sCO2-4-NPP: Innovative sCO_2-Based Heat Removal Technology for an Increased Level of Safety of Nuclear Power Plants

Deliverable D7.1

First version of sCO2-4-NPP exploitation plan

Work programme topic addressed: NFRP-2018-10: Encouraging innovation in nuclear safety for the benefit of European citizen

Type of action: Innovation action

Grant Agreement number:	847606
Start date of project: 1 September 2019	Duration: 36 months
Lead beneficiary of this deliverable:	EDF
Due date of deliverable: 28/02/2021	Actual submission date: 28/02/2021
	Version #: R1.0

Type		
R	Document, report excluding the periodic and final reports	X
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	
Dissemination level		
PU	PUBLIC, fully open, e.g. web	X
CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	

Revision History

Release	Date	Reason for Change	Author	Distribution
R0.1	13/02/2021	Document outline for completion	Susan Barreault	Consortium
R0.2	15/02/2021	Draft for approval	Albannie Cagnac	General Assembly
R1.0	26/02/2021	Final version	Susan Barreault	Public

Deliverable Contributors

Authors

Partner	Name
EDF	Albannie Cagnac

Contributors

Partner	Name
ARTTIC	Susan Barreault
JSI	Andrej Prošek

Internal Reviewers

Partner	Name
USTUTT	Jörg Starflinger

Table of contents

List of Tables

List of Figures

1 List of Acronyms

Abbreviation / Acronym	Description / meaning
AFNOR	Association Française de Normalisation
ASN	Autorité de Sûreté Nucléaire
CCPN	Comité de Coordination et de Pilotage de la Normalisation
Cenelec	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
CFD	Computational Fluid Dynamics
CSP	Concentrated Solar Power
EIMT	Exploitation and Innovation Management Team
EQ	Equipment Qualification
EU	European Union
HX	Heat eXchanger
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IP	Intellectual Property
IPR	Intellectual Property Rights
NPP	Nuclear Power Plant
PCHE	Printed Circuit Heat Exchanger
PFHE	Plates and Fins Heat Exchanger
RL	Reference Level
RWE	Rhine-Westfalia Electricity Factory
SSCs	Structures, Systems and Components
SNETP	Sustainable Nuclear Energy Technology Platform
TRL	Technology Readiness Level
VVER	Vodo-Wodyanoi Energetichesky Reaktor (Water-Water Energy Reactor)
WENRA	Western European Nuclear Regulators Association

2 Executive Summary

The D7.1 is the first version of the sCO2-4-NPP exploitation plan issued mid-project. This report describes the exploitation plans for the sCO2-4-NPP system and system components including the technological, regulatory, financial and organisational (business plan) roadmaps for reaching TRL9.

A final version of the sCO2-4-NPP exploitation plan, including the technological, regulatory, financial and organisational roadmaps to reach TRL9, the D7.2, will be issued at project end.

3 Introduction

The definition of the Exploitation Plan will be led by the Exploitation and Innovation Management Team (EIMT) and will ensure that all IP-owning partners as well as potential and confirmed exploitation partners will work towards successful technology and knowledge transfer. The Plan shall serve as the basis for future business models and will define commercialisation strategies. It will have to answer the following questions:

- WHAT: clarification of exploitation results and development of exploitation routes;
- WHO: identification of lead partners to achieve and exploit each result;
- HOW: form(s) that the exploitation will take (direct industrial use, patenting, technology transfer, publication, input to regulation, etc.);
- BARRIERS: identification of (overlapping) IPR and commercialisation conditions, risk management actions; existing or emerging competing solutions; availability of knowledge and resources among participants and willingness to contribute to the results.

4 Overall Strategy for Exploitation of the sCO2-4-NPP Technology

The main strength of sCO2-4-NPP is to bring together stakeholders covering the entire value chain (e.g.: EDF as plant operator/end-user, NRI as boiler designer, NP TEC as turbomachinery manufacturer, FIVES as heat exchanger manufacturer) as well as complementary experts in research and technology development (UDE for turbomachinery behaviour, CVR for cycle testing) with background and expertise to help the industry move forward. Synergies detected among players will lead to new research activities and new business opportunities.

Bringing the technology to a TRL9[1], requires a step-by-step approach to the different requirements for a nuclear technology. The technological, regulatory, financial, and commercial roadmaps are developed to support this objective. An outline of this plan is presented below.

a) Technological roadmap:
   - Robustness and reliability: The different materials and components of the sCO2-4-NPP system must demonstrate their robustness and reliability for the entire operating life of the system. The work carried out within the project will make it possible to integrate this approach. To do this, the entire system and each of these components must be qualified for use in a nuclear environment (cf. regulatory approach). Risk assessment (probabilistic, deterministic) will also have to be carried out. The interaction of the sCO2-4-NPP system with specific operational and emergency systems of Nuclear Power Plants (NPPs) will be assessed.
   - Large scale testing availability: A pilot site will have to be identified for the installation of a technology pilot. This installation can only be considered once the system has been qualified. An MW scale prototype will also have to be built for long term testing. The Chinese Academy of Science is currently setting up a test loop for components running with sCO2. By purpose, this test loop shall be open to companies and research organisations around the world. The main performance data (max. 700 °C, max. 25 MPa, max. 5 MWth, and max. 26 kg/s sCO2) allow for testing equipment and components on MW scale.

b) Regulatory roadmap:
   - Equipment qualification (EQ): The safety function of a piece of equipment is generally established in terms of its required behaviour (active or passive) and its duration. The EQ is a process adopted to confirm that the system is capable of meeting, throughout its operational design life, the demands for performing its functions while being subject to the environmental conditions (vibration, temperature, pressure, jet impingement, electromagnetic interference, irradiation, humidity or any likely combination thereof) prevailing at the time of need. Environmental conditions to be considered include the variations expected in normal operation, anticipated operational occurrences, design basis accidents and design extension conditions without significant fuel degradation. Moreover, consideration shall be given to ageing effects caused by various environmental factors (such as vibration, irradiation and extreme temperature) over the expected lifetime of the equipment. The qualification programme shall replicate as far as

[1] TRL 9 –actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space), https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/euratom/h2020-wp1920-euratom_en.pdf Appendix F.

practicable the conditions imposed on the equipment by the natural phenomenon, either by test or by analysis or by a combination of both.

- Approval of the safety authorities: once the technology has been qualified, the operator who wishes to install the technology must have the approval of the national safety authority on which he depends. This approval is based on probabilistic safety studies, and deterministic studies confirming the improvement or non-degradation of reactor safety. Preparatory work will start during the project with WP3 studying the requirements and other WPs taking them into account in the design of the system.

c) Standardisation roadmap: In order to obtain their qualification, each element of the technology must be developed according to the reference standards. As part of the sCO2-4-NPP system, the consortium has already identified that the standards for compact heat exchangers for nuclear and turbomachines for sCO_2 are not finalised. For this reason, it has included in its dissemination plan an important communication with the various standardisation organisations.

d) Intellectual property: The technology of sCO2-4-NPP and the improvements that will be made up to its exploitation can be part of a patent process. Given the history of patents already existing for the concept of the technology or for the different components, technology developers will have to be careful to respect these IP rights. These include citing the existing patents to avoid future conflicts and to show that the sCO2-4-NPP patent is a real improvement of the former patent. Also, with regards to the current patent of RWE, specific conditions will be negotiated when the patent application is submitted (see table on key project results).

e) Sustainability of financing after the EU funding: To ensure sustainability of financing, the partners will seek funding through joint ventures and direct investment through venture capital to make the system robust and reliable, pilot plan development, large-scale testing and bringing the system to industrial scale. On the basis of the amounts allocated to other international projects related to the sCO_2 cycle, and taking into account the need to qualify this type of system for nuclear energy, at least €100 million would be needed to provide the necessary test benches and first test loops.

Securing an industrial integrator to adapt the sCO2-4-NPP technology to industrial scale: During the project, the solution will be presented to different integrators, such as Framatome, to create partnerships for future industrialisation.

Besides the preparation of the exploitation plan and the different roadmaps mentioned above, sCO2-4-NPP partners will carry out several activities during the project which will prepare the future exploitation:

- An IP portfolio will be set up and managed by the EIMT and a strategy for patenting and publications will be proposed
- A workshop with end-users to validate the technology and make them aware about the developments
- Contacts with potential investors to finance the next steps
- Contacts with regulatory bodies such as WENRA

4.1 Expected Results to be Exploited

The key project results which can be exploited are the following:

Table 1: Key project results

RESULT	PARTNER	Specific EXPLOITATION ROUTES and STRATEGIES
sCO2-4-NPP sCO_2 heat removal system for nuclear power plants	Consortium (led by EDF)	The consortium will study whether patent possibilities are possible depending on the development of equipment and related innovations.
TURBOCOMPRESSOR New integral turbocompressor design for sCO_2 power generation	NP TEC UDE	NP TEC will use sCO2-4-NPP results to validate market assumptions and create an industrialisation program to improve its commercial offers (global cycle solution, turbomachinery alone for integrators) for any energy sector (including nuclear).
HEAT EXCHANGER solutions based in PCHE/PHFE (in stainless steel and nickel-based alloys) for sCO2	FIVES	FIVES will open new business lines for innovative HX for sCO_2 cycles suitable for conventional plant, CSP, biomass, etc. (global cycle solution, HX alone as main equipment for integrators). The exploitation routes are guided by market needs which are mainly compactness, robustness, and efficiency at a reasonable cost.
SAFETY EDF operation of sCO2-4-NPP system	EDF	As the largest operator of nuclear power plants in Europe, EDF has the capacity to support the development of a technology, within partnerships and collaborations, if its merits are demonstrated.

In addition to these main results, other partners will exploit their results in the following ways.

Table 2: Secondary results

Partner	Planned Result	Planned Use of Project Result	Main User(s)
USTUTT	Improved ATHLET code, improved ATHLET input deck.	If code improvements will be a result, the new code version will be transferred to GRS (Gesellschaft für Reaktorsicherheit, code developer) at project end for inclusion in the next code release.	GRS or other users, who want to include sCO_2 systems in their plant or studies (for codes benchmarks for example)
GfS	Running various sCO2-cycle scenarios	Experience for demonstration of the sCO_2 cycle	• Nuclear technology experts • Students • Engineers • Nuclear operators
KSG	Robust HeRo-Loop on Glass Model, PWR simulator equipped with sCO_2 system	Presentation by KSG/GfS during Glass Model training and during expert courses	• Authorities • Technical expert groups

Partner	Planned Result	Planned Use of Project Result	Main User(s)
			• Nuclear personnel
CVR	• Transient (accident) simulations of the whole system (PWR with sCO_2 heat removal) (coupling ATHLET/CATHARE with Modelica). • The thermodynamic cycle design of the sCO_2 heat removal system. • Testing of the natural circulation and condensation of the steam cycle cooled by sCO2. • Optimisation and testing of the sink HX.	• Offer services in design (optimising the design and control system of sCO_2 units) and operation of sCO_2 units. • Offer customised thermal hydraulic software for sCO_2 applications. • Share general know-how in sCO_2 technology with other experts. • Broaden the sCO_2 interest and sCO_2 market. • Provide feedback to the developer of heat exchangers.	• NPP designers • NPP operators • NPP regulators
JSI	New knowledge and experience gained in independent review of licensing documents.	Experience used in other independent reviews.	• Krško NPP • Slovenian Nuclear Safety Administration • International Nuclear Safety community
UDE	• Increased expertise in sCO2-turbomachinery design and operation • New educational content	• sCO_2 turbomachine design integrated in different lectures (CFD and Gas Turbine Technology) • Support industry in the design of turbomachines for sCO_2 cycles for energy production (waste heat recovery, solar power). • Knowledge used in new project CO2OLHEAT – EU Project starting June 1st, 2021)	• Students • Engineers • Industry
NRI	Transient (accident) simulations of the whole system (PWR with sCO_2 heat removal, coupling ATHLET/CATHARE with Modelica) responsible for the ATHLET part Review of licensing documents Design heat removal system from containment	• Offer services focused on licensing and safety requirements • Offer operators with technology VVER	• Nuclear regulators • NPP (VVER) operators

Each technical partner will be the owner of its developments and will own the exploitation rights, under the legal constraints.

5 Exploitation planning and management of intellectual property

An "Exploitation and Innovation Management Team" (EIMT) has been setup and is composed of representatives of the partners concerned by the exploitation of key results and involved in preparing the roadmap to TRL9 (EDF, USTUTT, NP TEC, FIVES CRYO, JSI, UDE, ARTTIC). The EIMT is tasked with development of the sCO2-4-NPP Exploitation Plan that will cover the specific results of the sCO2-4-NPP project and the coordination of efforts to implement the exploitation. In addition, the EIMT will also manage the Intellectual Property and exploitation of sCO2-4-NPP results, in accordance with the sCO2-4-NPP Consortium Agreement. This will include the setup of an IP portfolio, strategy for patenting, strategy for publications, management of the evolution of the Consortium Agreement and market watch.

The technology of sCO2-4-NPP may be part of patents process. Given the history of patents already existing for the concept of the technology or for the different components, technology developers in the project will have to be careful to respect these IP rights. These include citing the existing patents to avoid future conflicts and showing that the sCO2-4-NPP patent is a real improvement of the former patent.

5.1 IP Portfolio

The purpose of the IP Portfolio is to clarify ownership of project results to facilitate future exploitation. sCO2-4-NPP Consortium partners can submit Results at any time for approval of the General Assembly. Once approved, an updated version of the IP Portfolio will be circulated. The sCO2-4-NPP IP Portfolio should be considered as a tool to implement the provisions of the Consortium Agreement.

5.1.1 Approval Process

To secure and guarantee the evidence that the Result belongs to the partner, a partner should register their Result to the IP Portfolio.

The process is as follows:

1. IP Registration Form to be completed by the partner claiming the Result.
2. Completed form to be sent by email to the Project Coordinator, copy the Project Office.
3. Project Coordinator to invite by email the General Assembly to approve the registration.
4. From receipt of the invitation, the General Assembly has 15 calendar days to raise objections. Objections shall be made to the partner claiming registration with a copy to the Project Coordinator. Allowable objections are those invoking legitimate interest with evidence attached (as stated in the EC Grant Agreement, when invoking legitimate interest, a Partner must show they will suffer disproportionately great harm).
5. After 15 days and if no objection, the Result is registered by the Project Office in the IP Portfolio to secure evidence that the Result belongs to the partner which claims it.

5.1.2 IP Registration Form

Table 3: IP Registration Form

Result	
Name of the Party	Name of organisation responsible
Owner(s)	Partner name(s)
Nature	Patent, design, software, etc.
Registration / Protection	Patent number, copyright, etc.
Title / Description	1/ Provide title of Result
	2/ Identify the task or WP where the Result has been produced
	3/ Description of the Result and when relevant, if the Result is co-owned by several participants
	4/ Background required to use the Result if Background needed
Access conditions for research in the project / Limitations	Description of the access conditions and if access is conditional to a specific licence agreement, agreement of co-owners, etc.
Access conditions for use / Limitations	Description of the access conditions for use, including for purpose, (i.e., further research, internal usage or commercial usage), and rights granted
Licensee(s) in the project	Name of the licensee (add additional licensees as necessary)
	Date of allocation:
	Type of licence:
Licensee(s) for use	Name of the licensee (add additional licensees as necessary)
	Date of allocation:
	Type of licence:
Dissemination	Dissemination undertaken for the Result outside licensing (publications, technology transfer, etc.)

5.2 Project Activities to Prepare for the Exploitation of Results

In addition to the preparation of the exploitation plan and the different roadmaps mentioned above, sCO2-4-NPP partners will carry out several activities during the project to prepare the future exploitation.

The strategy for publication is described in D8.1 Dissemination and Communication Plan.

sCO2-4-NPP intends to prepare and participate in the following events orientated toward potential end-users:

- **Joint event with sCO2-Flex**

A joint event is of interest in particular to reach end-users in the energy sector where sCO_2 technology is also applicable.

- **International conferences**

Participation in several international industrial conferences will allow the project results to be presented to a panel of potential users. Industrial symposia, such as those of SNETP (Sustainable Nuclear Energy Technology Platform), TURBO-EXPO will be considered.

The online European sCO_2 Conference is taking place on March 23rd & 24th 2021 and is hosted by UDE and supported by the project partners. Four papers are related to the project and accepted for publication.

- **End-user Workshop**

This workshop will be organised in M26 (October 2021) tentatively at KSG in Essen, Germany, and will include demonstrations of the transient loop behaviour of the system at the PWR Glass Model. The End-user Group will be invited to make them aware about the developments and to validate the technology.

- **sCO2-4-NPP Symposium and Demonstration**

A demonstration event targeting NPP operators will be organised towards the end of the project (M34, June 2022) tentatively at the KONVOI PWR simulator at KSG in Essen, Germany. The consortium will demonstrate the interaction of the sCO2-4-NPP system with the virtual NPP. A public symposium is planned targeting mainly nuclear actors (operators, research institutes, safety authorities) to disseminate sCO2-4-NPP results.

6 Technological roadmap to reach TRL9

The long and mid-term planning of necessary technological and scientific steps for bringing sCO2-4-NPP to TRL9 will be further detailed in this task. The results from WPs 4, 5 and 6 will be the starting point. Technological developments on both component scale and system architecture, as well as necessary steps for testing, validation, qualification as well as integration in existing and future NPPs will be studied, taking into account regulatory and licensing aspects and market and organisational factors.

The technological roadmap defined in the sCO2-4-NPP project will aim to provide a macroscopic and as exhaustive as possible view of the locks to be lifted and the next steps needed to develop the technology. Thus, the consortium will work to:

- Identify the technological locks to be lifted.
- Define the steps needed to take the technology from TRL 4-5 (end of project sCO2-4-NPP) to TRL 8-9.
- Establish the needs relating to the qualification, testing and acceptance of the sCO_2 system by the nuclear community (from the manufacturers associated with the components to the safety authorities).

Particular attention will also be paid in the roadmap to the potential use of the system and its components for areas other than nuclear safety.

Indeed, the system's components, such as turbomachines or heat exchangers, are components that can be used in fields such as the chemical industry, oil & gas and the progress in cycles using supercritical CO_2 in recent years could be of interest to these industries.

6.1 Identification of technological locks

Although the objectives of the sCO2-4-NPP project are to remove many technological obstacles, some issues remain to be validated, as they could not be dealt with during the project. These include issues related to the ageing, maintenance and reliability of the system. The technological roadmap proposed by the consortium will try to identify them in order to propose ways to improve the system.

6.2 System and components improvement

Based on the identified locks, the consortium will propose a roadmap for making the necessary improvements to the system and its components. In addition to the improvements aimed at increasing the reliability and robustness of the components (choice of materials, back-up systems, etc.), the consortium will also examine aspects related to risk management (need for deterministic and probabilistic studies, etc.) and safety (measurement methods, risk of leakage, etc.).

6.3 Qualification and test

A pilot site will be interesting for the qualification and test of a pilot. This installation can only be considered once the system has been qualified. An MW scale prototype will also have to be built for long term testing. The Chinese Academy of Science is currently setting up a test loop for components running with sCO2. By purpose, this test loop shall be open to companies and research organisations around the world. The main performance data (max. 700 °C, max. 25 MPa, max. 5 MWth, and max. 26 kg/s sCO2) allow for testing equipment and components on MW scale.

7 Regulatory roadmap to reach TRL9

Based on the output of WP3 and the technological and financial and organisational roadmaps, this task will develop a detailed long-term planning of the necessary steps to achieve licensing of the sCO2-4-NPP system in future user countries to be able to integrate the real operating environment system in existing and future NPPs.

The purpose of the regulatory roadmap is to provide recommendations for future qualification and licensing of the NPP system:

- Equipment qualification (EQ): Equipment qualification includes environmental and seismic qualification. The safety function of a piece of equipment (electrical or mechanical or I&C equipment) is generally established in terms of its required behaviour (active or passive) and its duration. The EQ is a process adopted to confirm that the system is capable of meeting, throughout its operational design life, the demands for performing its functions while being subject to the environmental conditions (vibration, temperature, pressure, jet impingement, electromagnetic interference, irradiation, humidity or any likely combination thereof) prevailing at the time of need. Environmental conditions to be considered include the variations expected in normal operation, anticipated operational occurrences, design basis accidents and design extension conditions. Moreover, consideration shall be given to ageing effects caused by various environmental factors (such as vibration, irradiation and extreme temperature) over the expected lifetime of the equipment. The qualification programme shall replicate as far as practicable the conditions imposed on the equipment by the natural phenomenon, either by test or by analysis or by a combination of both.
- Testing considerations: Service conditions include many considerations for equipment qualification: environmental, loading, power, and signal conditions expected during normal operation; expected abnormal extremes in operating requirements; and postulated conditions for design-basis events. Postulated design-basis events are those used during the design of the plant to establish the requirements for the acceptable performance of structures, systems, and components. They include large-break loss-of-coolant accidents, high-energy line breaks, main steam line breaks, and similar events that can cause high-temperature, high-pressure fluid sprays, flooding, or pipe whip. Design-basis events can also be caused by natural phenomena such as an earthquake. Service conditions also include operating conditions such as self-heating, cycling, process fluid conditions, and electromagnetic interference. Qualification of equipment shall be accomplished by test, analysis, documented operating experience, or some combination of these methods. Type testing is the preferred method for qualification of equipment.
- Equipment aging: The aging of systems and components is a potential common cause failure mechanism. Equipment qualification testing for the effects of aging typically applies techniques that use accelerated aging methods on test specimens to simulate years of service under the expected operating conditions.
- Operating environment: The environment in which equipment operates (harsh or mild) and the consideration of seismic events plays a large role in determining the qualification process. Whether the equipment is classified as electrical or electromechanical or mechanical also influences the qualification process. For example, in a mild environment, the only design-basis event of consequence is a seismic event. Also mild environments are not considered to have significant aging mechanisms.

- Seismic qualification: Seismic qualification of safety-related equipment includes meeting both structural integrity and operability requirements under such conditions. For simple safety-related equipment, seismic qualification can often be done through analysis. For complex safety-related equipment, testing must be performed to show that the equipment meets these requirements under seismic conditions. Mechanical aging is also a consideration in seismic qualification. The dynamic qualification of the equipment shall be achieved by testing, analysis or a combination of testing and analysis.
- Licensing requirements:
  - WENRA RL G4.1: The design of SSCs important to safety and the materials used shall take into account the effects of operational conditions over the lifetime of the plant and, when required, the effects of accident conditions on their characteristics and performance.
  - WENRA RL G4.2: Qualification procedures shall be adopted to confirm that SSCs important to safety meet throughout their design operational lives the demands for performing their function, taking into account environmental conditions over the lifetime of the plant and when required in anticipated operational occurrences and accident conditions.

  Requirements for implementing EQ in nuclear power plants are prescribed by various national and international standards, codes and guides. For example, ASN Guide No. 22 tells us that equipment important to safety must be qualified to ensure its ability to meet its defined requirements for the conditions under which it is needed. The most commonly used industry standards that provide qualification requirements are developed by the Institute of Electrical and Electronics Engineers (IEEE) and the International Electrotechnical Commission (IEC). For example, general standard 627-2019 - IEEE Standard for Qualification of Equipment Used in Nuclear Facilities, provides the basic principles for qualification of equipment (all types of mechanical, instrumentation, and electrical equipment) used in nuclear facilities; it does not define the scope of equipment requiring qualification nor does it provide guidance on how to classify equipment. The range of operational conditions includes also design extension conditions. Finally, requirements for qualification in Czech Republic and France are specified in Chapter 5 of deliverable D3.3.
- Approval of the safety authorities: once the technology has been qualified, the operator who wishes to install the technology must have the approval of the national safety authority on which he depends. This approval is based on probabilistic safety studies, and deterministic studies confirming the improvement or non-degradation of reactor safety. Preparatory work will start during the project with WP3 studying the requirements and other WPs taking them into account in the design of the system. Prior to the granting of a licence, the applicant shall be required to submit a safety assessment. Safety assessment is a systematic process that is carried out throughout the design process (and throughout the lifetime of the facility or the activity) to ensure that all the relevant safety requirements are met by the proposed (or actual) design. Regulatory elements for design of components and system have been identified in D3.1. The nuclear licensing requirements consist of legislation, guidelines, and codes and standards.

7.1 Contacts with regulatory bodies

Any new safety systems need to go through specific qualifications on a nuclear regulatory level. An independent review of the acceptability of set requirements and criteria to be considered in the licensing process will be carried out (WP3). The project will also collaborate with an external regulatory advisor. The results will provide input for defining the regulatory roadmap to reach TRL9.

The project foresees meetings with national and European (e.g. WENRA) bodies to present results, dissemination through the project advisors who are regulatory experts, and publications from WP3 (both public deliverables and publications in journals) demonstrating the compliance of the technology with official NPP safety standards.

7.2 Contacts with standards bodies

To understand the potential need and opportunities for standardisation of the sCO2-4-NPP technology, the project will monitor and align with any evolution of relevant standards in NPP safety. Partners will alert standards bodies on the need for evolution of standards for the main components of the sCO2-4-NPP system. The standards for compact heat exchangers for nuclear applications and turbomachines for sCO_2 are not finalised.

Participation in standardisation committees relating to system components (or contact) can be envisaged for the industrial partners directly concerned. At present, the existing standards on sCO_2 equipment are mainly for use in the chemical industry and not for power generation.

The main standardisation committees that may be interested are CCPN, AFNOR, IEC and CENELEC.

8 Financial and organisational roadmap to reach TRL9

In this task the partners will propose financial, organisational and marketing roadmaps for bringing the sCO2-4-NPP system to TRL9 with the technological and regulatory roadmaps developed. The business plan will be used to contact different stakeholders (financial, industrial partners) to establish partnerships so as to ensure the continuation of the developments on a financial and industrial level.

- Standardisation roadmap: In order to obtain their qualification, each element of the technology must be developed according to the reference standards. As part of the sCO2-4-NPP system, the consortium has already identified that the standards for compact heat exchangers for nuclear and turbomachines for sCO_2 are not finalised. For this reason, it has included in its dissemination plan an important communication with the various standardisation organisations.
- Sustainability of financing after the EU funding: To ensure sustainability of financing, the partners will seek funding through joint ventures and direct investment through venture capital to make the system robust and reliable, pilot plan development, large-scale testing and bringing the system to industrial scale. On the basis of the amounts allocated to other international projects related to the sCO_2 cycle, and taking into account the need to qualify this type of system for nuclear energy, at least €100 million would be needed to provide the necessary test benches and first test loops.
- Securing an industrial integrator to adapt the sCO2-4-NPP technology to industrial scale: During the project, the solution will be presented to different integrators, such as Framatome, to study the relevance and possibility of continuing work on the development of the NPP system with nuclear manufacturers.

8.1 Preliminary Business Model

A sketch of the main elements of the smart system business model is presented in Figure 1, following the CANVAS method.

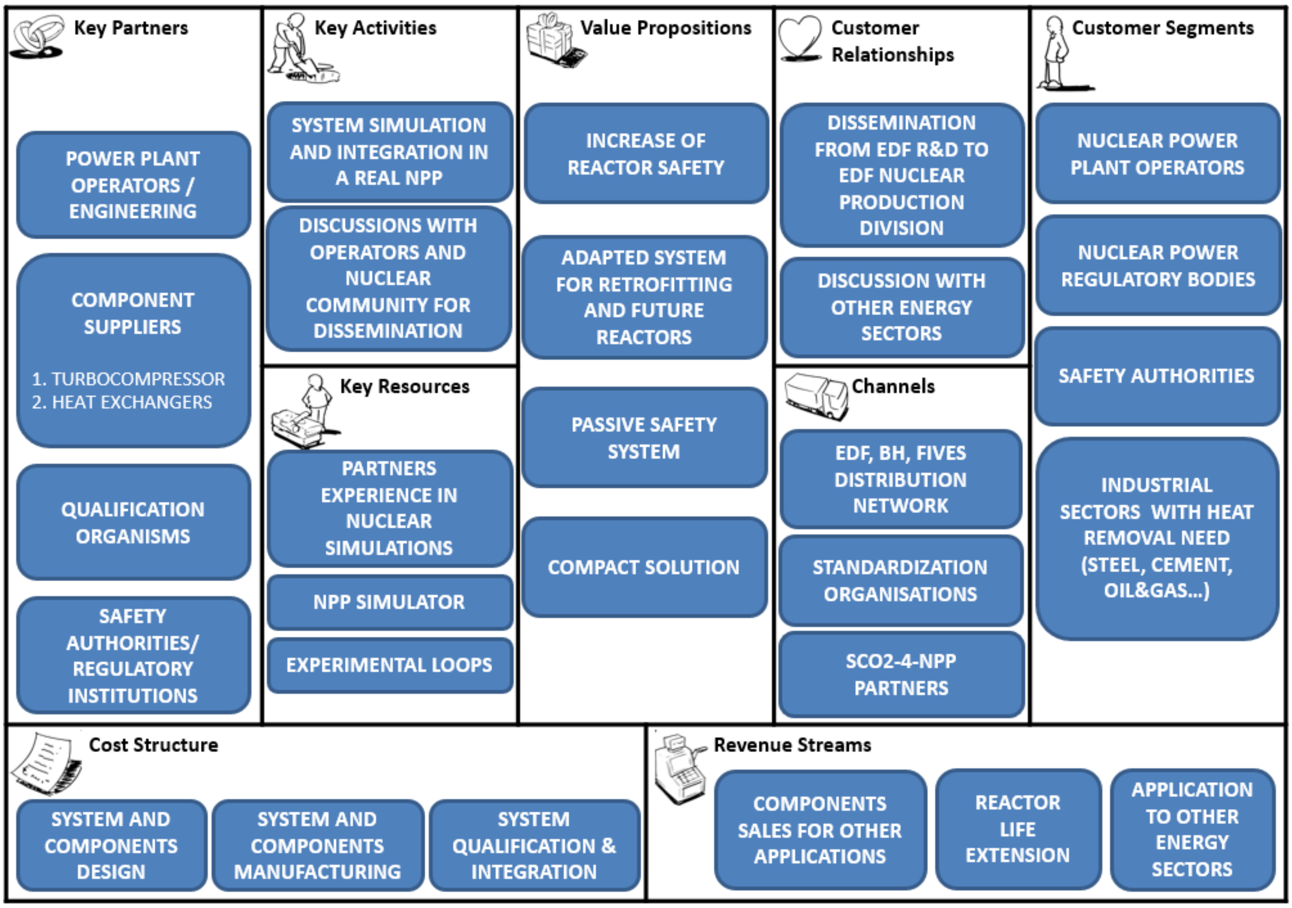

Figure 1: sCO2-4-NPP business model (CANVAS methodology diagram)

8.2 Contacts with potential investors to finance the next steps

In view of the safety and security issues related to nuclear power plants, the next steps in the development of the NPP system will have to be taken in collaboration or with the agreement of the safety authorities (and thus legislators in some countries). This type of technological development project requires very significant investment and strong collaboration between partners.

The financial plan to support this type of project will have to include insurance from the investors. The funds could come from private funds, but also from public funds dedicated to research or nuclear safety.

During the course of the project, the consortium will identify possible investment modalities and may contact potential investors if the results of the project and the technology are convincing.

9 Conclusion

This report describes the draft exploitation plans for the sCO2-4-NPP system and system components including the technological, regulatory, financial and organisational (business plan) roadmaps for reaching TRL9.

The overall strategy for exploitation is described, together with steps to be taken during and following the project for the technology to reach TRL9. Challenges to be overcome in order to reach these objectives are also identified.

A final version of the sCO2-4-NPP exploitation plan, including the technological, regulatory, financial and organisational roadmaps to reach TRL9, the D7.2, will be issued at project end.