D8.1 – First Exploitation Plan

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sCO2-Flex

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Technical References

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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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1.1	14/12/2018	ALL PARTNERS	/(comments and reviews)
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Summary

The purpose of this deliverable is to present the various works related to the exploitation of the results of the sCO2-Flex project.

After a review of the various strategies defined, the actions carried out during the first year are presented.

Disclaimer

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1 Purpose

The objective of this business plan is to describe the main results achieved in the first year of the sCO2-Flex project and the means available to make the most of these results.

First, we will recall the possible mechanisms for all project partners to make the most of the project's results, then after describing the main results of the first year, we will come back to the actions carried out by the consortium.

2 Exploitation Strategies for sCO2-flex

The purpose of this paragraph is to recall the different operating mechanisms for the sCO2-Flex project, as identified during the project preparation process.

2.1 Exploitation mechanisms

The definition of the Commercial Exploitation Plan is led by EDF, with the support of ZABALA, and ensures that all IP-owning partners as well as potential and confirmed exploitation partners will work towards successful technology and knowledge transfer. The Plan serves as the basis for future business models and will define mid-term commercialization strategies.

The exploitation strategy's structure will be twofold: exploitation of the (i) results, (ii) knowledge generated. Due to partners' different natures, the exploitation plan is specific to each organization. It will be reviewed periodically and will be regularly updated.

Each technical partner is the owner of its developments and owns the exploitation rights, under the legal constraints.

A sketch of the main elements of the **smart system business plan** is presented below, following CANVAS method:

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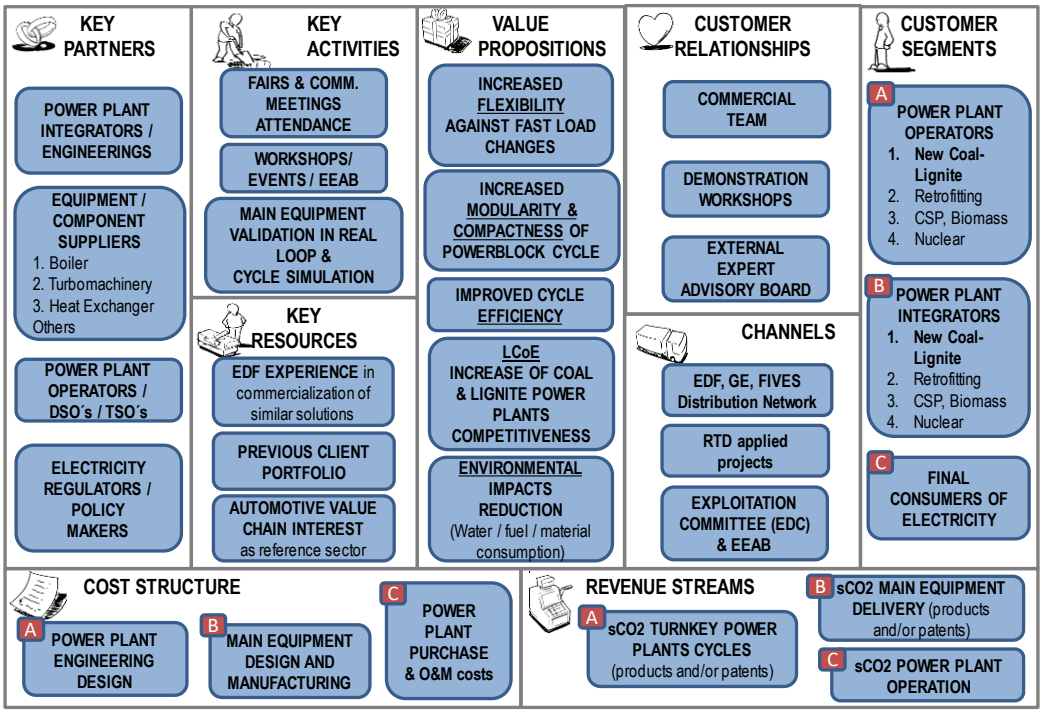

Figure 1: Sco2-Flex Exploitation Plan Scheme (Canvas Methodology Diagram)

As shown in the CANVAS diagram, sCO_2-Flex could develop 3 potential and compatible exploitation strategies (A, B, C):

- Exploitation strategy A: the global solution (design of cycle with main equipment and I&C tools) is designed as a cycle turnkey solution to be sold to power plant operators. The setting up of a sCO2-Flex marketing agreement benefiting to all the partners will be analysed.
- Exploitation strategy B: Perfectly compatible with scenario B, in which key components manufacturers (GE, FIVES, UJV) of sCO2-Flex could design, build and commercialize equipment.
- Exploitation strategy C: Long-term scenario in which EDF, as plant operator, would exploit future or retrofitted coal plants and sell the electricity produced to end-users (industry, households, …).

In exploitation strategy A, the entire consortium will benefit from the incomes resulting from the turnkey cycle design, main components exploitation, I&C systems and strategies. In exploitation strategy B, the main equipment manufacturers will be the beneficiaries of the commercialization of turbomachinery, heat-exchangers and boilers.

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The **key project results** which **can be exploited** at 3 different levels/strategies (A, B, C) are the following:

RESULT	PARTNER	Specific EXPLOITATION ROUTES and STRATEGIES
(A) TURNKEY PLANT CYCLE: highly flexible and efficient sCO_2 cycle for coal plants.	Consortium (led by EDF)	The consortium will discuss the patenting of the cycle's design (integrating conditions, main equipment designs, I&C solutions &) so that to the exploitation benefits to all the partners.
(B1) BOILER for sCO_2 cycle (enabling high cycle efficiency & pre-heating stages up to 600ºC).	Partnership UJV	UJV (as boiler designer) will analyse 2 alternative & compatible commercial alliances: with GE and with Vitkovice Machinery Group (Czech boiler manufacturer in close relation with UJV).
(B2) TURBOMACHINERY New integral turbomachinery design for sCO_2 power generation	GE	GE will include turbomachinery suitable for sCO_2 cycle into its commercial offers (global cycle solution, turbomachinery alone for integrators).
(B3) HEAT EXCHANGER solutions based in PCHE/PHFE (in stainless steel and nickel based alloys) for sCO_2	FIVES	FIVES will open new business lines for innovative HX for sCO_2 cycles suitable for fossil-fired, CSP, biomass, etc (global cycle solution, HX alone as main equipment for integrators). The exploitation routes are guided by markets needs which are mainly compactness, robustness, and efficiency at a reasonable cost.
(C) ELECTRICITY: EDF operation of sCO_2-Flex plants	EDF	By operating and selling electricity to the final end-users with new plants in Europe.

Table 1: Key project results

2.2 Potential market and customers segments

2.2.1 Potential Market

Availability of a sCO2 cycle is of high interest in areas with growing RES concentration, where the need for a highly flexible fossil plant is crucial to face the challenges of RES intermittent production. That is mostly true in Europe (Germany, Poland, Czech Republic, etc), where RES keep spreading and create some grid management issues, but also in other regions (especially Asia). Moreover, the sCO2 cycle being transferable to biomass, solar and nuclear

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applications too, the potential benefits of the development of such a cycle can extend to energy sectors other than coal and lignite.

sCO_2-Flex will provide solutions to plants suppliers and integrators, components' producers, plants' operators and to network system operators, given that sCO_2-Flex will enhance the ability of coal plants to provide ancillary services (balancing, frequency control, etc). As sCO_2-Flex coordinator, EDF has carried out an initial market analysis. Building on the projected electricity generation from coal power generation technologies in IEA's ETP 2ºC scenario worldwide, focusing on Exploitation Strategy A, the market expectations are:

Table 2: sCO_2-FLEX worldwide POTENTIAL MARKET from 2025

TW / Year	2025	2030	2035	2040	2050
Coal/Lignite (New)	200	400	400	400	400
Coal/Lignite (retrofit)	800	1600	2600	3600	4100

Table 2 shows only expectations based on preliminary market analysis. Obviously other technologies could be used for the retrofit of existing plants or construction of new plants. These figures will be updated and refined through task 6.4 (replicability and applications analysis) and task 8.1 (final exploitation plan definition) to clearly define the market potential for the sCO_2 cycle. However, given the trends in coal-power generation and the benefits of the sCO_2 cycle, the partners strongly believe that the solution could be widely implemented and reach a market of hundreds of TWh from 2025 to 2050.

2.2.2 Customer segments

Plant integrators and operators can be considered as end-users and play a key role in the market uptake of the sCO_2-Flex solutions. To guarantee success and market acceptance, it is essential to count on their support.

- **Power Plant Operators** will have strong interest in operating sCO2-Flex Brayton cycles providing high flexibility, efficiency and sustainability with optimal CAPEX and OPEX costs.
- **Power Plant Integrators/Builders** will have interest on acquiring equipment, I&C solutions and cycle design since they will integrate the sCO2 cycle in their commercial offers.
- **Consumers:** industry, public services/drives and all citizens connected to the grid.

Besides, main equipment suppliers could be also considered as another customer segment since they will be able to adopt sCO2-Flex solutions (design, material, etc), enabling them to operate sCO2 Brayton cycle (pressure, temperature, corrosion), ensuring efficiency in thermodynamic behaviour in the equipment, increased lifetime, high flexibility (quick and efficient response against fast load changes in cycle) and reduced size and cost.

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2.3 Exploitation strategies

2.3.1 Commercialization/Distribution channels and exploitation strategy

As already mentioned there are **3 main results to be exploited** (See A, B, C in Figure 1):

- The cycle design, developed for plant operators and integrators: EDF and GE will use their own marketing channels and rely on public tenders to implement sCO2-Flex's global engineering solutions.
- The 3 critical components developed in the project (Boiler, Turbomachinery and Heat-Exchanger):
- Selling electricity to the final consumers (all the industrial and domestic final consumers): In this case EDF will make use of its distribution and commercialization channels.

EDF will ensure and expand leadership in flexible and efficient generation:

- Commercially: Huge market in geographical areas with high RES concentration, where the need for a highly flexible power plant is crucial to balance RES intermittent production.
- Technically: Potential replication of sCO2 cycle for biomass, CSP or even nuclear generation.

GE will be the EU leader of sCO2 turbomachinery:

- Commercially: will expand its portfolio of turbomachinery and applications in this emerging market
- Technically: will define a new strategic R&D line dedicated to supercritical fluids turbomachinery analysis and definition of innovative products for additional applications.

FIVES will pursue leadership in Heat-Exchangers systems for the power plant industry:

- Commercially: FIVES will develop new business line for sCO2 heat exchangers (HX) exploitation
- Technically: will define a new strategic R&D line dedicated to sCO2 HX analysis and define innovative products for additional applications. HX developments will be very useful to other sectors, especially Oil & Gas and energy (recovery, production) industries (offshore, mobile applications) that are looking for compactness, robustness, efficiency and flexibility.

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2.3.2 Exploitation interest from RTD partners (UJV, POLIMI, CSM, UDE, USTUTT, CVR)

Since these partners are non-profit research entities, their exploitation strategy will be **to feed the know-how generated during the project into new projects and training sessions, to improve their technological expertise, to ensure that the knowledge created will be used in future research and to keep on generating and transferring knowledge to the industry**. More specifically, they will aim to:

- Enhance educational offer, integrate results into courses through new educational content, offer new topics in Ph.D. and post-diploma courses to strengthen the attractiveness of their entity.
- Increase and extend research expertise to: attract highly skilled students and staff, increase publications, create new research projects that can obtain public funding, strengthen the academic community, update curricula in the M.Sc. and post-diploma programs.
- Transfer knowledge to industrial partners by creating new direct collaboration with industry, IPRs, possibilities of licencing and possibilities for patenting / patents with other partners.

OBJECTIVE	PARTNER	DESCRIPTION
New educational content	EDF	Internal training for EDF workers and participation to university education programs
	USTUTT	Condensation heat transfer to supercritical fluids will be included in fluid mechanics lecture. Student research projects on sCO_2 will be offered. 1 PhD student will be involved in experimental work and will collaborate with other Ph.D. students (UDE).
	POLIMI	Master thesis on power cycle dynamic simulation and control will be offered. Main results of the study will be included in Energy conversion lectures in the “closed gas cycle” topic for the students of Energy Engineering. A PhD thesis can be proposed on the topic for a three year numerical study.
	UDE	Design of turbomachines for supercritical fluids will be included in the lecture. Student research projects on sCO_2 will be offered. 1 PhD student will be involved in the project.
	GE	sCO_2 compression will be added to existing internal training on compression.
Increase R&D expertise	EDF	Increased expertise and knowledge will lead to participation in other projects related to sCO_2 cycles focused on CSP, Biomass and Nuclear power generation.
	USTUTT	Performing experiments, expertise will be gained in using sCO_2 as a working fluid. High quality validation data shall be

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		provided to partners and selected ones shall be published in high level scientific journals.
	CSM	The experimental sCO_2 testing campaign will increase expertise and knowledge about materials properties in such challenging conditions.
	POLIMI	Availability of referenced performance maps for the different components will allow for cutting edge publication on the topic and participation to conferences and seminars focused on CO_2 use in power generation.
	UDE	Enhanced expertise regarding the design of turbomachines for supercritical fluids close to the critical point combined with the requirements of a flexible operating regime.
	CVR	Experimental data obtained from sCO_2 loop will be used for benchmarking, validation and further improvement of the computational codes developed.
	GE	Compressor tests will increase modelling and prediction capability for complex gases (and eventually multi phase fluids). High temperature material testing will increase material property databases and materials behaviour in harsh conditions.
	FIVES	Increase knowledge of sCO_2 (thermodynamic behavior, corrosion…), understand the impact of the HX performance on energy production cycles, grasp material features at high temperature and pressure, improve manufacturing processes (brazing, welding, diffusion bonding) dedicated to steel alloys. Learn more about components (boiler, rotating equipment, control system…), and their integration in the whole system.
Licencing	UJV	Protect “boiler design” and assess possible licencing through potential commercial agreements with GE and/or Viktovice Machinery Group.
	FIVES	Manufacturing process, HX channel geometry and HX hydraulic distribution could be licensed.
Transfer of knowledge to industry	EDF	Transfer of knowledge to EDF’s engineering and production departments and to EDF’s subsidiaries all over the world.
	USTUTT	The results of the sCO_2 pseudo condensation experiments will be available to all partners. The data can be used to validate in-house design and analysis codes from industry. Additionally, the results will support designers to assess the operational capabilities of the HX for this special sCO_2-application. Thus, the industry partner will avoid not fulfilling the design requirements.
	CVR	Experimental data on corrosion and erosion will be collected and utilized for material selection by industrial partners involved in the development of sCO_2 components.

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	CSM	The results of the experimental testing campaign will be available to all the partners and will be published in international conferences.
	POLIMI	The definition of optimal control strategies will be available for all the partners and it will define the benchmark for the operation of prototypes and commercial scale plants.

Table 3: Exploitation strategy for RTD partners

3 First year Exploitation ActionsActions for exploitation strategy A

Strategy A aims to exploit the results of the project for the entire developed cycle. Although this strategy cannot be fully implemented until the third year and in the continuation of the project, the results obtained within the WP1 framework have made possible some exploitation actions.

WP1 had the objective of defining the most interesting configurations of the supercritical CO2 cycle in order to develop a very flexible and efficient cycle. During the work of this WP, the partners analysed several possible configurations and conducted an analysis of all current and future constraints for flexibility.

As leader and main contributor of the WP, EDF has carried out several actions related to the exploitation of this work:

- Cycle configurations: EDF has conducted several workshops to present possible configurations to various engineering and fossil fuel plant operating entities. These workshops made it possible to present the future benefits sought in the sCO2-Flex project and to gather opinions from professionals on the best cycle configurations and future equipment development. These workshops also made it possible to inform these teams of possible changes in operation (operability, maintenance,...) and construction related to a supercritical CO2 cycle.
- Flexibility constraints: To better understand flexibility constraints and adapt our cycle to them, EDF organised several technical meetings with power plant and network operators to present the solution developed in sCO2-Flex and gather their opinions.

Following the first results and the internal communication carried out by the project management, a workshop with EDF's Group Strategy Department will be organised in 2019 to present the issue of supercritical CO2 cycles and all possible applications to them.

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3.2 Actions for exploitation strategy B

Exploitation strategy B focuses on an exploitation dedicated to the equipment and components of the future cycle independently of the rest of the cycle. The objective for the concerned partners will be to identify different key areas where the achieved developments can have an impact.

This strategy concerns the industrial partners involved in WP2, WP3 and WP4. As with strategy A, technological developments can only be exploited at later phase of the project. The work of these WPs did not start until the second half of 2018 and the partners involved are still in the process of testing and identifying the problems to be solved.

Nevertheless, some exploitation mechanisms have been implemented:

- WP2: The selection of materials to be tested for the cycle at sCO2 allowed the partners concerned (mainly NRI) to discuss with various suppliers and to present to them the problems related to the use of supercritical CO2 at high temperature and very high pressure. The various suppliers have shown interest in this theme.
- WP3: Through its involvement in various networks and working groups, BHGE regularly shares its results with other stakeholders in the sector. UDE has also integrated the design of supercritical fluid turbomachinery into its lecture.
- WP4: FIVES has started to develop heat exchanger prototypes taking into account the requirements of operating a cycle at sCO2. Exchanges with other solution developers took place. In addition, as project coordinator, EDF has planned in 2019 to discuss with the actors of the American project on the qualification and definition of standards for compact heat exchangers for electricity production and to involve WP4 partners. This aspect of standardization is one of the key factors in the development of this type of exchanger in electricity production.

3.3 Actions for exploitation strategy C

Exploitation strategy C is a long-term scenario in which EDF, as plant operator, would exploit future or retrofitted coal plants and sell the electricity produced to end-users (industry, households, …).

This strategy will be implemented from the second half of the project, in collaboration with the entities concerned within EDF.

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Conclusion

During the first year of the project, few actions could be carried out by the consortium. This is due to two factors: innovation related to the use of a supercritical CO2 cycle that requires a very important work of presentation and popularization of the technology and the project's roadmap that implies that the main technological results of the project will be obtained in its second half.

Nevertheless, regular exchanges with target companies or entities have begun in the initial work of the project. This work will continue throughout the project and exploitation strategies will be refined based on the results in order to target the most relevant stakeholders.

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