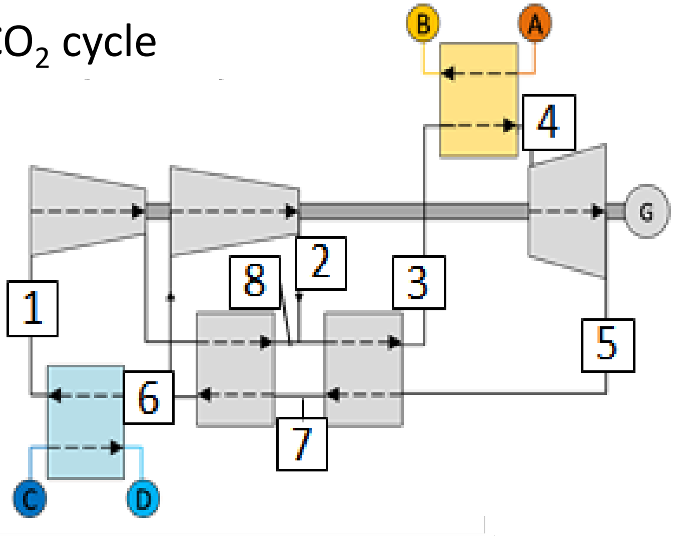
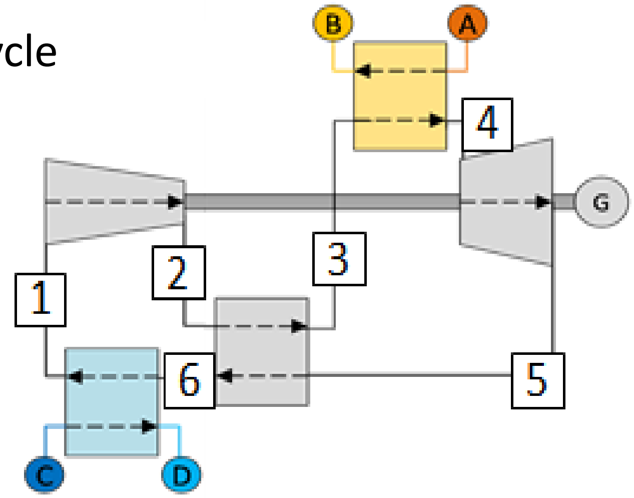
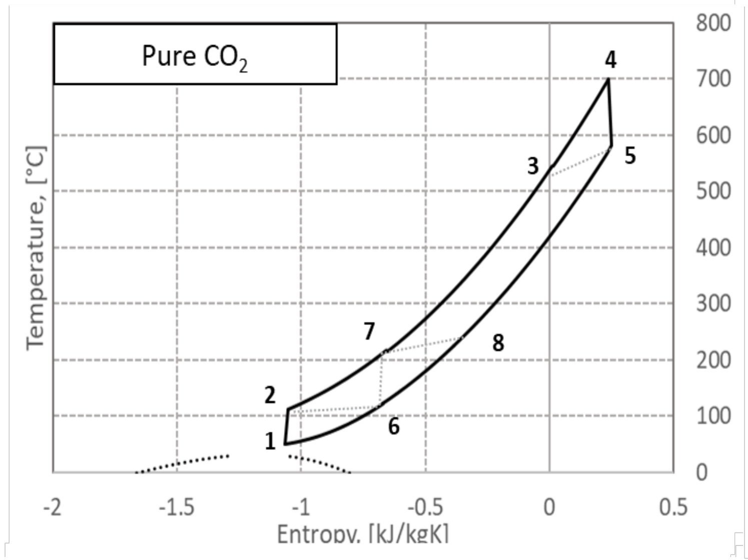
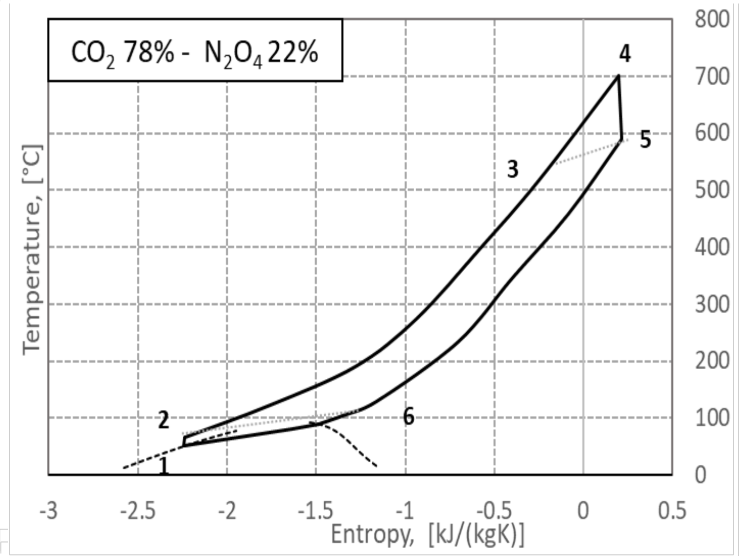
sCO_2 cycle

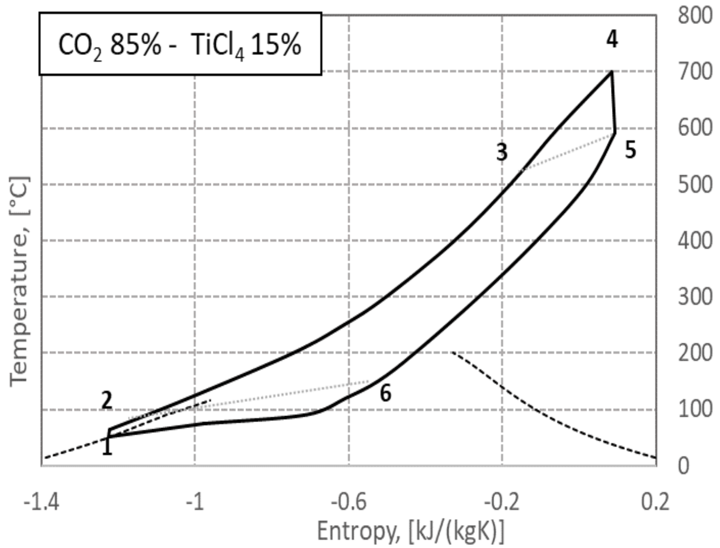


CO_2 blend cycle









Manzolini, G et al.(2019) Solar Energy, Volume 181, Pages 530-544

CO2 blends cycle performance and costs

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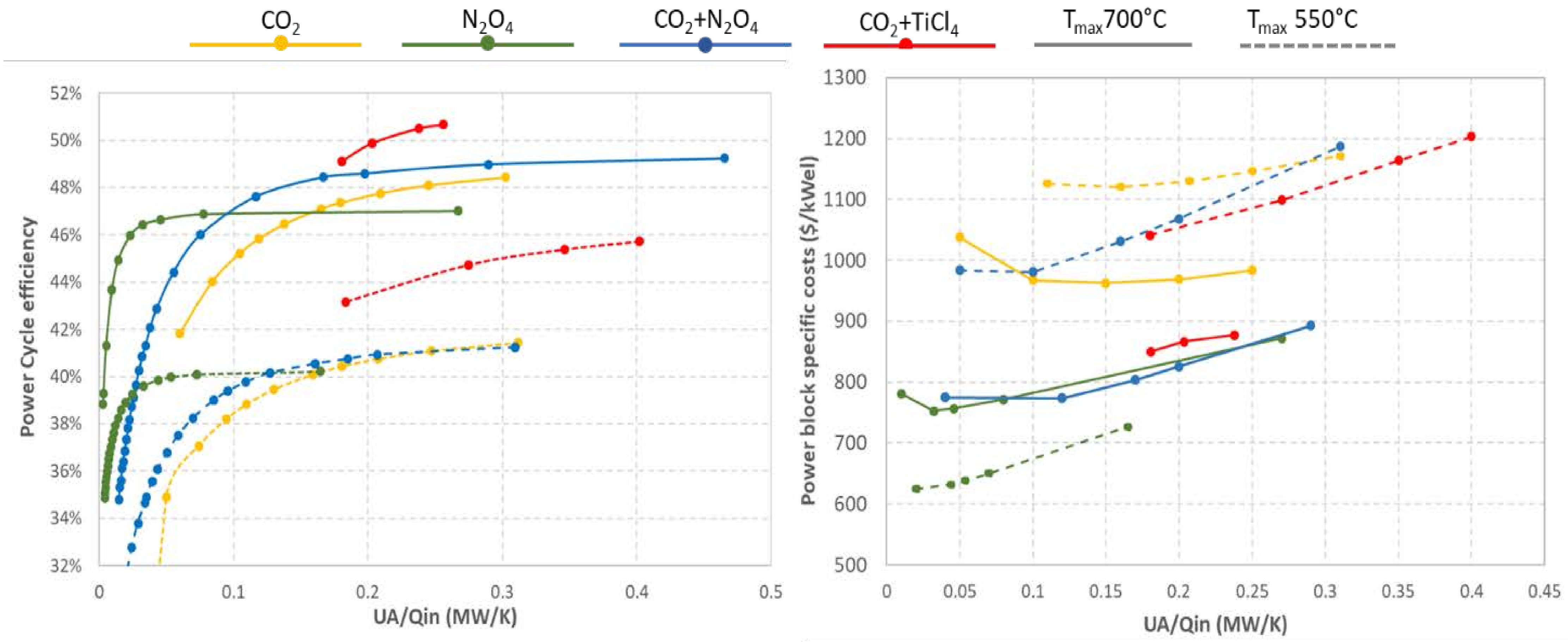

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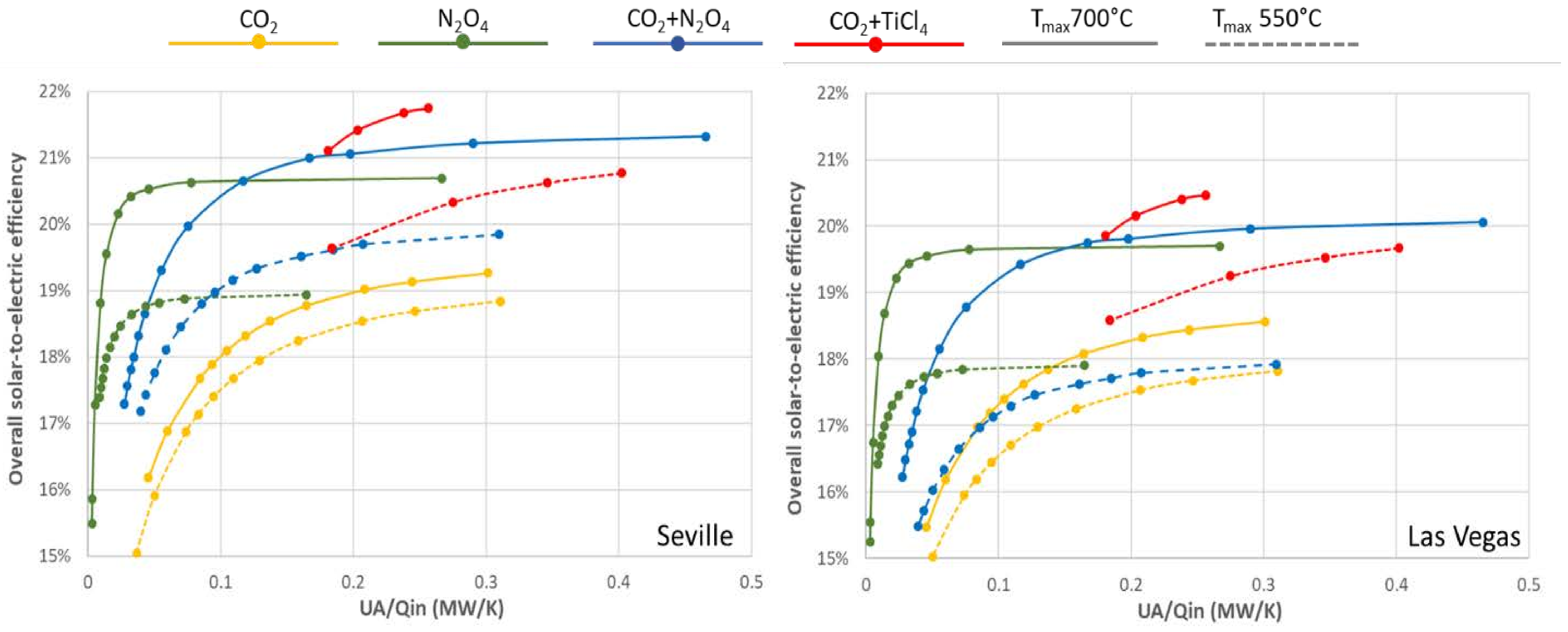

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CO_2 blends can be promising for CSP application:

Higher performance and lower cost wrt sCO2

However:

Performance strongly depends on adopted EOS → lack of experimental data

Thermal stability of the blend hast still to be demonstrated

Dynamic behaviour of the blend must be evaluated

Turbomachinery must be designed and performance evaluated

Heat exchangers must be developed

Economic assumptions must be checked.

Project objectives

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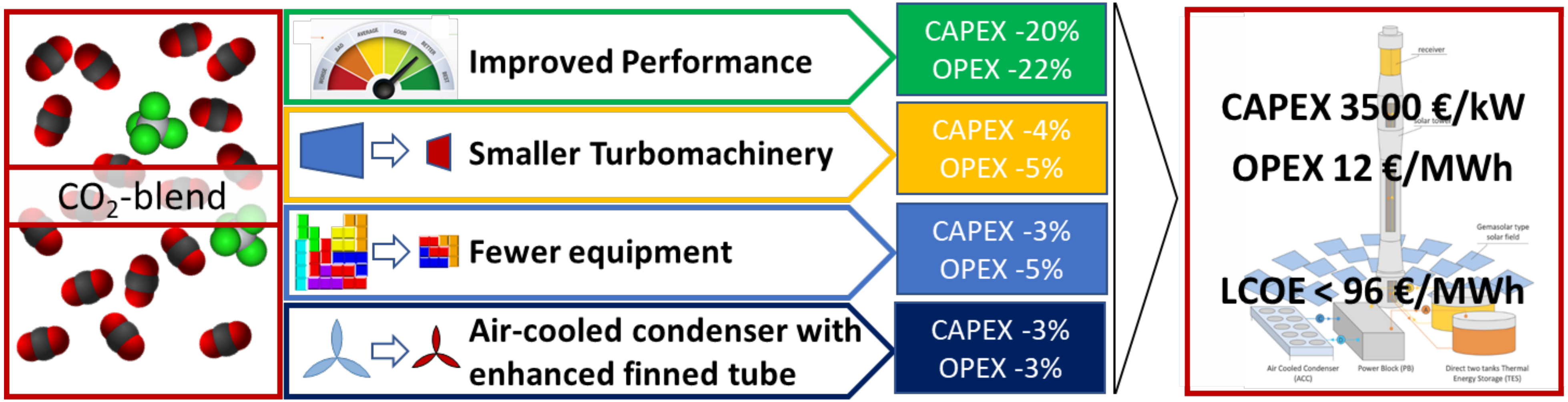
The aim of the **SCARABEUS project** is to **demonstrate** that the application of **supercritical CO_2 blends to CSP plants** has the potential **to reduce CAPEX by 30% and OPEX by 35%** with respect to state-of-the-art steam cycles, thus exceeding the reduction achievable with standard supercritical CO_2 technology. This translates into a **LCoE lower than 96 €/MWh, which is 30% lower than currently possible**. The project will **demonstrate the innovative fluid** and newly developed heat-exchangers **at a relevant scale (300 kW_{th}) for 300 h** in a CSP-like operating environment.



The consortium

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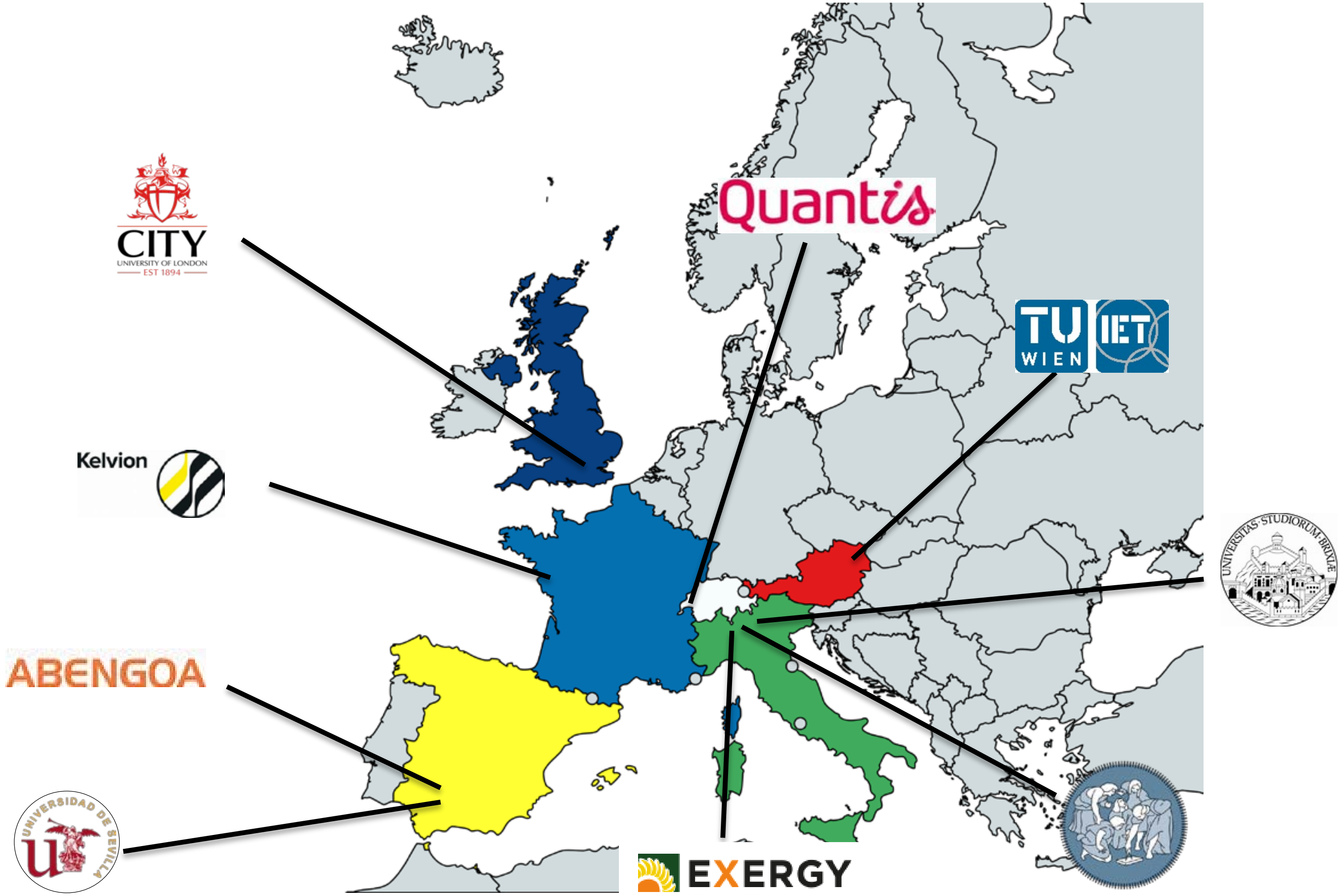

Five universities

- City, University of London (UK)
- Politecnico di Milano (IT)
- Technical University of Wien (AT)
- Universidad de Seville (ES)
- Università degli studi di Brescia (IT)

One SME

- Quantis (CH)

Three large companies

- Abengoa (ES)
- Exergy (IT)
- Kelvion (FR)

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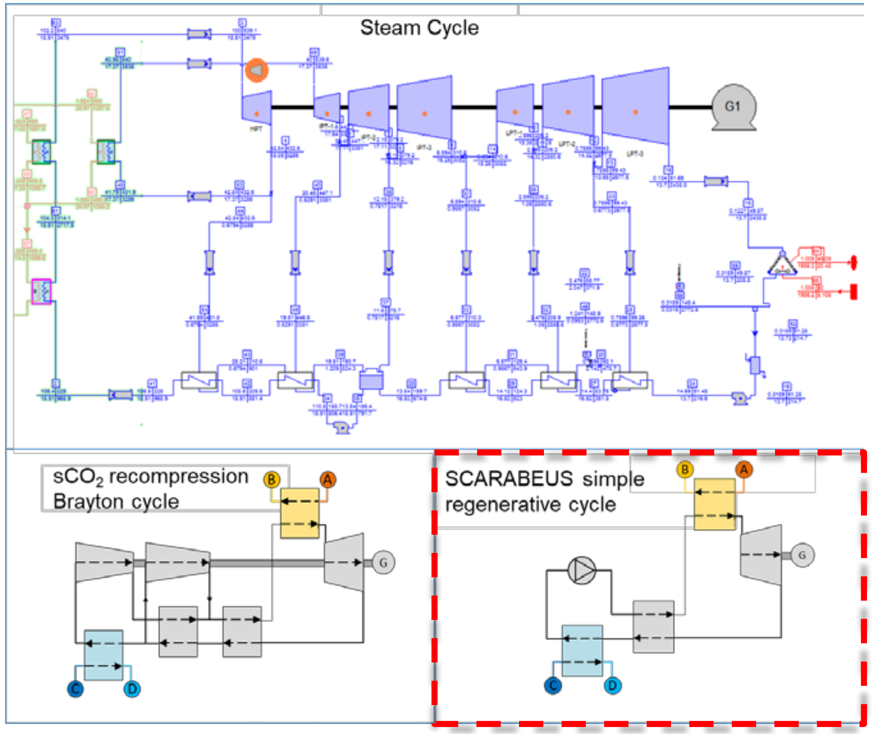
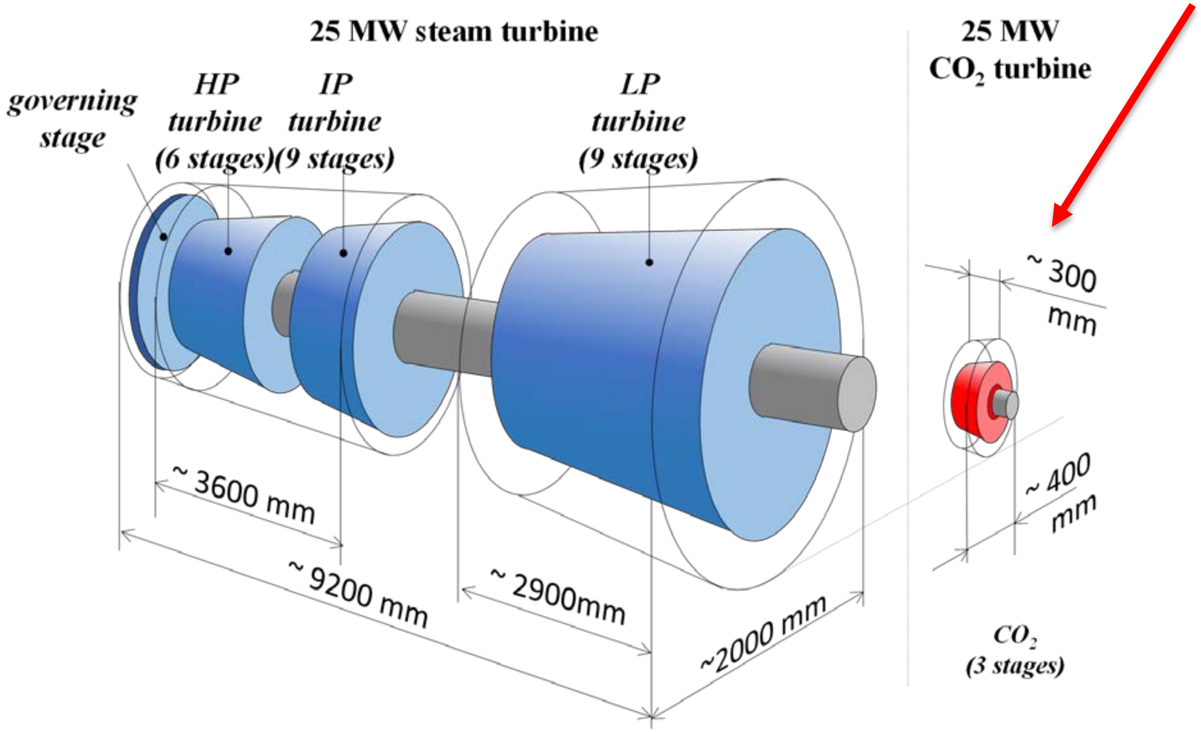
The **addition of small quantities** of selected compounds to the pure CO_2, yielding the so-called blended CO_2, can raise the corresponding critical temperature and **enable condensation at temperatures of 50°C to 60°C. leading to higher thermal-to-electricity conversion** efficiency with respect to conventional steam and sCO2 cycles.

Simpler cycle (reduced equipment)



Smaller turbomachinery



Project structure

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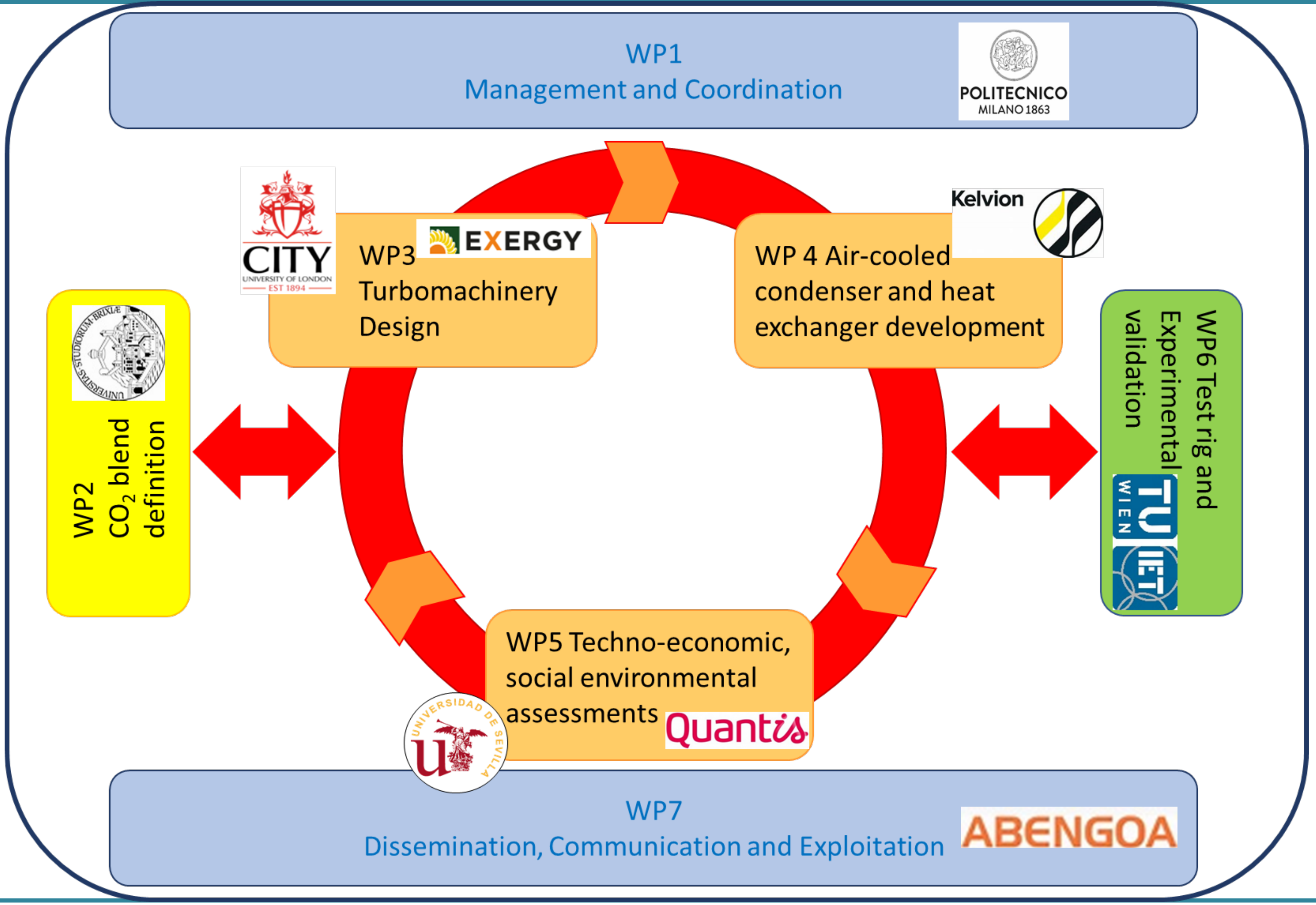

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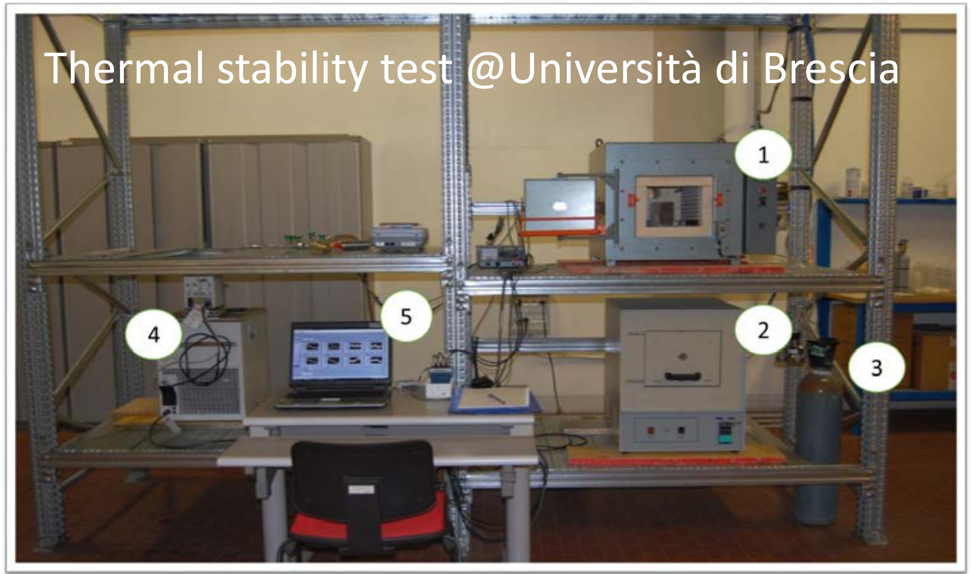
Objectives

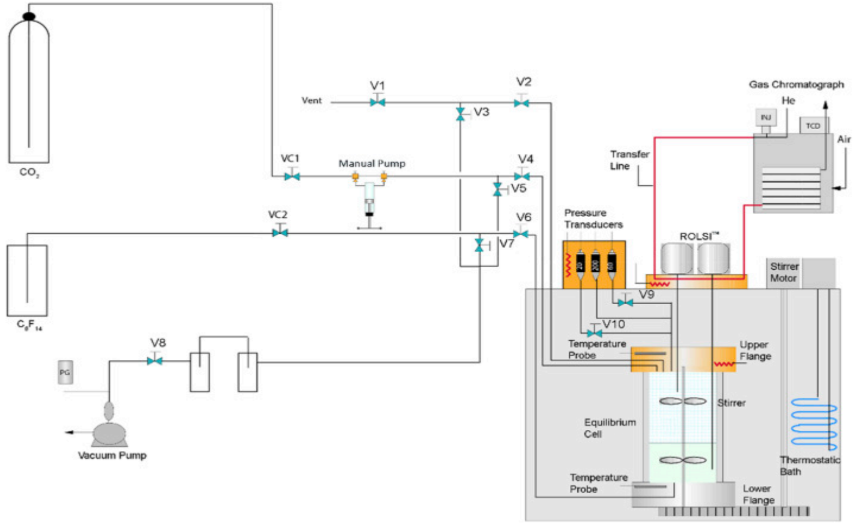
- **Determine the most promising fluid** for blending the CO_2
- **Assess the thermodynamic properties** of the blended CO_2 in terms of critical curve and their stability up to 700 °C
- **Demonstrate the thermal stability** of the two CO_2 blends for 2000 hours

Experimental facilities:



Thermal stability test @Università di Brescia

VLE Apparatus @LEAP/Politecnico di Milano



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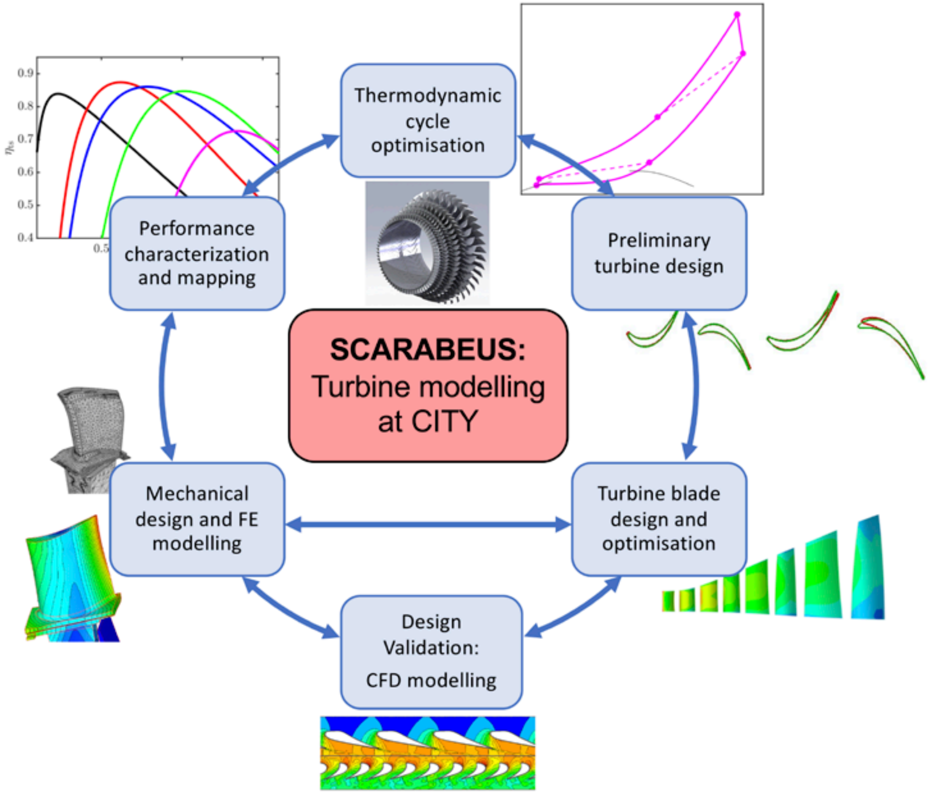
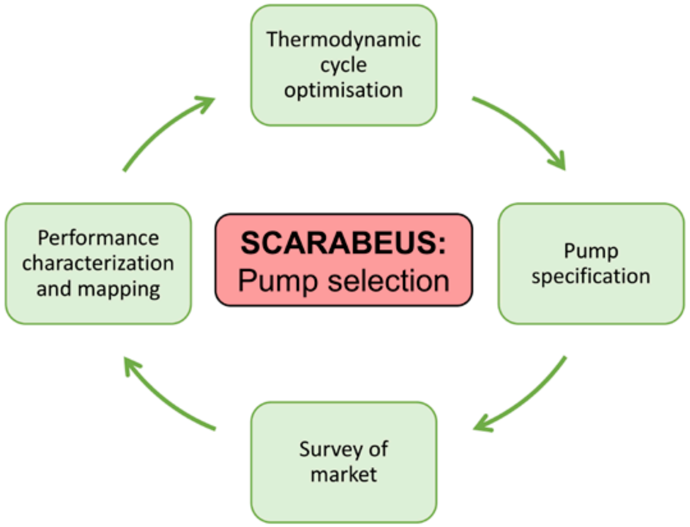
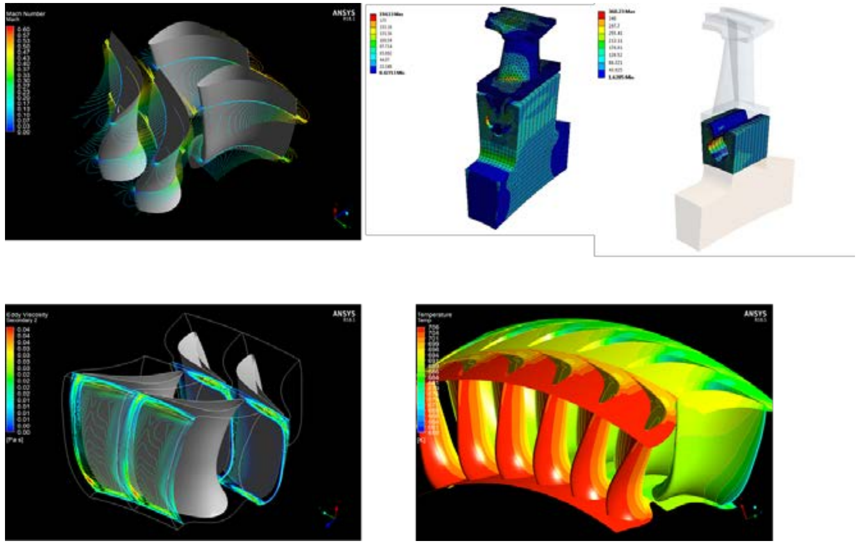
Objectives

- To develop **innovative turbomachinery designs** that are able to operate **with high efficiency** across the range of anticipated variable operating conditions to sustain a high cycle efficiency.
- The ultimate goal is to **enable accurate calculations of cycle performance and costing** of the proposed plant.





Design approach @Exergy



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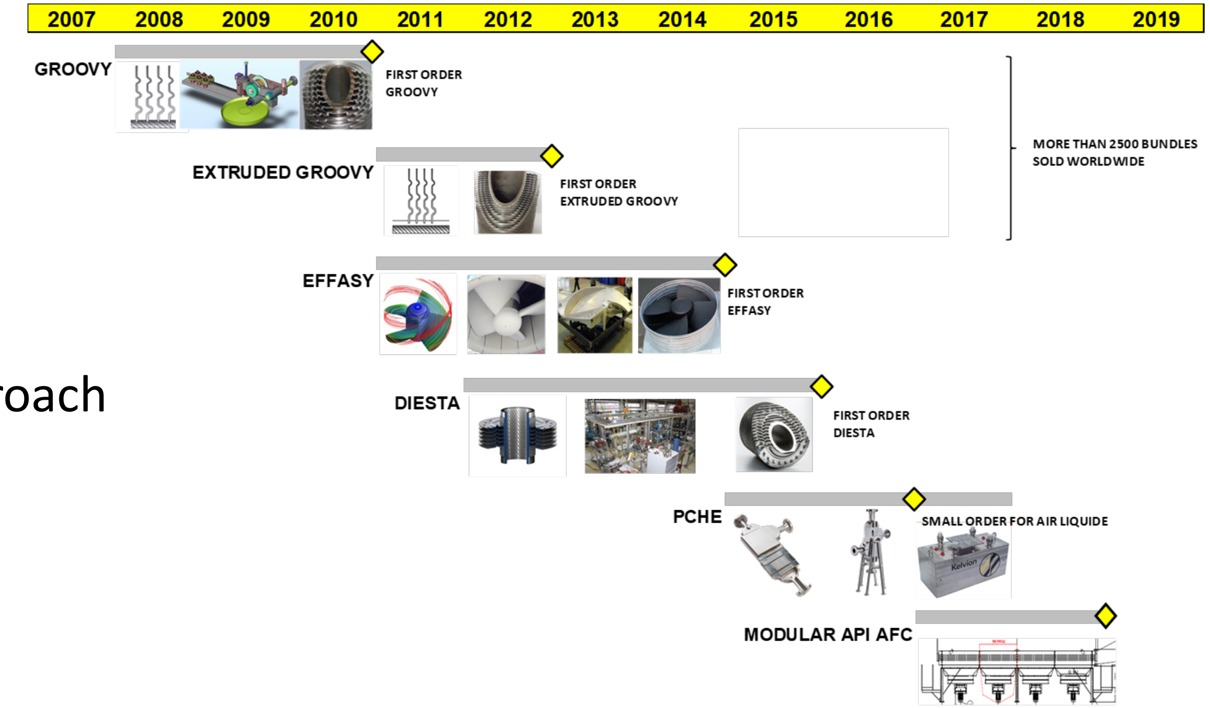
Objectives:

- **Optimize the design of an air-cooled condenser** and a **recuperative heat exchanger** specially tailored for the blended CO_2
- **Design and manufacturing** of the recuperative heat exchanger and air-cooled condenser for the testing
- **Design and cost assessment** of large scale recuperative heat exchanger and air-cooled condenser

Kelvion R&D approach



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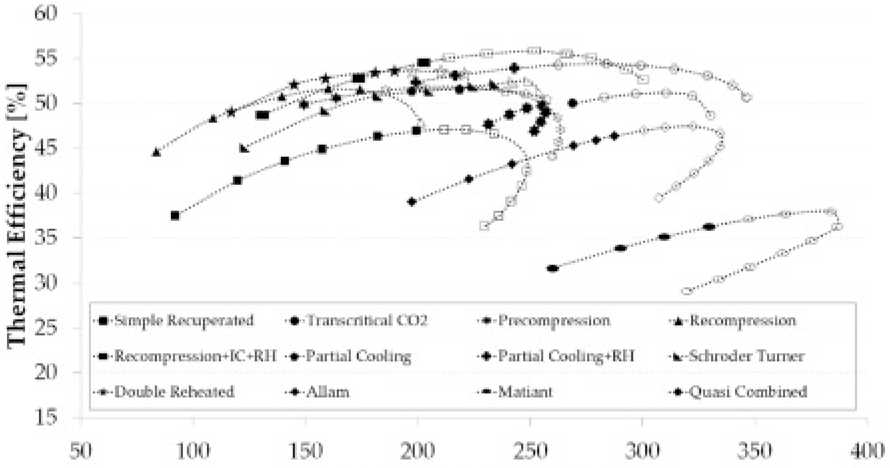
Objectives

- **Assess the economic performance** to demonstrate the targeted cost reduction (CAPEX =3500 €/kW$_e$,OPEX=12 €/MWh$_e$,LCOE <96 €/MWh$_e$);
- **Determine the environmental impact** concept by means of Life Cycle Assessment;
- **Identify and quantify the social impact** at large of the SCARABEUS concept through the Natural Capital Valuation Assessment

Universidad de Seville cycle optimization



(a) Comparison of cycles operating at TIT=750 °C

Quantis approach for LCA

Abengoa industrial view

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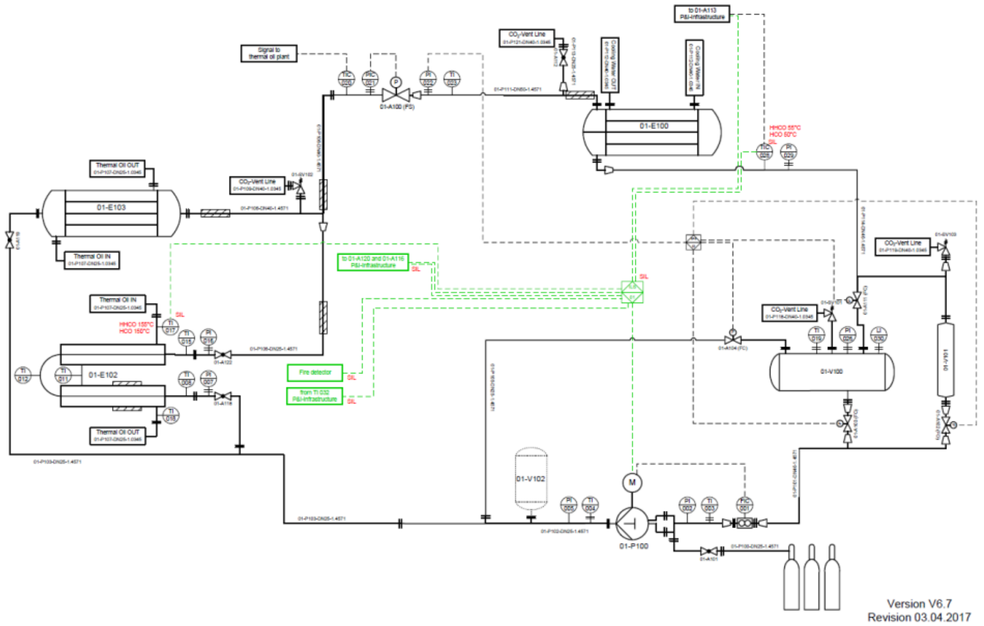
Objectives

- **Successful demonstration of the operation with sCO2 blend for more than 300 hours**
- **Demonstration of the new heat exchangers** (recuperative and air-cooled condenser) operating with the sCO2 blend

Test rig @ Technische Universiteit of Wien



Project timeline

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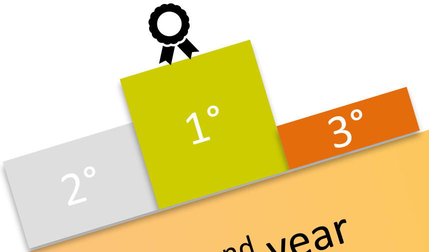
April 2019

1st year

Identification of the most-promising CO_2 blends



2nd year

Selection of the CO_2 blends and demonstration of efficiency and cost targets

3th year

Inauguration of the test rig and CO_2 blend testing

March 2023

Demonstration of the SCARABEUS technology

SMART targets

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Technical objectives:

- To develop **an innovative cycle concept**, specifically tailored to the proposed working fluid, which can achieve a **thermomechanical conversion efficiency higher than 50%;**
- To **develop and demonstrate innovative heat exchangers**, in particular air-cooled condensers, which can fully exploit the properties of the new working fluid;
- To **develop innovative turbomachinery designs** achieving high efficiency when operating with the new working fluid across the range of anticipated variable operating conditions.

Economic objectives:

- To **develop and demonstrate a cost-effective air condenser technology with 20% lower costs**, working with the proposed working fluid blends while allowing fluid condensation at typical CSP locations;
- To **develop and demonstrate innovative and cost-effective heat exchangers with 10% lower costs** for the selected CO_2 blends.

Environmental and social objectives:

- **To reduce the carbon footprint of the innovative power plant by 33%** against state-of-the-art commercial CSP plants and other competitive renewable technologies;
- To assess and **quantify the economic and social impact** of the technology.

SCARABEUS on the web

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For further information, take a look at www.scarabeusproject.eu

And/Or follow us on https://www.linkedin.com/company/scarabeusproject/

And/Or Supercritical-CARbon-dioxide-Alternative-fluids-Blends-for-Efficiency-Upgrade-of-Solar-power-plant

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THANK YOU FOR YOUR ATTENTION