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sCO2-Flex

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Technical References

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Project Title	Supercritical CO2 Cycle for Flexible and Sustainable Support to the Electricity System
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[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

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Document history

V	Date	Beneficiary	Author
1	24/06/2019	Zabala Innovation Consulting	Gustavo Jacomelli
2	28/07/2019	EDF	Albannie Cagnac
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Publishable Summary

Summary of the context and overall objectives of the project

The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95%, when compared to 1990 levels, by 2050. The EU 2050 Energy Strategy includes therefore new challenges and opportunities.

Renewable energy (such as wind and solar) is gaining momentum and now raises the question of grid stability in the event of large power output fluctuations. In this context, enhancing the flexibility and the performance of conventional power plants is seen as a good opportunity to both secure the energy grid while reducing their environmental impact. Therefore, it is necessary to develop innovative and cost-effective ways of enabling existing and future fossil fuelled power plants to be flexible enough to deal with load fluctuations and also to reduce emissions

The sCO2-flex consortium seeks to develop a scalable/modular design of a 25MWe Brayton cycle using supercritical CO2. This will enable an increase in the operational flexibility (fast load changes, fast start-ups and shutdowns) and efficiency of existing and future coal and lignite power plants, thus reducing their environmental impacts, in line with EU targets.

Supercritical carbon dioxide (aka sCO2) is a fluid state of carbon dioxide where it is held at or above its critical temperature and critical pressure. The fluid presents interesting properties that promise substantial improvements in conventional power plant system efficiency.

Due to its high fluid density, sCO2 enables extremely compact and highly efficient turbomachinery. sCO2 based technology therefore has the potential to meet EU objectives for highly flexible and efficient conventional power plants, while reducing greenhouse gas emissions, residue disposal and also percentage water consumption reduction.

sCO2-FLEX is led by French Utility EDF and brings together researchers, technology providers and industry experts covering the whole value chain. The aim is to demonstrate how supercritical CO2 could contribute to Europe’s climate change and energy transition goals by making fossil-fuelled power production more capable of supporting a smarter and more flexible energy market.

The project involves building expertise on sCO2 for electricity generation and project leader EDF is also interested in investigating its possible application to renewables such as CSP (Concentrated Solar Power) and biomass.

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Figure 1: Partnership value chain

During the first 18 months, the project sought to:

- select the 3 most convenient cycle architectures for the project (see Objectives of WP1),
- start the work of the WPs dedicated to components and cycle flexibility (WP2, 3, 4 and 5),
- set up dissemination and management actions (WP8, 9, 10).

<u>Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far</u>

The first eighteen-month period of the project was intended to determine the cycle architecture that is expected to meet performance and flexibility requirements (among 21 proposed cycle architectures).

1. <u>Works and Results on WP1:</u>

Three cycle architectures have been selected (among the 21 analysed configurations) regarding the following 3 main criteria:

i) Cycle performance,
ii) Boiler integration/integrity,
iii) Cycle simplicity/feasibility (manufacturing constraints, flexibility, control and regulation).

This cycle selection enabled the partners to focus on designing a specific and reduced number of cycle architectures. The heat and mass balance tables for these selected cycles have been provided to all partners to go on the next steps of the project.

The D1.3 deliverable was significantly updated shortly after it was sent to the commission. This update was made following the first work of WP 2 and 4, which revealed a more interesting architecture than cycle #13, namely cycle #16.

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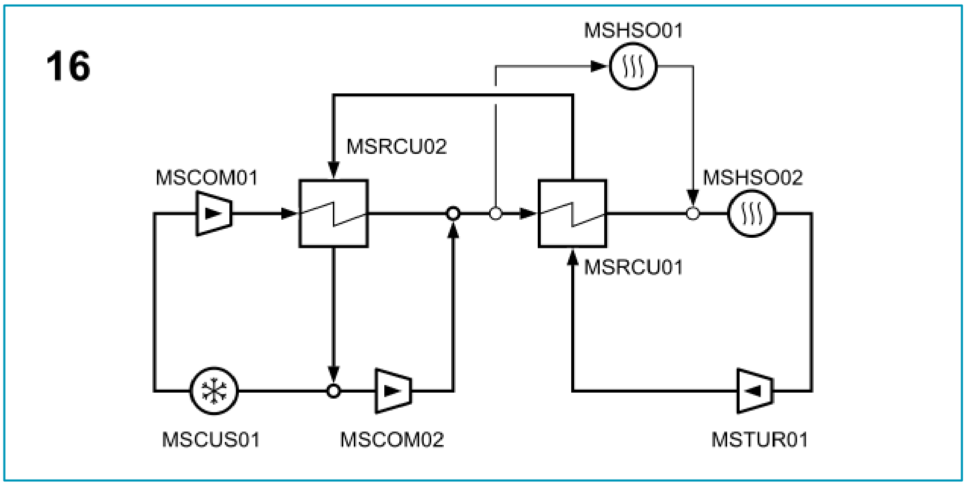
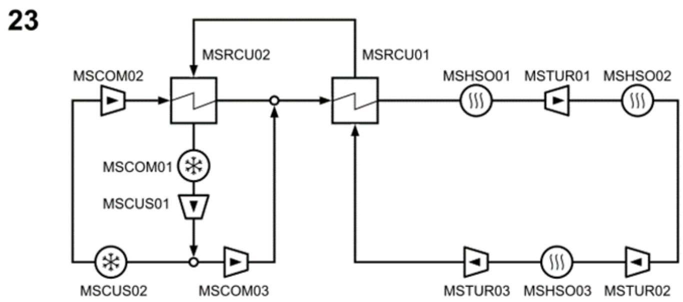
The consortium subsequently decided to update the deliverable and the new version was available at the end of October 2018.

The 3 selected cycles for the next step of sCO2-Flex project are the following (see D.1.1 and D1.3 for cycle numbering):

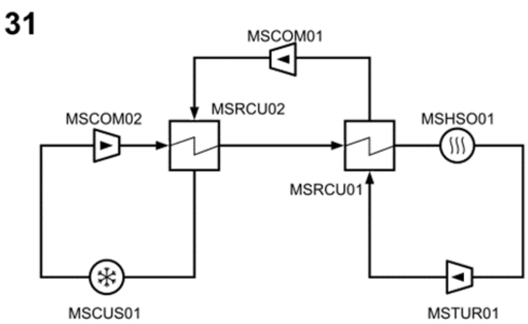
- Cycle #16 for cycle performance:



- Cycle #23 for both boiler integrity and turbomachines (good turbomachine performances):



- Cycle #31 for simplicity, turbomachines and boiler integrity:



The Work Packages for equipment development (WP2 for the boiler, WP3 for turbomachinery, WP4 for heat exchangers) and flexibility (WP5) started shortly before the end of WP1 (M5), and are still in progress. The work resulting from these WPs was based

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on the results of WP1 and has already made it possible to choose a cycle configuration among the 3 proposed in the WP1.

Cycle #31 was quickly abandoned (in November 2018) because of its too low performance and cycle #23 was abandoned (in January 2019) because of the complexity of the boiler and turbomachinery which were not likely to allow the desired flexibility from an operational point of view (the cycle is flexible but too complex to operate and therefore not desired by potential users and stakeholders).

2. Works and results on the boiler and materials (WP2):

Boiler calculations and material selection have been done for “cycle #16”. Boiler calculation and optimization require a lot of time and cannot be done for a large number of cycles (a compromise must be found between several parameters such as flexibility, material and cost, design/thickness/mass, acceptable stresses, pressure drops…during boiler design). In this context, it has been decided by the consortium that UJV will do calculations only for a small and specific number of cases.

The procedure of the erosion test on an “air foil-shaped” test sample has been made by CV REZ with recommendation for material selection and coating. The experimental plan has been defined for material testing at CSM.

3. Works and results on the turbomachines (WP3):

Until now, the preliminary material selection, the conceptual design and the mechanical configuration of turbomachinery have been done.

The fluid model selection and the study of boundary layer behaviour have been investigated by UDE.

BHGE defined compressors and turbine arrangement in order to guarantee the maximum cycle operational flexibility. The compressors are both with variable IGV (Inlet Guide Vane) and equipped with VFD systems; due to a high rotating speed, the turbine is connected through a gear box to the electric generator. This turbomachinery configuration allows to achieve a partial load down to 20% of cycle rated power.

A full-scale prototype compressor is under design phase. Prototype performance tests are expected within 2020 to verify aerodynamics and performance prediction in proximity of the CO_2 critical point.

4. Works and results on the Heat Exchangers (WP4):

Since heat exchangers are one of the key components for supercritical CO_2 Brayton cycles applications, their technical development is an important step in the sCO_2-flex project.

An important work was achieved at FIVES in order to reach higher levels of mechanical resistance of the assembly. In fact, a reproducible rupture pressure value of 1200 bar was achieved so far, which is very noteworthy.

USTUTT and CVR built up test sections in order to evaluate thermal and hydraulic performances of sCO_2 in respectively plates and fins HXs and printed circuit HXs. HXs prototypes were discussed and defined with FIVES to be tested in these sections, and are being manufactured.

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Moreover, USTUTT investigated the characteristics of sCO2 cooling heat transfer in tubes. Potential materials for HXs manufacturing were selected and prepared by FIVES for corrosion/erosion tests to be run at CSM.

5. Works and results on the Cycle flexibility (WP5):

The static modelling and simulations at system level showed that the part-load range to study is quite large (from 20% to 100% of nominal load). To achieve good performance estimation at low load conditions, POLIMI needs accurate data concerning components behaviour in off-design conditions. Up to now, simplified correlations have been used by POLIMI to perform calculation. Also, a MATLAB model has been created and benchmarked against the D1.1 results for steady state calculations. These calculations resulted in a review of D1.1 initial hypothesis and led to a pressure optimisation of "cycle family n°2" (partial cooling architectures). Sensitivity analyses have been performed for "cycle family n°1" taking into account different maximum and minimum CO2 temperatures, as well as other system's parameters variations. **All obtained results are in line with previous conclusions of partners studies.**

Progress beyond the state of the art, expected results until the end of the project and potential impacts:

The next few months of the project will be used to continue work on the work packages already in progress, with the construction and testing of the various prototypes.

Different WPs will also start:

- WP6 aims to validate the calculations performed in WP5 taking into account the design criteria defined in WP2/3/4. The consolidated results are used to design a 25 MWe sCO_2 cycle with a focus on flexibility and reliability in transient conditions. Finally, the overall concept is extended to other application fields to prove the replicability of the developed concept.
- WP7 is scheduled to start at M24, meaning there is no progress to report now. WP7 aims at performing an economic, environmental and social assessment of the sCO_2 Cycle. WP7 will: Carry out a detailed cost-benefit analysis and financial assessment of the 25 MWe cycle design and study the cost of a 100 MW sCO_2 cycle to foster market uptake and industrial deployment from 2025.
    - Assess the impact of sCO_2 cycle on the LCOE of coal and lignite power plants.
    - Assess the environmental impacts of the sCO_2 cycle in terms of water consumption, fuel consumption, material consumption and greenhouse gas emissions reduction.
    - Prepare and foster the social acceptance of sCO_2 technology.

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