Horizon 2020 - N° 814985

SCARABEUS:

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

Project presentation at M27

Presentation Outline

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

Main objectives

The consortium

The concept

Smart targets

Preliminary results

Project objectives

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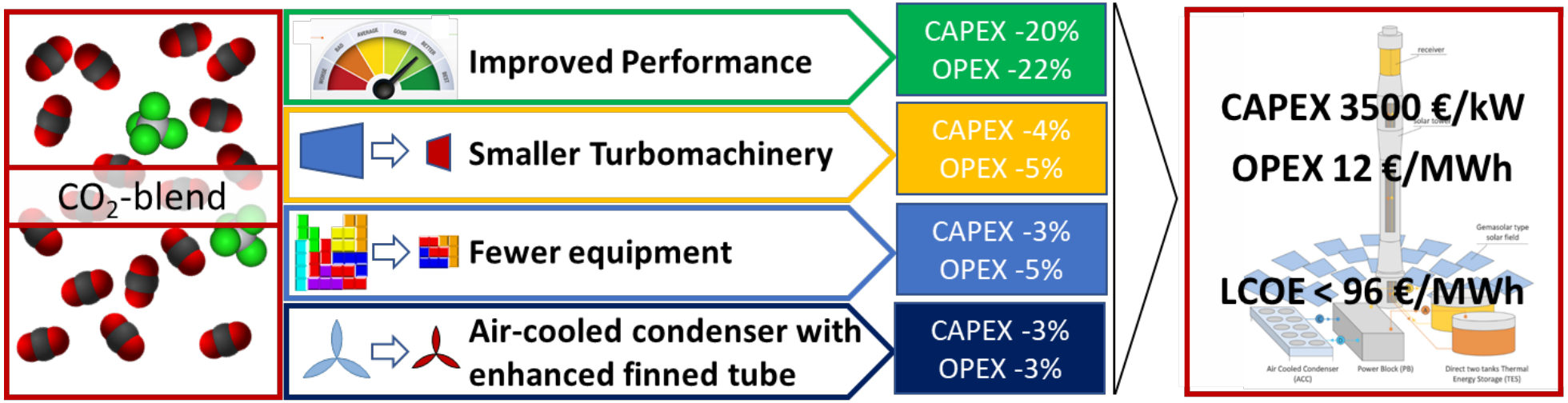
The aim of the **SCARABEUS project** is to **demonstrate** that the application of **supercritical CO_2 blends to CSP plants** has the potential **to reduce CAPEX by 30% and OPEX by 35%** with respect to state-of-the-art steam cycles, thus exceeding the reduction achievable with standard supercritical 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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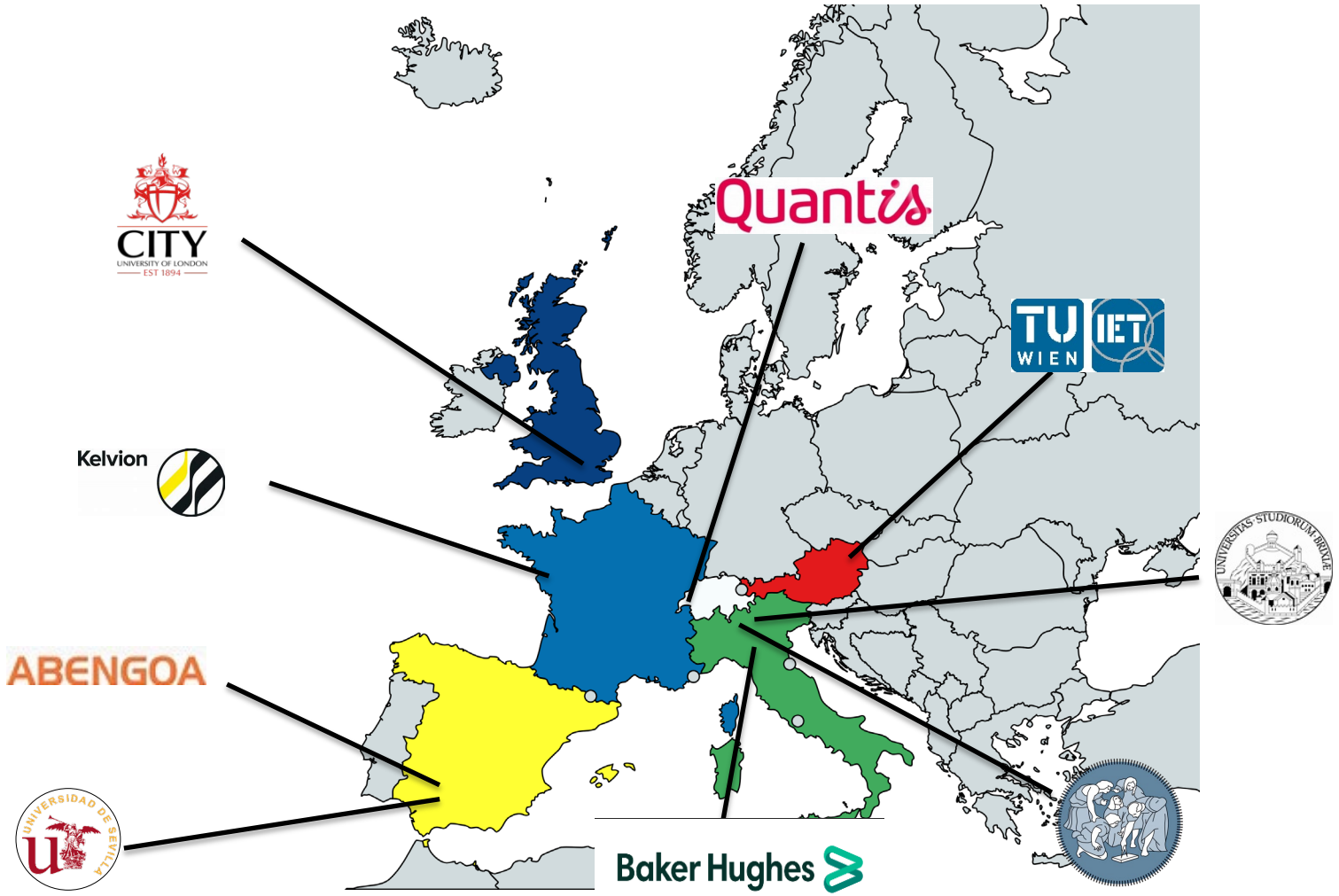

Five universities

- 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)
- Kelvion (FR)
- Baker Hughes (IT)

The concept

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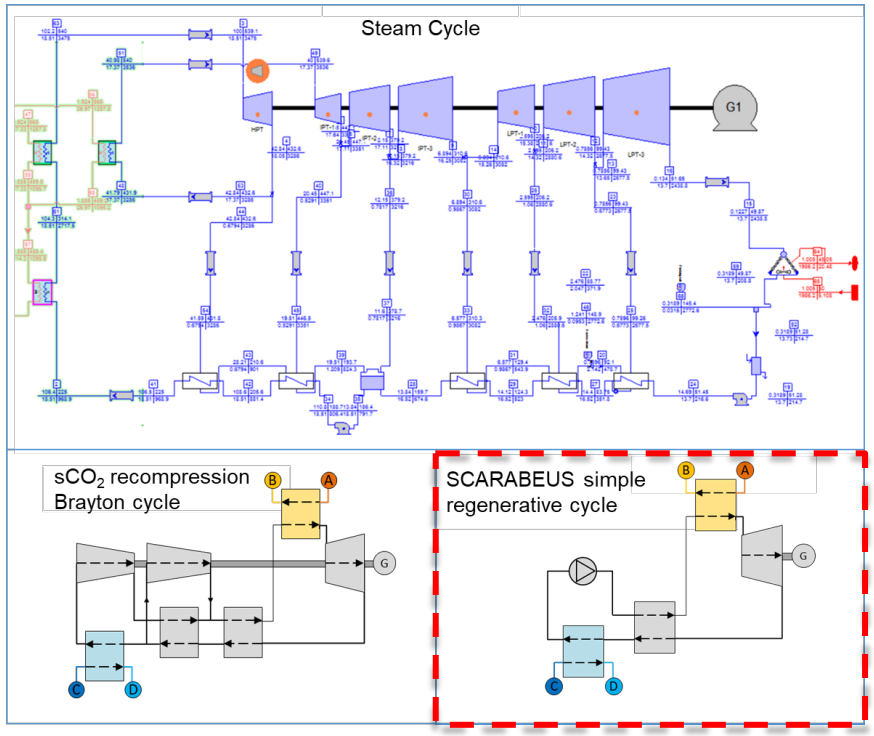
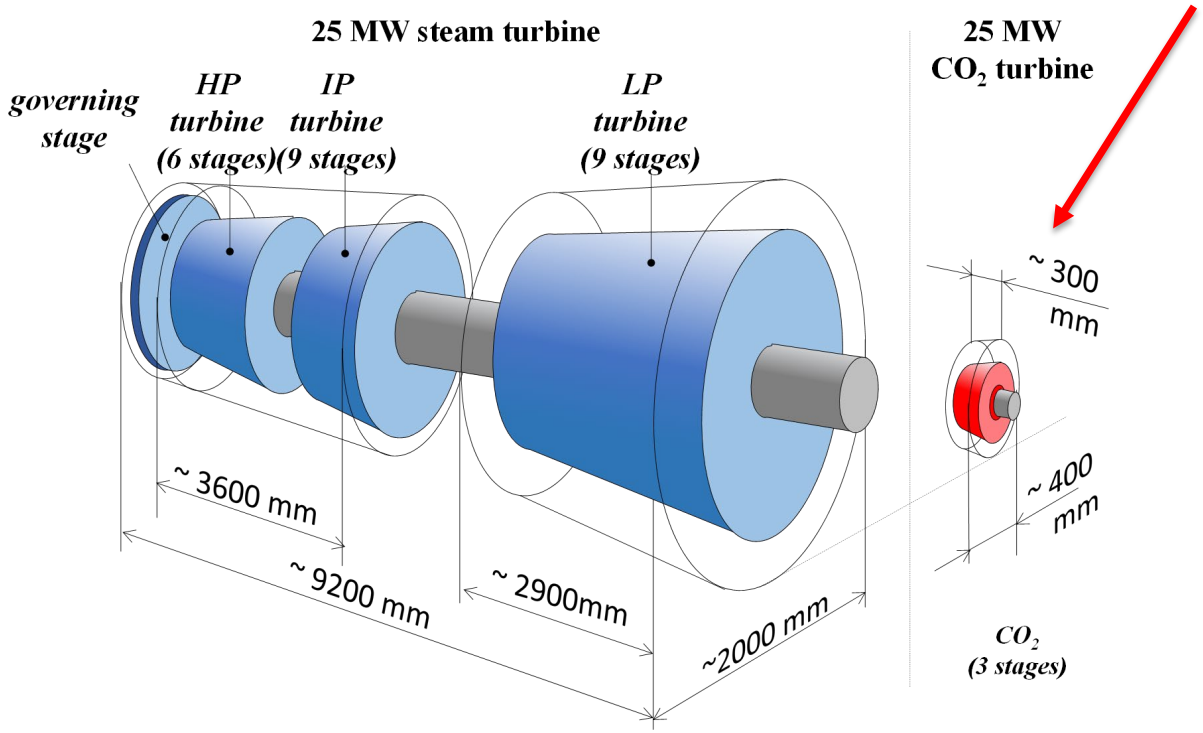
The **addition of small quantities** of selected compounds to the pure CO_2, yielding the so-called blended CO_2, can raise the corresponding critical temperature and **enable condensation at temperatures of 50°C to 60°C. leading to higher thermal-to-electricity conversion** efficiency with respect to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

Simpler cycle (reduced equipment)



Smaller turbomachinery



Project timeline

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April 2019

December 2020

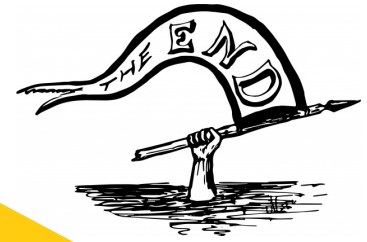
Identification of the most-promising CO_2 blends

July 2021

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

September 2022

Inauguration of the test rig and CO_2 blend testing



Demonstration of the SCARABEUS technology

Fluid identification approach

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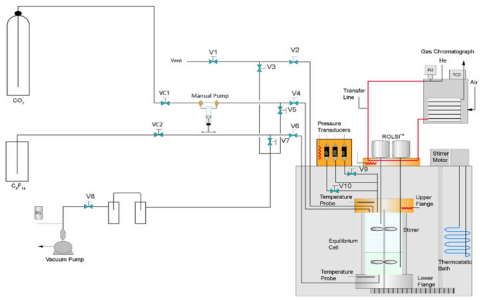
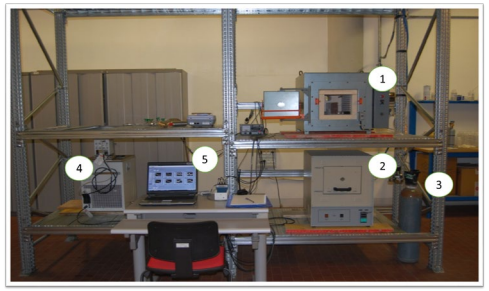
Objectives

- 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

INGREDIENTS
CO_2 blends





Vapour-Liquid equilibrium test

Calibration of the proper Equation of state with the experimental data

Critical mixture behaviour

Mixture thermodynamic properties in all the cycle regions

Thermal stability test up to 700 °C

Thermal decomposition evidence with measurement deviation from Isochoric line (fresh mixture)

Identification of the maximum operating temperature of the cycle

Fluid identification achievements

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Thermal stability
Chemical reactive at low T

Thermal stability
Low Tcr

Selected dopants (Dx) for experimental tests

D1 – D2 – D3 – ~~D4 – D5~~

5 dopants in the 1st year

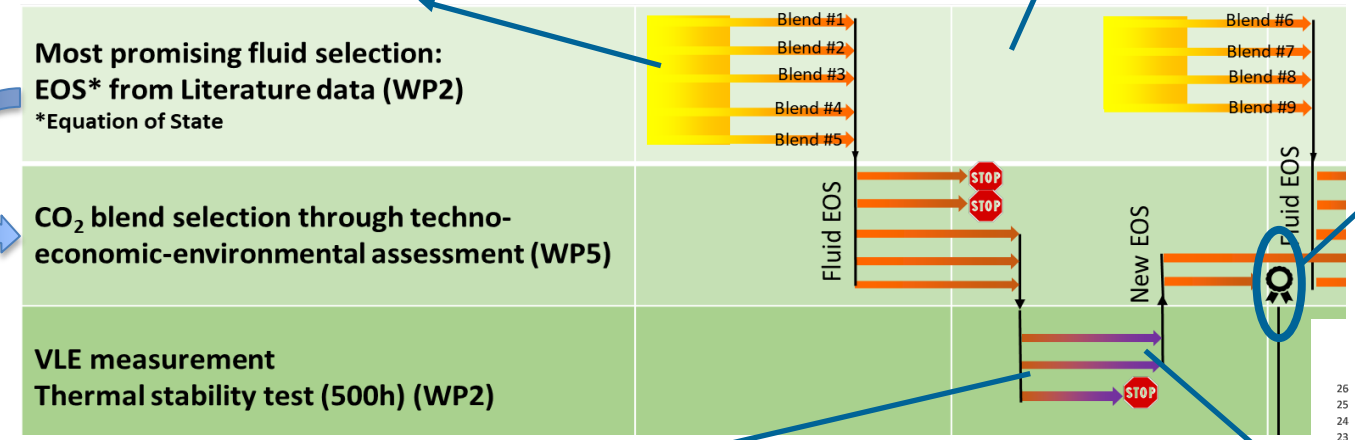
Other 2 dopants in the 2nd year:

D6– D7

D1 showed a good thermal stability up to 550 °C, suitable for CSP molten-salts application

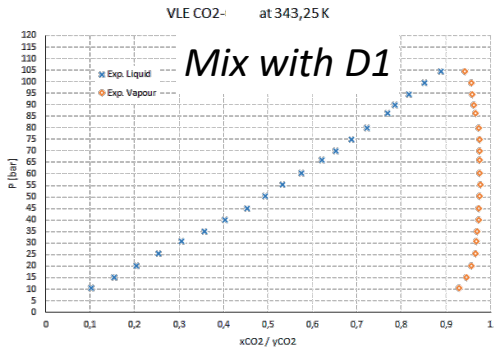
First TDN assessment

Simple Peng Robinson with Binary interaction parameter from literature data



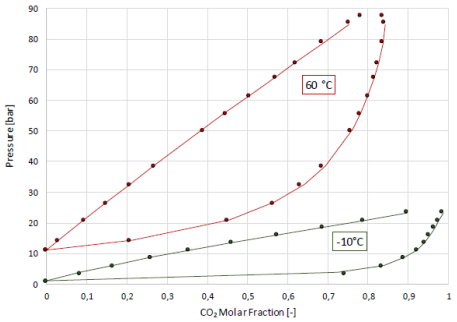
VLE test (2 mixtures D1 – D2)

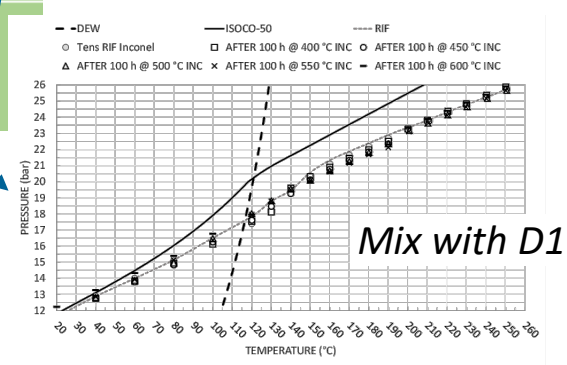
LEAP
Laboratorio Energia e Ambiente Piacenza



Mix with D1

EoS calibration





Thermal stability test at UNIBS (3 mixtures D1-D2-D6 + Pure CO_2)

Turbomachinery design approach

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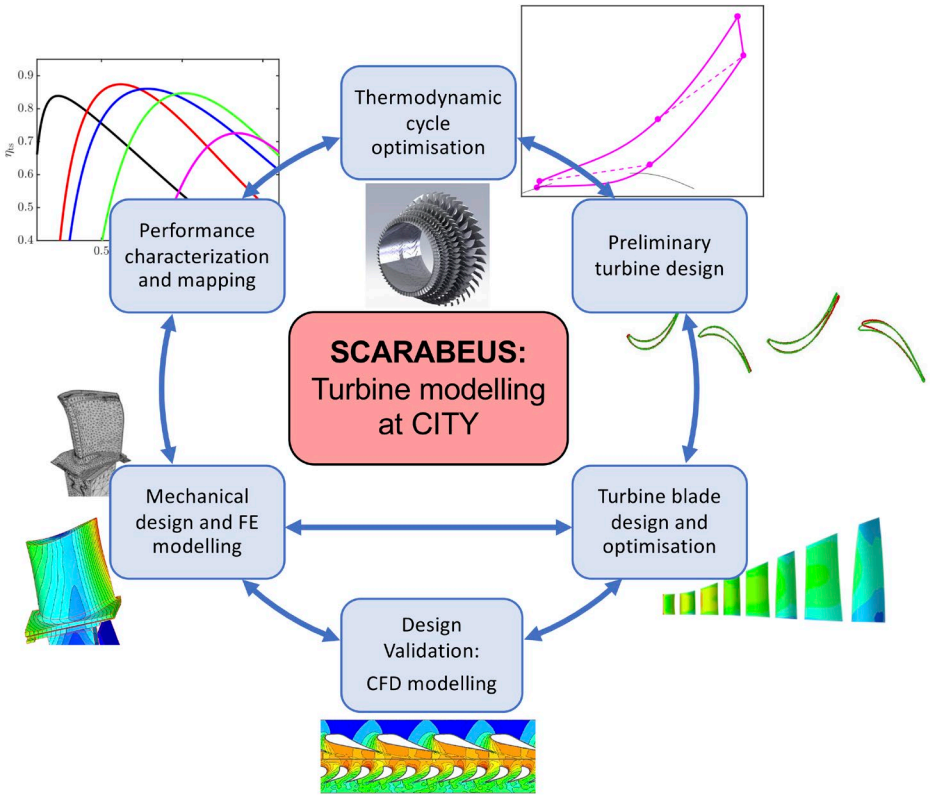
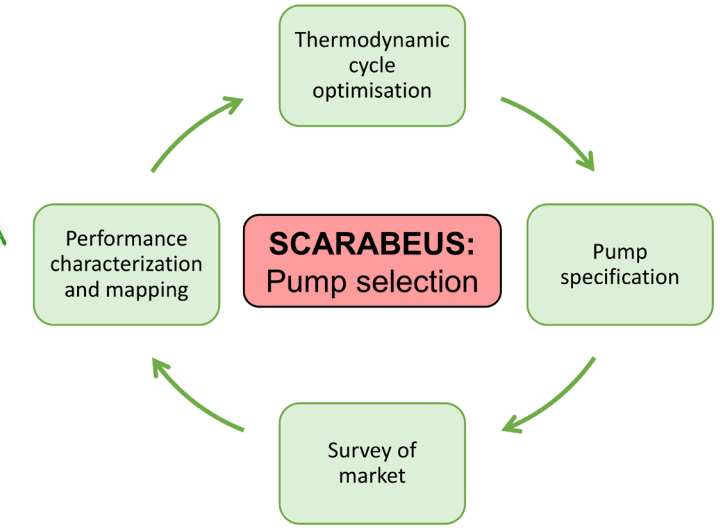
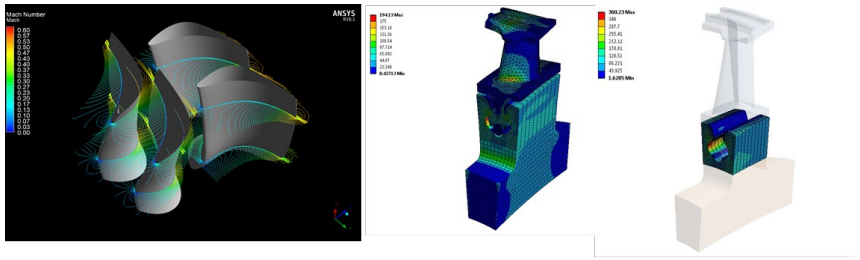
Objectives

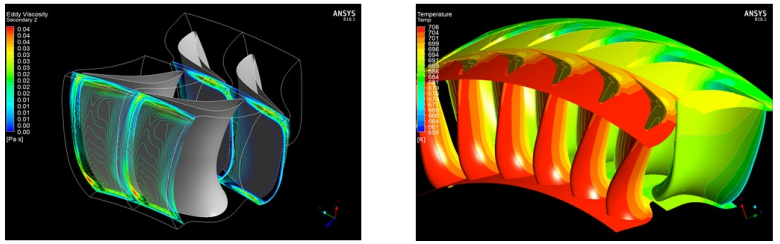
- To develop innovative turbomachinery designs that are able to operate with high efficiency across the range of anticipated variable operating conditions to sustain a high cycle efficiency.
- The ultimate goal is to enable accurate calculations of cycle performance and hence costing of the proposed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





Analysis performed @Baker Hughes





Turbomachinery design achievements

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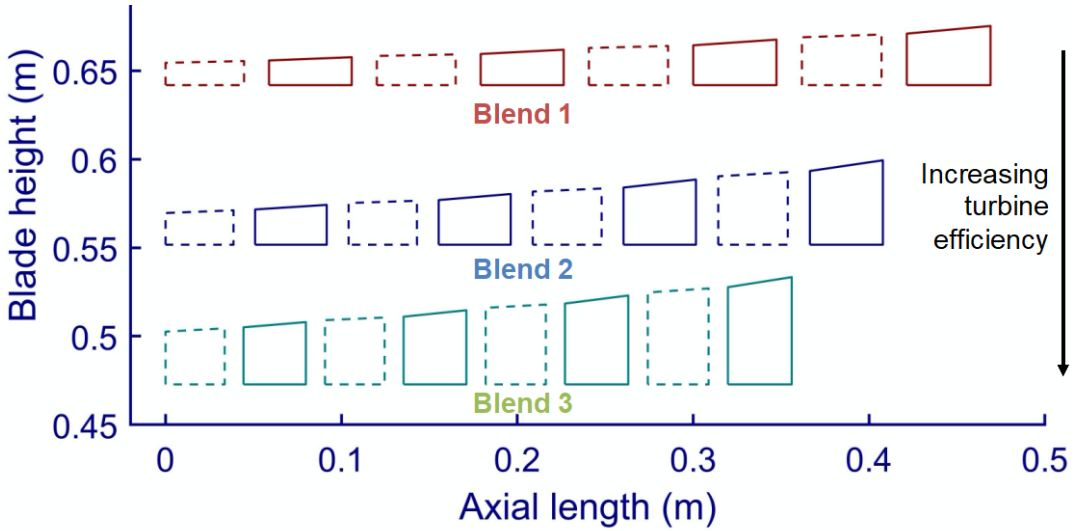
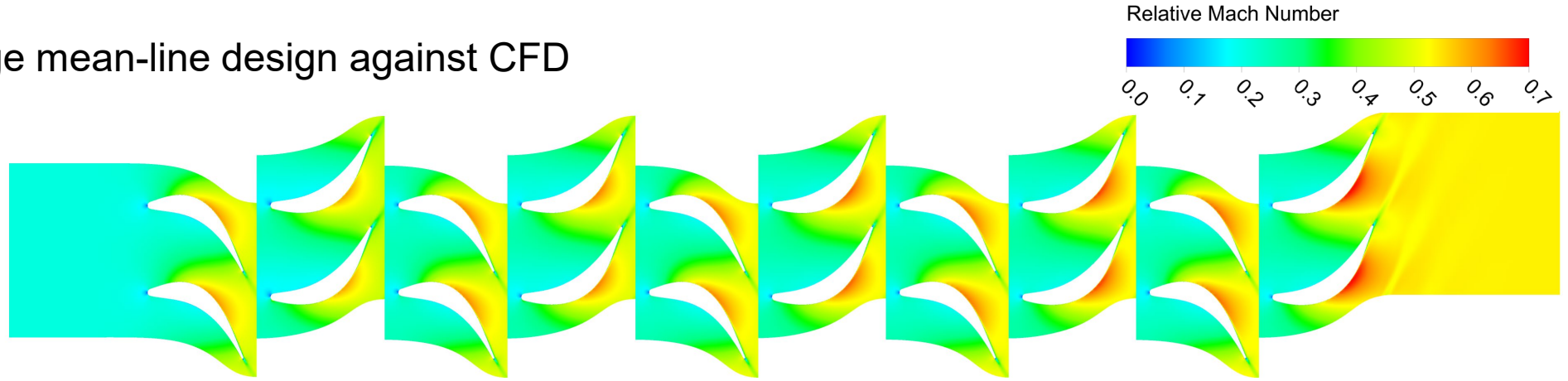
- ✓ Quantified the effect of dopant molar fraction on turbine design for multiple mixtures
- ✓ Assessed the significance of the uncertainty in the fluid thermophysical property model on turbine design
- ✓ Realised and validated an axial turbine mean-line design tool with embedded loss models
- ✓ Developed flow path designs for candidate mixtures
- ✓ Verified the multi-stage mean-line design against CFD



Meanline meridional profiles for candidates blends



Mid-span relative Mach number contours

Heat exchanger development approach

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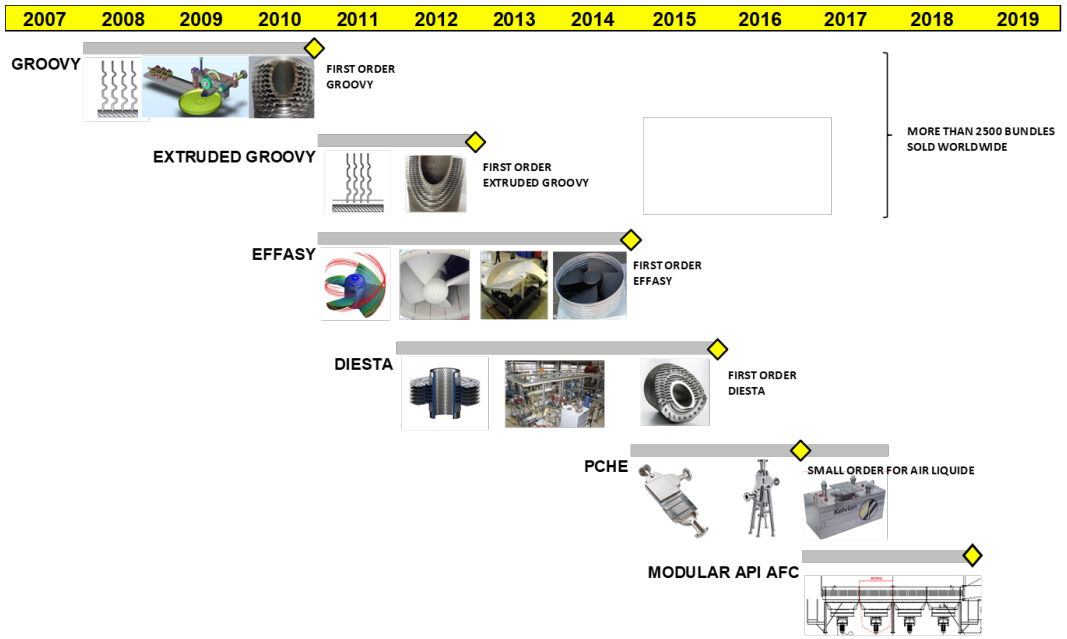
Objectives:

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

Kelvion R&D approach



Heat exchangers development achievements

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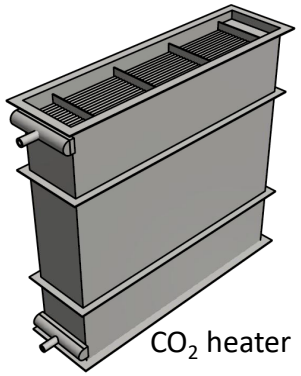
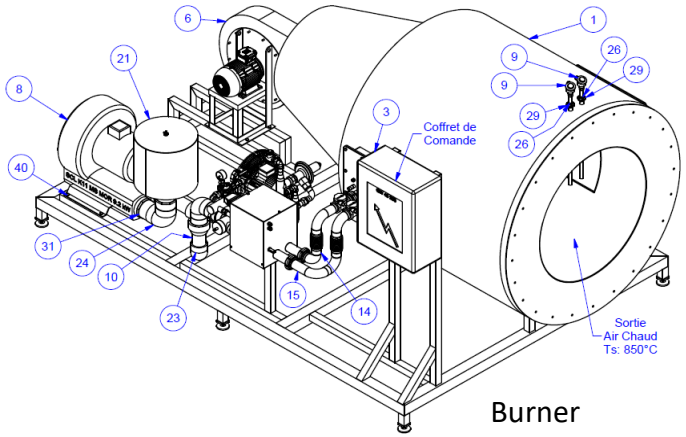
- First modification of the test rig
  - Burner is ordered
  - CO_2 heater is ordered

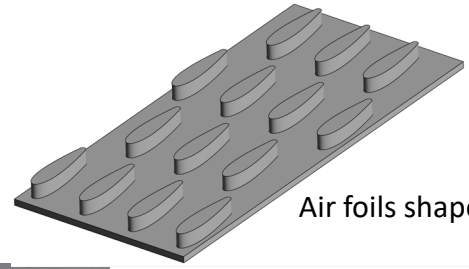


CO_2 heater



Burner

- Heat transfer correlations
  - Cooling and condensing tests with pure CO_2 and blend 0 in enhanced tubes [air cooled condenser]
  - CFD simulations with new shapes for PCHE [recuperator]



Air foils shape

- Printed circuit heat exchanger
  - Recuperator#1 is designed and under construction

Recuperator#1 - Core

- Diffusion bonding tests
  - Manufacturing test with Inconel 625.
  - Manufacturing test with air foils shape.

Air foil – Manufacturing test

Techno-economic-environmental analysis approach

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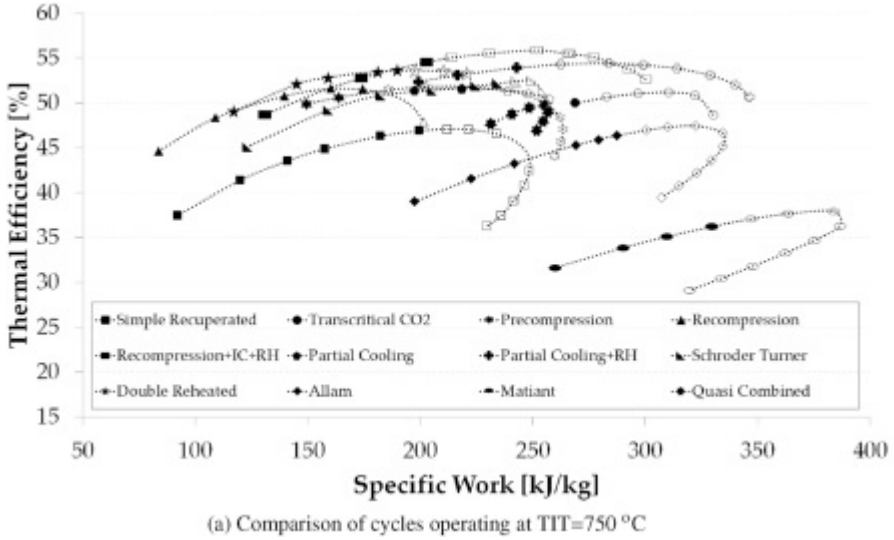
Objectives

- 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

Techno-economic-environmental analysis achievements

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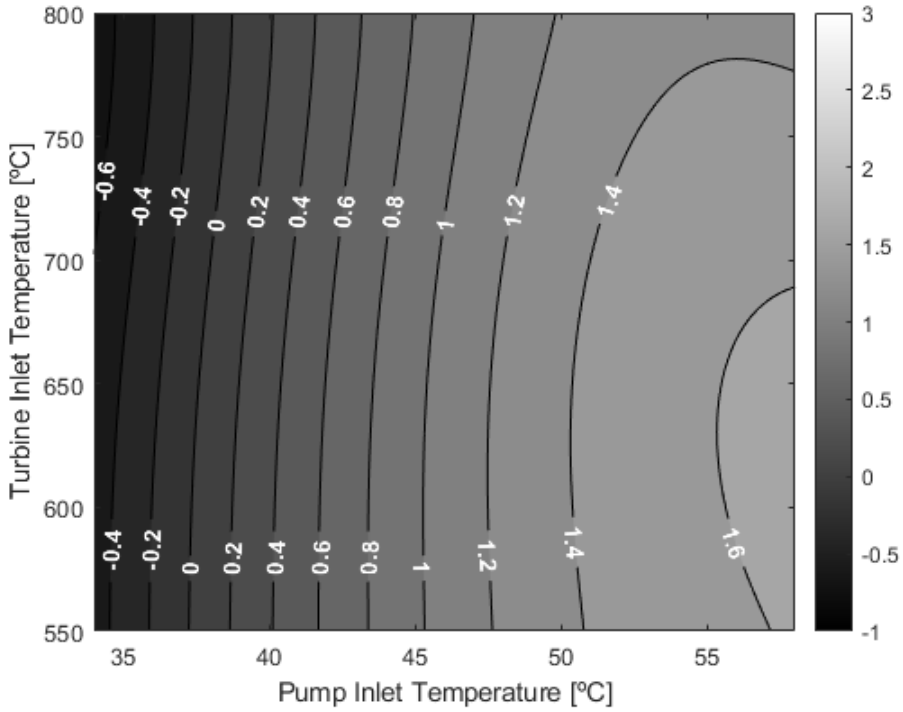
- BAT in state-of-the-art CSP plants with central receivers
- Thermodynamic analysis of closed cycles using CO_2-based WFs completed
- $\eta_{th} > 50\%$ → Target thermodynamic performance of SCARABEUS technology at 60ºC confirmed! (MILESTONE)

$$\Delta\eta_{th,Dx} = \eta_{th,Dx} - \eta_{th,sCO_2Recompr.}$$

D1 Blends



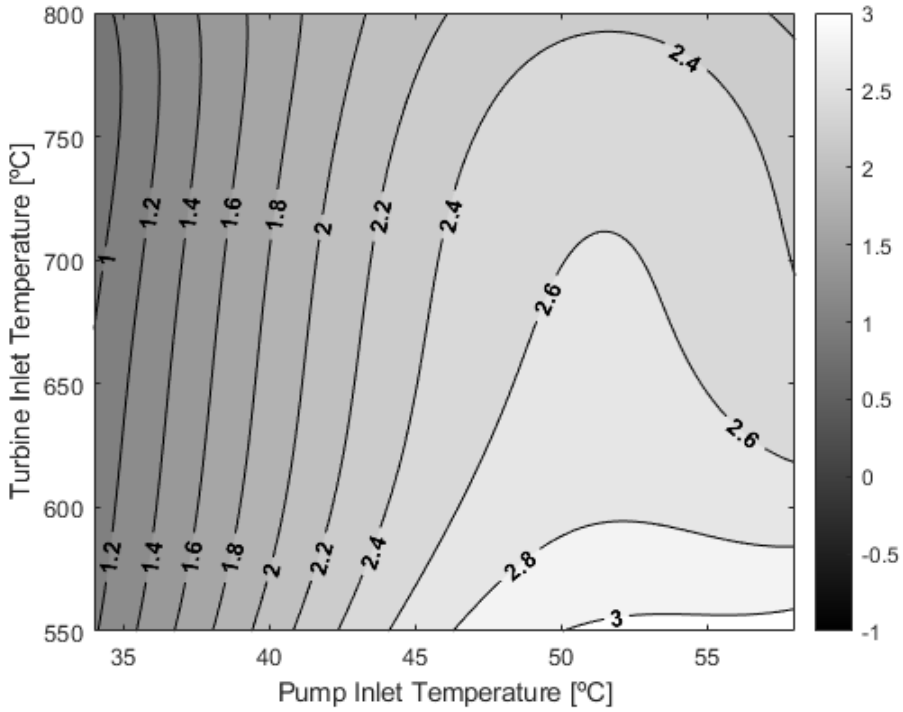
$$\Delta\eta_{th,D2} > \Delta\eta_{th,D1}$$

Up to 3pp Up to 1.6pp

Highest $\Delta\eta_{th}$ for high Tmin values

SCARABEUS concept confirmed!

D2 Blends



Techno-economic-environmental analysis achievements

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- $\eta_{th} > 50\%$ → Target thermodynamic performance of SCARABEUS technology at 60ºC confirmed! (MILESTONE)
- Performed the screening LCA analysis comparing conventional technology and best available technology
- Defined the roadmap and approach for data collection and modelling for the scarabeus technology

Validation approach

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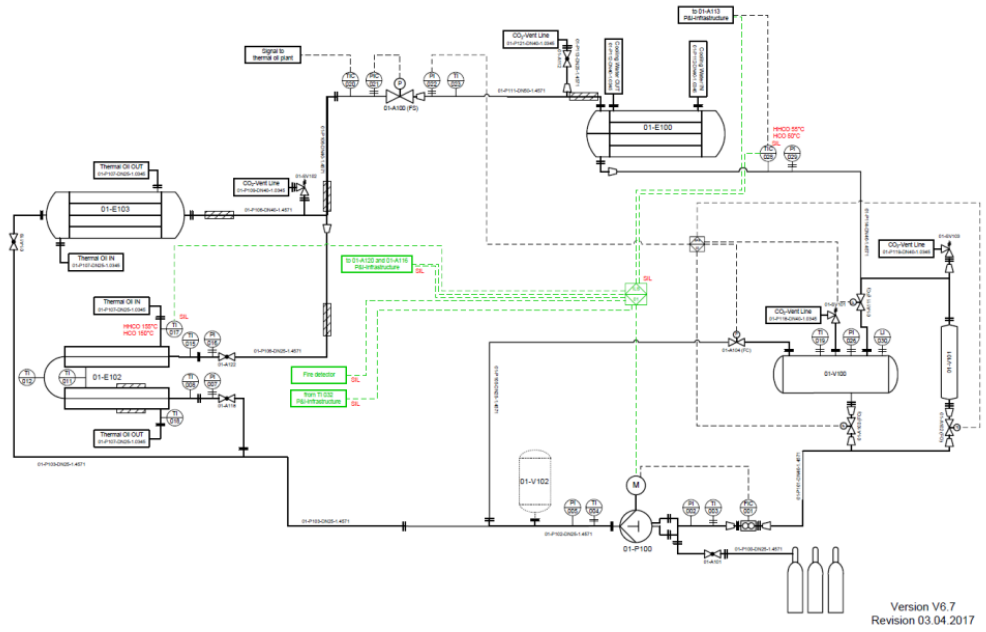
Objectives

- 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 Universität of Wien



Experiments and first results

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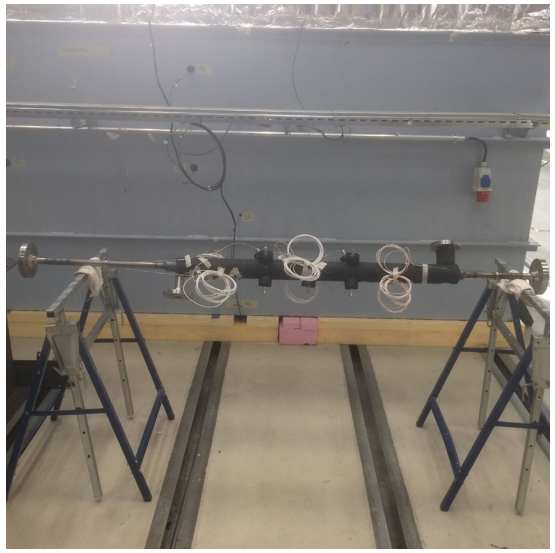
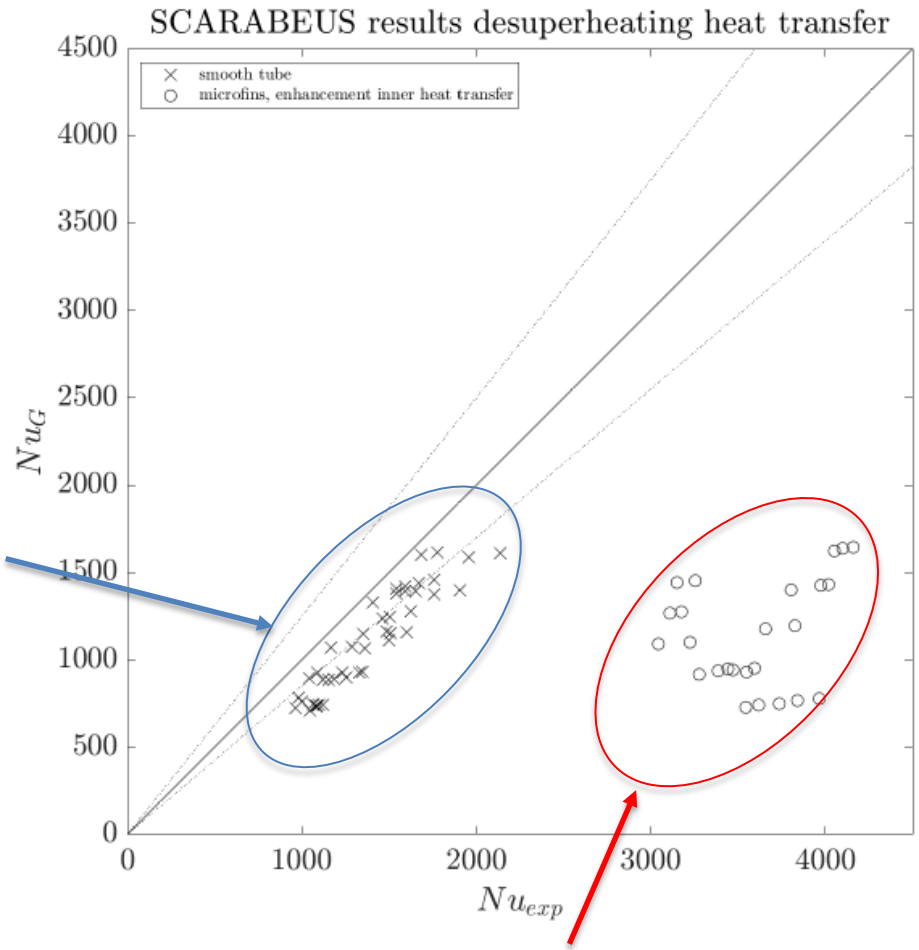
Test tube installed

Test tube



Comparison of calculated and experimental Nu-numbers for tubes with smooth inner surface



….and for inner finned tubes – HTC ↑

SCARABEUS on the web

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

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

Or follow us on Supercritical-CARbon-dioxide-Alternative-fluids-Blends-for-Efficiency-Upgrade-of-Solar-power-plant

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