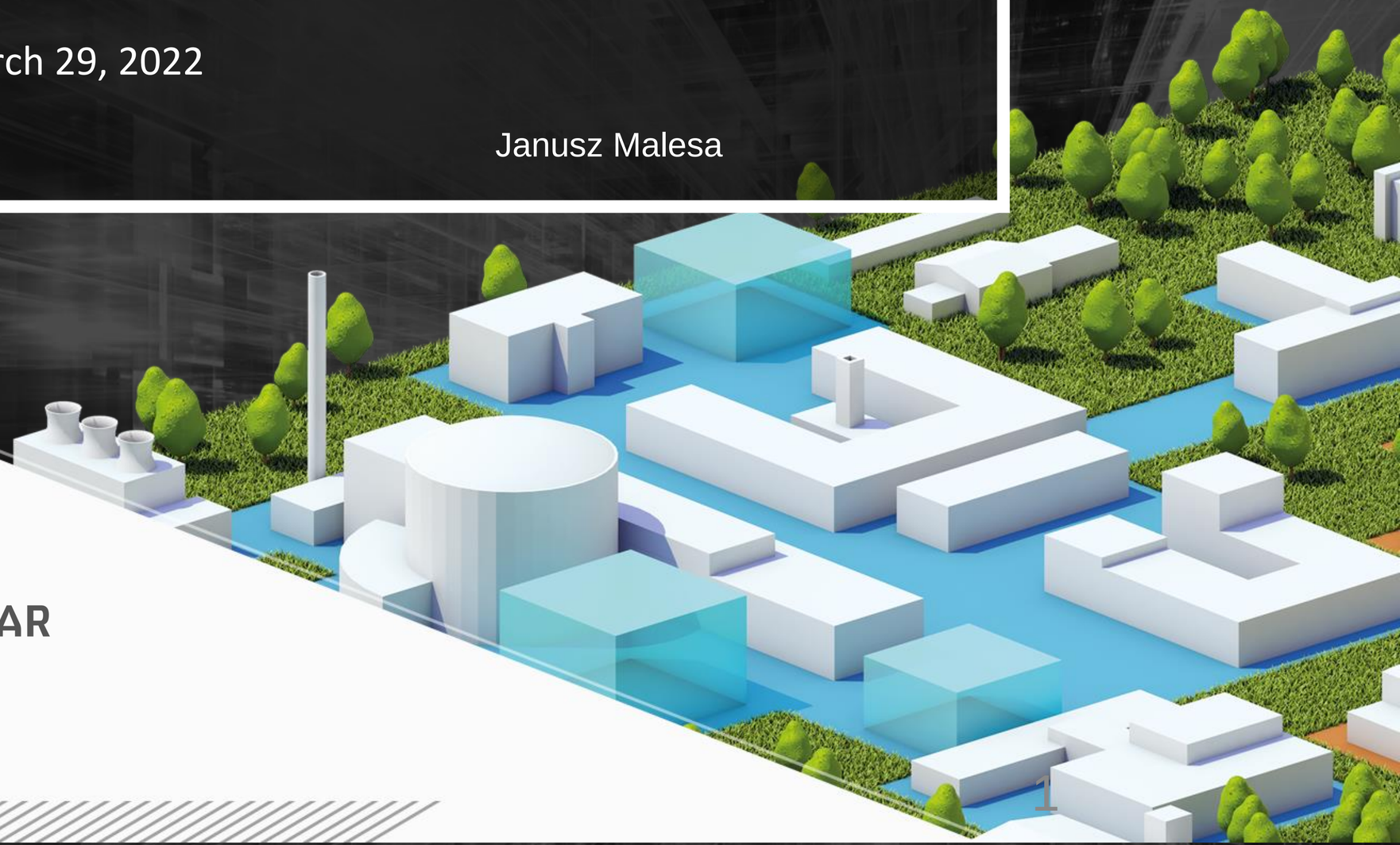
GEMINI For Zero Emission
Project objectives

UZ3 Seminar, March 29, 2022

Janusz Malesa



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- GEMINI+ System concept
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  - Objectives
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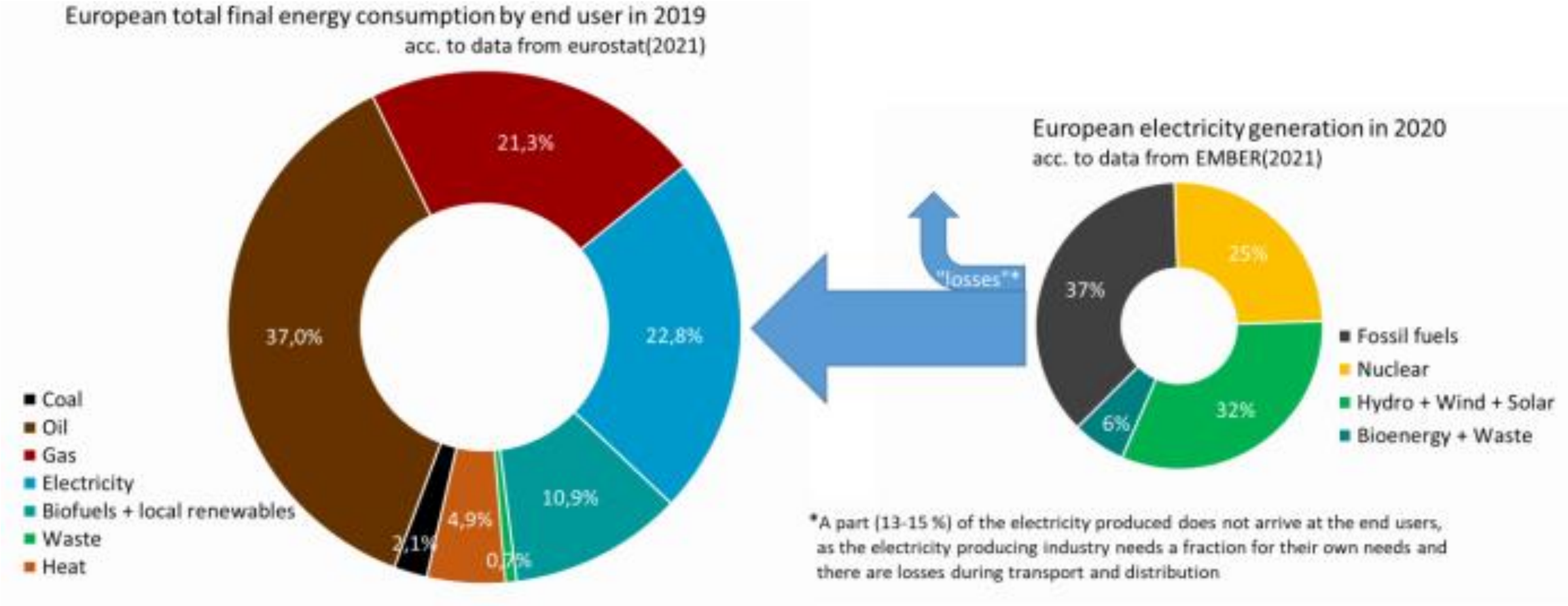
- Summary

GEMINI Plus follow-up project entitled GEMINI 4.0 will be launched in June. It was positively assessed and received funding under the Euratom Research and Training Program (HORIZON-EURATOM-2021). NCBJ takes part in the implementation of this international action prepared by partners within NC2I association. As part of the project, the concept of using a HTGR reactor for emission-free production of process and municipal heat, hydrogen, ammonia and others will be developed. NCBJ is responsible for leading the work package on "Optimizing safety and competitiveness of the GEMINI+ design". We also participate in almost all other topics, including fuel technology options and fuel cycle strategy. During the seminar, I will introduce the objectives and tasks of the project.

The presentation is based on a papers, presentations and other materials prepared by members of the NC2I, partners of GEMINI Plus project and partners preparing GEMINI 4.0 Proposal

Introduction

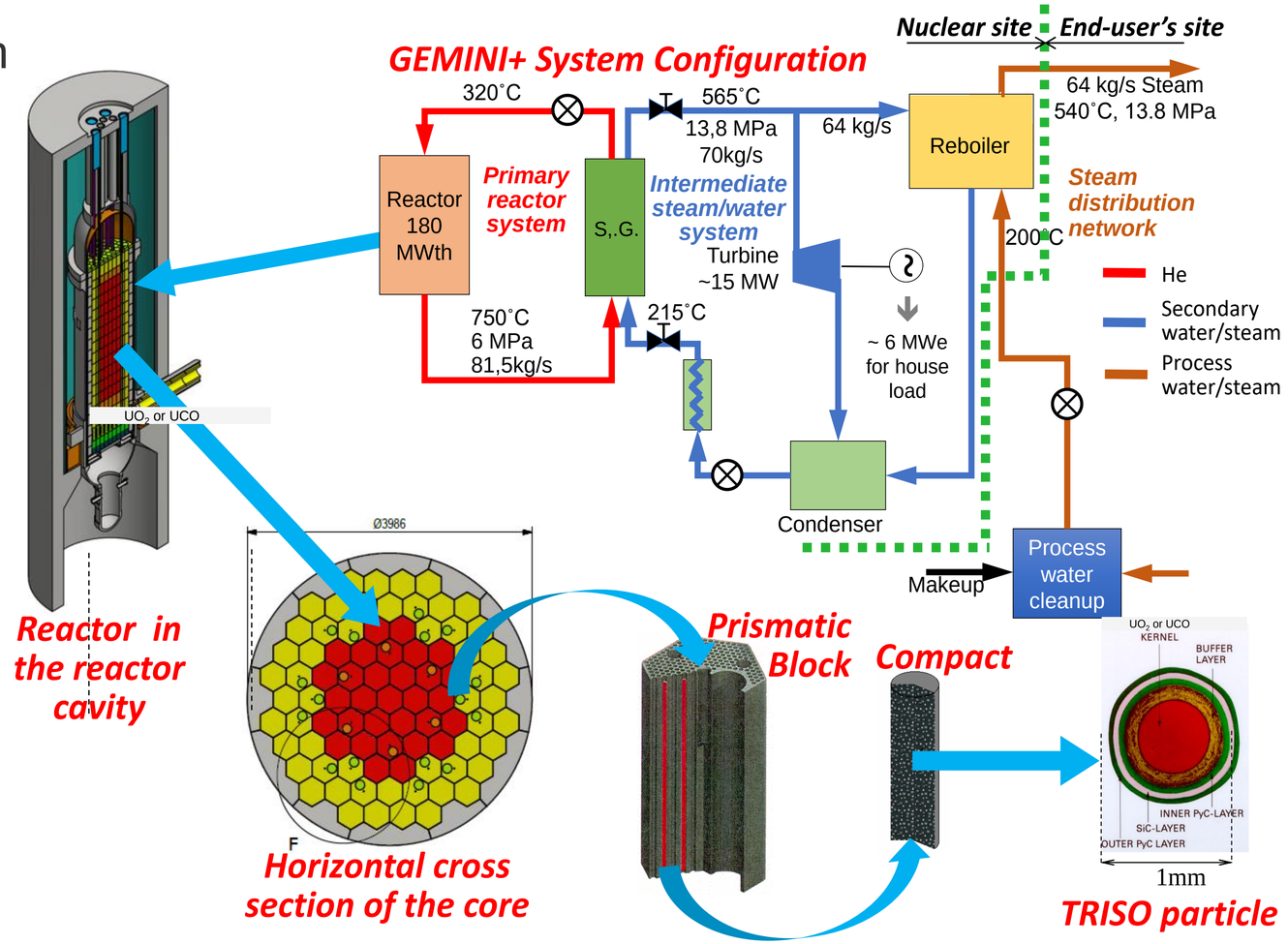


Electricity generation with its CO_2 emission structure in quantitative relation to other CO_2 sources, in terms of final energy consumption; European view.
Graphics established on the basis of data from Eurostat 3 (left) and EMBER 4 (right)

MAIN ACHIEVEMENTS OF GEMINI PLUS

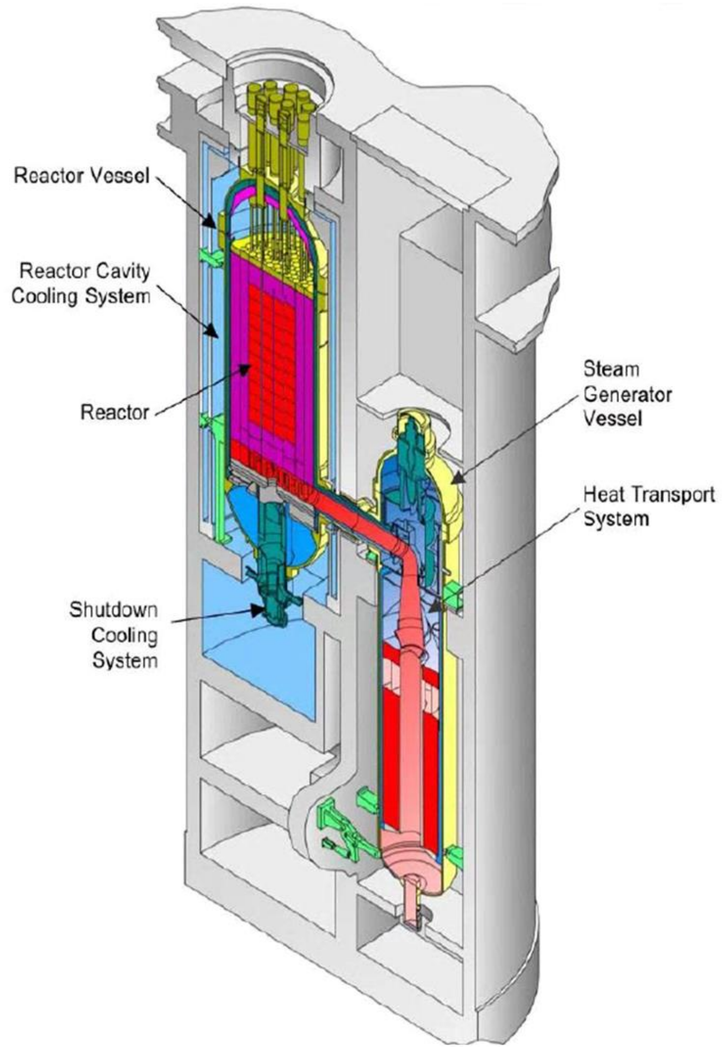
GEMINI+ project has been designed to support an early demonstration of industrial nuclear cogeneration of electricity and steam in Poland using an inherently safe HTR

- Main results:
  - A flexible standard design that can address versatile steam industry needs
  - A safety approach meeting present highest safety standards
  - An identification of residual technology gaps
  - A better understanding of industrial application needs: Importance of hydrogen for industrial applications
  - An understanding of the integration of high temperature nuclear cogeneration systems in global or local energy systems



GEMINI+ HTGR Design

PARAMETER	VALUE
Thermal power:	180 MW
Core inlet temperature:	325˚C
Core outlet temperature:	750˚C
Primary pressure:	6 MPa
Number of blocks in column:	11
Number of fully fuel loaded blocks in core:	275
Number of fuel blocks with control rods in core:	66
Number of reflector blocks with control rods in core:	198*
Number of reflector blocks in core:	396*
*only core region, without lower and upper permanent reflector	
Number of reflector blocks- upper:	255
Number of reflector blocks- lower:	340
Gap between blocks:	2.0 mm



Isometric View of Generic HTR – picture based on NGNP Reactor Module

European Projects on HTGR

- HTR, HTR E, HTR N, HTR M – R&D early 21 century
- RAPHAEL (FP6) – IRP 2005 – 2009
- EUROPAIRS (FP7) – R&D 2009 – 2011
- ARCHER (FP7) – R&D 2011 – 2015
- NC2I-R (FP7) – R&D 2013 – 2015
- GEMINI Plus (Horizon 2020/ Euratom) – R&D 2017 – 2021

GEMINI+ 4.0

- GEMINI for Zero Emission (Horizon Euratom) – RIA 2022 – 2025

NC2I
Nuclear Cogeneration Industrial Initiative

SNETP
Sustainable Nuclear Energy Technology Platform

GEMINI FOR ZERO EMISSION

Acronym: **GEMINI 4.0**

Topic: **HORIZON-EURATOM-2021-NRT-01-05 Nuclear Research and Training, Safety of HTGRs)**

- Type of Action: EURATOM-RIA
- Duration: 36 months (2022 – 2025)
- No of partners: 22+, Lead – Framatome SAS
- Current status:
  Preparation of the Grant Agreement and Consortium Agreement
- Begin (KoM): June 2022
- Budget: 3.13 M€

Specifically

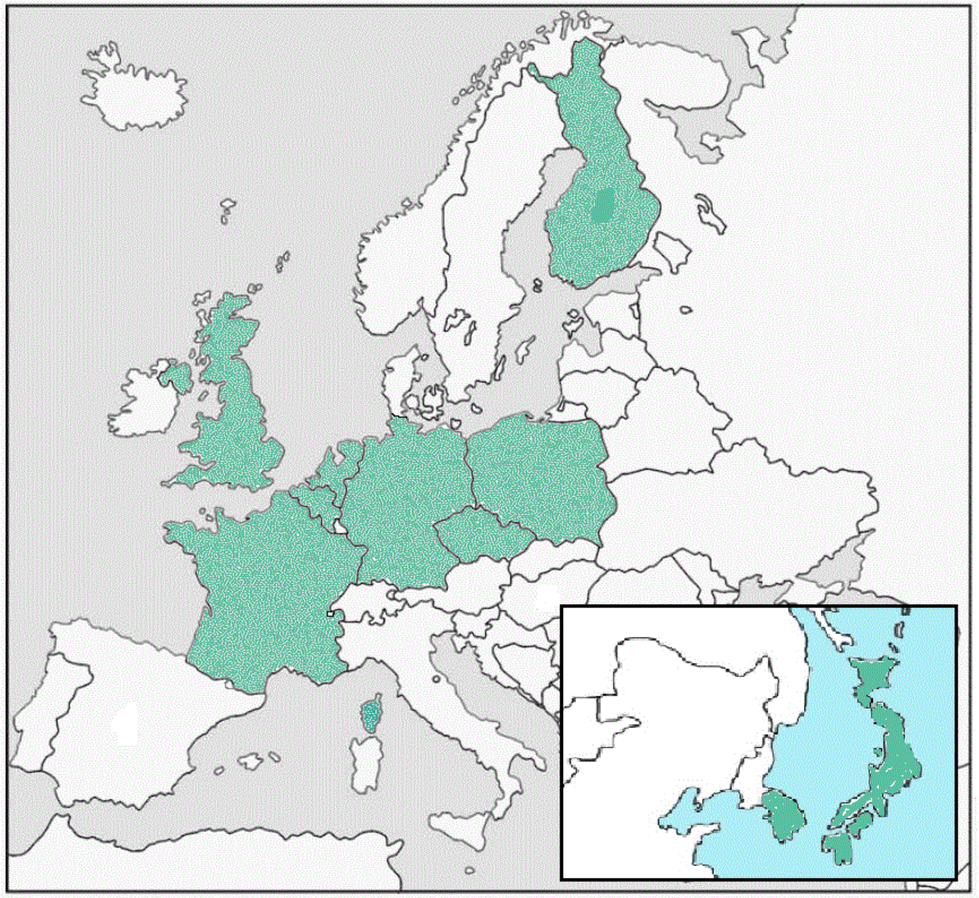
- GEMINI 4.0 proposal received the SNETP label (nr. 2021NC2I0006)

Modified cover page of „GEMINI+ Booklet”

#	Participating Organisation Name	Short Name	Country
1	**FRAMATOME SAS**	**FRAMATOME**	**FR**
2	LGI SUSTAINABLE INNOVATION	LGI	FR
3	ELECTRICITE DE FRANCE	EDF	FR
4	FRAMATOME GMBH	FRAMATOME GMBH	DE
5	**INSTYTUT CHEMII I TECHNIKI JADROWEJ**	**ICHTJ**	**PL**
6	INSTITUT DE RADIOPROTECTION ET DE SURETE NUCLEAIRE	IRSN	FR
7	**NARODOWE CENTRUM BADAN JADROWYCH**	**NCBJ**	**PL**
8	NUCLEAR RESEARCH AND CONSULTANCY GROUP	NRG	NL
9	Panstwowa Agencja Atomistyki (???)	PAA (???)	PL
10	TRACTEBEL ENGINEERING	TRACTEBEL	BE
11	TUV RHEINLAND INDUSTRIE SERVICE GMBH DE	TUV-R	DE
12	ULTRA SAFE NUCLEAR CORPORATION EUROPE FR	USNCE	FR
13	NATIONAL NUCLEAR LABORATORY LIMITED UK	NNL	UK
14	HIT TECH RELAY	HTR	FR
15	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	VTT	FI
16	BRINKMANN GERD FRIEDRICH – BRIVATECH CONSULTING	BRIVATECH	DE
17	**SYNTHOS GREEN ENERGY SPOLKA AKCYJNA**	**SYNTHOS**	**PL**
18	CENTRUM VYZKUMU REZ SRO	CVR	CZ
19	UNIVERSITY OF BRISTOL	UNIVERSITY OF BRISTOL	UK
20	KOREA ATOMIC ENERGY RESEARCH INSTITUTE	KAERI	KR
21	JAPAN ATOMIC ENERGY AGENCY	JAEA	JP
22	JRC -JOINT RESEARCH CENTRE- EUROPEAN COMMISSION	JRC	EU

GEMINI+ 4.0

Partners



+ US participants: OSU, Framatome Inc.

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

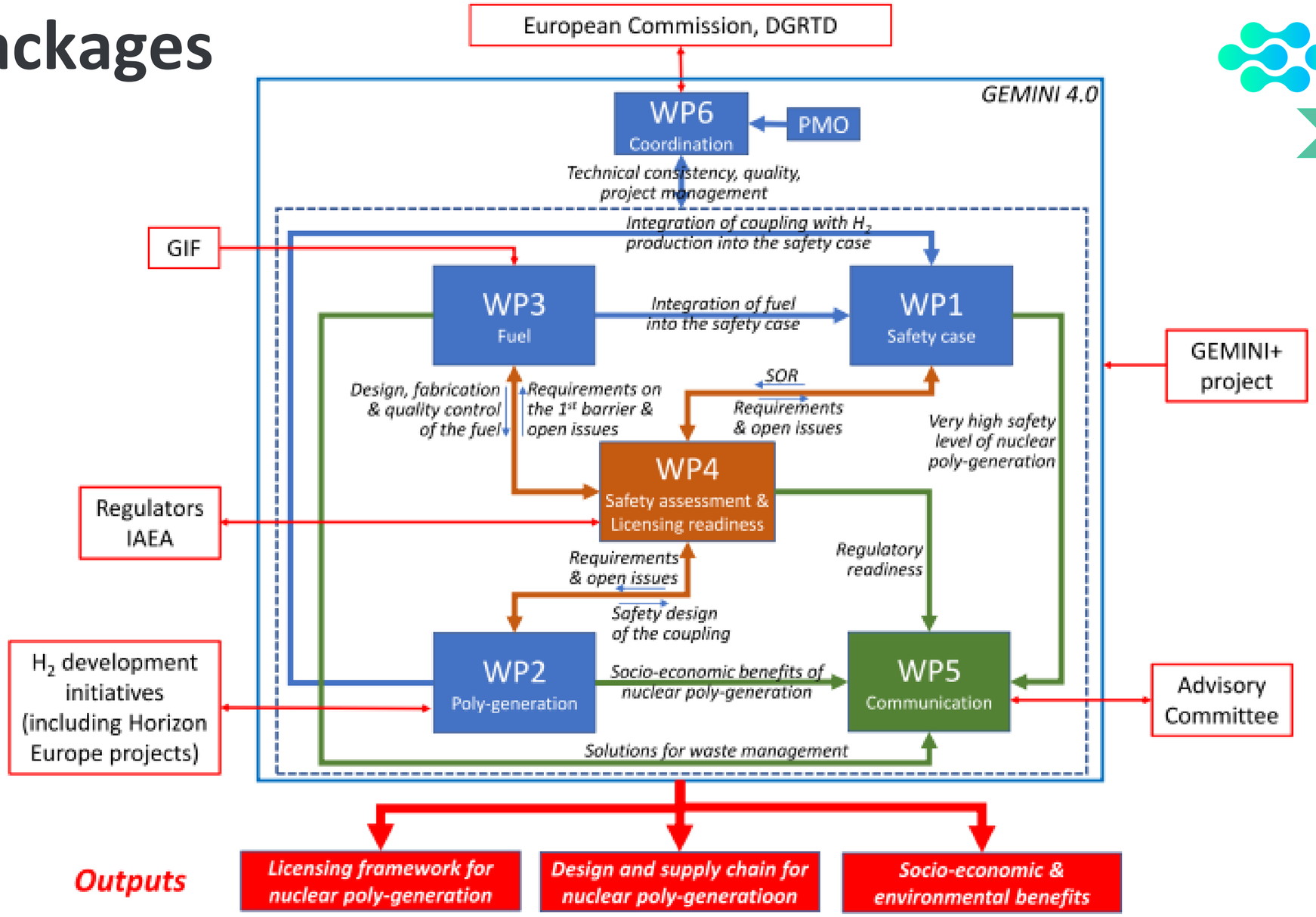
Project objectives

- Improvement of the design, by:
  - Resolving safety/licensing issues in Safety Option Report (SOR)
  - Core optimisation, Closing selected technology gaps
- Extension of applications: poly-generation, special focus on hydrogen plant,
  - Propose several comprehensive applications (coupling)
  - Provide technological schemes supported with techno-economic analyses
  - Safety and licensing of coupled systems
- Fuel for HTGRs in Europe
  - Plan for the development of European fuel cycle
  - Reference fuel, possible alternative fuels
- Licensing readiness
  - Assessment of the SOR by TSOs and regulators
  - Support potential candidate countries in the licensing of HTGR system
- Enhancing awareness of nuclear cogeneration
  - Develop and activate communication plans in different EU countries

Work Packages

#	Title	Led by	PMs	Start	End
WP1	Optimizing safety and competitiveness of the GEMINI+ design	NCBJ	94,5	M1	M36
WP2	Towards full decarbonization of European industry with nuclear poly-generation	JRC	103,0	M1	M36
WP3	Fuel technology options and fuel cycle strategy for the GEMINI+ system	FRA-SAS	46,9	M1	M36
WP4	Assessment of the licensing readiness of the GEMINI+ system for multipurpose industrial cogeneration	IRSN	37,5	M1	M32
WP5	Nuclear cogeneration for European citizens	HTR SAS	34,5	M1	M36
WP6	Project management	FRA-SAS	23,0	M1	M36
		TOTAL	**339,4**		

Work Packages



GEMINI+ 4.0

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

WP1 - Optimizing safety and competitiveness of the GEMINI+ design (1/2)

GEMINI+ 4.0

- **WP leader: NCBJ – initially Janusz Malesa**
  - Response to open questions listed in the review of the Safety Options Report (SOR)
  - Core optimisations and safety analyses
  - Strengthening the licensing readiness of this design for industrial applications
- **Tasks**
  - 1.1 Proposals for resolution of the open questions in the review by TSO of GEMINI+ SOR, (M1-M28)
    - Participants: BriVaTech, HTR SAS, **NCBJ**
  - 1.2 Core design optimisation (M1-M34)
    - Participants: FRA-SAS, NRG, BriVaTech, HTR SAS, **NCBJ**, NNL
  - 1.3 Minimization of hot gas streaking at the core outlet (M1-M35)
    - Participants: HTR SAS, NRG, NNL, + *OSU (subcontract)* + *volunteers in CFD benchmark*

WP1 - Optimizing safety and competitiveness of the GEMINI+ design (2/2)

GEMINI+ 4.0

❖ **Tasks**

- ❑ 1.4 Instrumentation (M13-M33)
  - ❑ Participants: BriVaTech, **NCBJ**, TUV
- ❑ 1.5 Stability of B4C as a burnable poison (M6-M24)
  - ❑ Participants: JRC, TUV
- ❑ 1.6 Readiness of codes and standards for the design of the GEMINI+ system (M1-M35)
  - ❑ Participants: FRA-SAS, JRC, **NCBJ**, NNL, CVR

WP2 - Towards full decarbonisation of European industry with nuclear poly-generation

GEMINI+ 4.0

- **WP leader: JRC – Michael Fütterer**
  - To identify of technical options, evaluate their economics and policy impact, and identify the safety options addressing the safety requirements defined in WP4 of such a nuclear poly-generation plant.

- **Tasks**
  - 2.1 Technical and economic feasibility of nuclear poly-generation (M1-M36)
    - Participants: USNCE, Framatome GmbH, EDF, **NCBJ**, JAEA, JRC, SYNTHOS, NNL
  - 2.2 Market, policy and socio-economic impact (M1-M36)
    - Participants: JRC, USNCE, FRA-GmbH, JAEA, KAERI, **NCBJ**, NNL, SYNTHOS, HTR SAS
  - 2.3 Safety performance of nuclear poly-generation (M1-M36)
    - Participants: Tractebel, IRSN, USNCE, JAEA

WP3 - Fuel technology options and fuel cycle strategy for the GEMINI+ system

GEMINI+ 4.0

- **WP leader: FRA-SAS – Pierre-Henri Louf**
  - To initiate the development of HTR fuel in Europe
  - Feasibility of building a consistent fuel cycle for HTRs with respect to fissile resources and safe and acceptable back-end
- **Tasks**
  - 3.1 Reference fuel product and fuel cycle (M1-M36)
    - Participants: FRA-SAS, NNL, **NCBJ**, IChTJ
  - 3.2 Back-end and Possible fuel cycles (M1-M36)
    - Participants: VTT, JRC, NNL, IChTJ , FRA-GmbH
  - 3.3 Possible alternative fuels, their merits and drawbacks (M1-M36)
    - Participants: HTR SAS, FRA-SAS, Bristol Univ, USNCE

WP4 - Assessment of the licensing readiness of the GEMINI+ system for multipurpose industrial cogeneration

GEMINI+ 4.0

- **WP leader: IRSN – Olivier Baudrand**
  - To assess the licensing readiness at European level
  - To support WP1 studies to resolve the pending safety issues
  - To built a set of commonly acknowledged safety requirements and expectations (less stringent) to guide applicants and authorities in the pre-licensing phase
- **Tasks**
  - 4.1 Validation of GEMINI 4.0 safety options (M1-M32)
    - Participants: TÜV, TRACTEBEL, IRSN, FRA-SAS, JRC
  - 4.2 Path and conditions to licensing of a HTR at European level, M1-M32
    - Participants: IRSN, PAA, **NCBJ**, TRACTEBEL, TÜV, FRA-SAS, JRC

WP5 - Nuclear High Temperature Cogeneration for European Citizens

GEMINI+ 4.0

- **WP leader: HTR SAS – Dominique Hittner**
  - To contribute to the awareness of European citizens about:
    - Importance of decarbonising non-electricity energy supply and industrial processes,
    - Key contribution of nuclear high temperature cogeneration to reach the decarbonisation objective in this field.

- **Tasks**
  - 5.1 Advisory Committee (M1-M36)
    - Participants: HTR SAS, FRA-SAS, IRSN, JRC, LGI, **NCBJ**
  - 5.2 Lessons learnt from the experience of cogeneration in Europe (M1-M36)
    - Participants: HTR SAS, **NCBJ**, TRACTEBEL, JRC
  - 5.3 Communication to European citizens (M1-M36)
    - Participants: HTR SAS, LGI, **NCBJ**, NNL, VTT, CVR
  - 5.4 Dissemination (M1-M36)
    - Participants: HTR SAS, FRA-SAS, IRSN, JRC, LGI, NCBJ
  - 5.5 Education and Training (M1-M36)
    - Participants: FRA-SAS, HTR SAS, **NCBJ**

WP6 - Project management

- **WP leader: FRA-SAS – Jean-Marie Hamy**
  - An appropriate governance structure and internal communication methods
  - Project monitoring & risk management
  - Project Quality Plan, Data Management Plan
  - Enforcing gender equality

- **Tasks**
  - Project coordination (M1-M36)
    - Participants: FRA-SAS, LGI, HTR SAS
  - Data and Risk Management (M1-M36).
    - Participants: FRA-SAS, LGI, HTR SAS

Lead	Tasks / Timing (months)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
NCBJ	**WP1 - Optimizing safety and competitiveness of the GEMINI+ design**																																				
Brivatech	**T1.1 Proposals for resolution of the open questions in the review by TSO of GEMINI+ SOR**																				M1								D1.1								
Framatome SAS	**T1.2 Core design optimisation**													M2													M3								D1.2		
NRG	**T1.3 Minimization of hot gas streaking at the core outlet**						M4															M5				M6									D1.3	
TÜV	**T1.4 Instrumentation**																																D1.4				
JRC	**T1.5 Stability of B4C as a burnable poison**						M7																		D1.5												
Framatome SAS	**T1.6 Readiness of codes and standards for the design of the GEMINI+ system**																		M8														M9		D1.6		
JRC	**WP2 - Towards a full decarbonisation of European industry**																																				
USNC	**T2.1 Technical and economic feasibility of nuclear poly-generation**																		D2.1 D2.3														D2.2				
JRC	**T2.2 Market, policy and socio-economic impact**						D2.4																											D2.5	D2.6		
NNL	**T2.3 Safety performance of nuclear poly-generation**																											D2.7									
Framatome SAS	**WP3 - Fuel technology options and fuel cycle strategy for the GEMINI+ system /**																																				
Partner	**T3.1 Reference fuel and fuel cycle**																																				D3.1
Partner	**T3.2 Back-end and Possible fuel cycles**																														D3.2						
Partner	**T3.3 Possible alternative fuels, their merits and drawbacks**																		D3.3																		
Partner	**WP4 - Assessment of the licensing readiness of the GEMINI+ system for multipurpose industrial cogeneration**																																				
TÜV	**T4.1 Validation of GEMINI 4.0 safety options**			M10	D4.1								M11																			D4.2	D4.3				
IRSN	**T4.2 Path and conditions to licensing of a HTGR at European Level**																								D4.4								D4.5				
HTR	**WP5 - Nuclear cogeneration for European citizens**																																				
HTR	**T5.1 Advisory Committee**																																				D5.1
HTR	**T5.2 Lessons learnt from the experience of cogeneration in Europe**															D5.2																					
HTR	**T5.3 Communication to European citizens**												D5.3																								D5.4
HTR	**T5.4 Dissemination**																																				
Framatome SAS	**T5.5 Education & Training**																																				
Framatome SAS	**WP6 - Project management**																																				
Framatome SAS	**T6.1 Project coordination**	KoM	D6.1	D6.2			PM						PM						PM						PM						PM						PM
Framatome SAS	**T6.2 Data and risk management**						D6.3																														

Involvement of NCBJ (1/2)

GEMINI+ 4.0

- **WP1: Optimizing safety and competitiveness…**
- **NCBJ leads the WP**
  - Task 1.1 Proposals for the **„new" SOR**
  - Task 1.2 Core design optimisation
    SERPENT, MELCOR -> update of input models, simulations to confirm safety
  - Task 1.4 Instrumentation
    To take into account the instrumentation proposed for EUHTER
  - Task 1.6 Readiness of codes and standards
    Review the application of codes in Poland and adaptation of nuclear codes within national nuclear programme.

- **WP2: Towards full decarbonisation…**
  - Task 2.1 Technical and economic feasibility of nuclear poly-generation
    Coupling with Hydrogen plant and other poly-generation options
  - Task 2.2 Market, policy and socio-economic impact
    Case proposal and studies for Poland

- **WP3: Fuel technology options**
  - Task 3.1 Reference fuel product and fuel cycle
    Feasibility study on the development of an experimental program in the MARIA MTR
    - Participation in deliverable:
      HTR fuel supply chain readiness in Europe

Involvement of NCBJ (2/2)

GEMINI+ 4.0

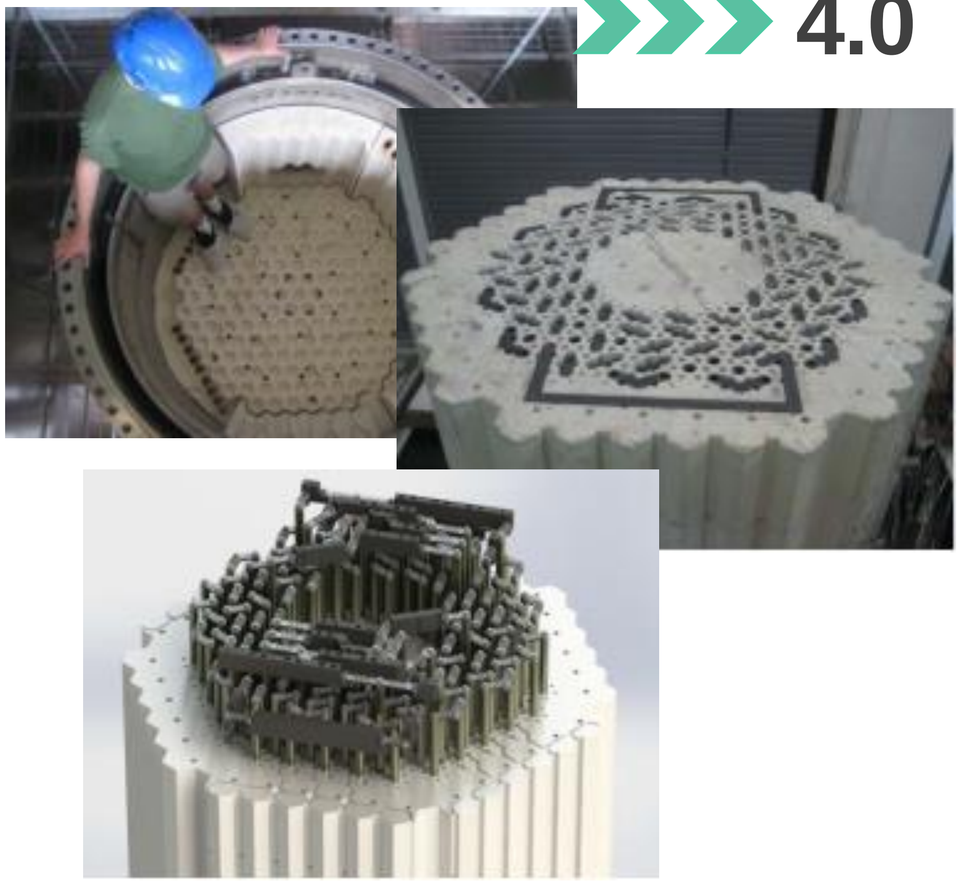
- **WP4: Assessment of the licensing readiness…**
  - **Task 4.2** Path and conditions to licensing of a HTR at European level
    Participation in deliverables:
    - Common European basis for licensing of an HTR at European level
    - Path and conditions for pre-licensing of a HTR in an European country

- **WP5: Nuclear High Temperature Cogeneration for European Citizens**
  - Task 5.1 Advisory Committee
    Member
  - Task 5.2 Lessons learnt from the experience of cogeneration in Europe
    About cogeneration in Poland…
  - Task 5.3 Communication to European citizens
    The plans targeting specific countries (Poland, Finland and the United Kingdom), will be developed by partners of these countries
    Participation in deliverables:
    - Lessons learnt from the experience of cogeneration in Europe **(NCBJ leading contributor)**
    - Initial Communication and Dissemination Plans
    - Updated Communication and Dissemination Plans and report on their implementations

CFD Benchmark (WP1, Task 1.3)

- **Oregon State University (OSU) will share its experience in HTR thermal-hydraulics validated by the comparison with tests on their unique HTTF facility representing a whole HTR, with helium flow and with an electrically heated core**
- The possibility of temperature fluctuations downstream of the core, with consequential fatigue for the concerned structures, will be investigated.
- Validation of CFD calculation of the amplitude and frequency of temperature fluctuations:
  - Experimental data from the HTTF facility from OSU, representing the MHTGR reactor at a ¼ scale, will be used
  - **OSU and NRG will propose to other participants in the Project interested in validating their own tools a blind benchmark**
- Further steps (NRG, NNL, TRACTEBEL, HTR SAS):
  - Optimisation of the design for reducing the amplitude of temperature fluctuations
  - Assessing the impact of residual temperature fluctuations for optimised design on thermal fatigue risks on structures downstream of the core

The participation in the benchmark is at partners' own costs. The limited budget does not allow funding for this task.



The Oregon State University High Temperature Test Facility (OSU-HTTF): assembly, core and electrical connection of the resistance heater rods.

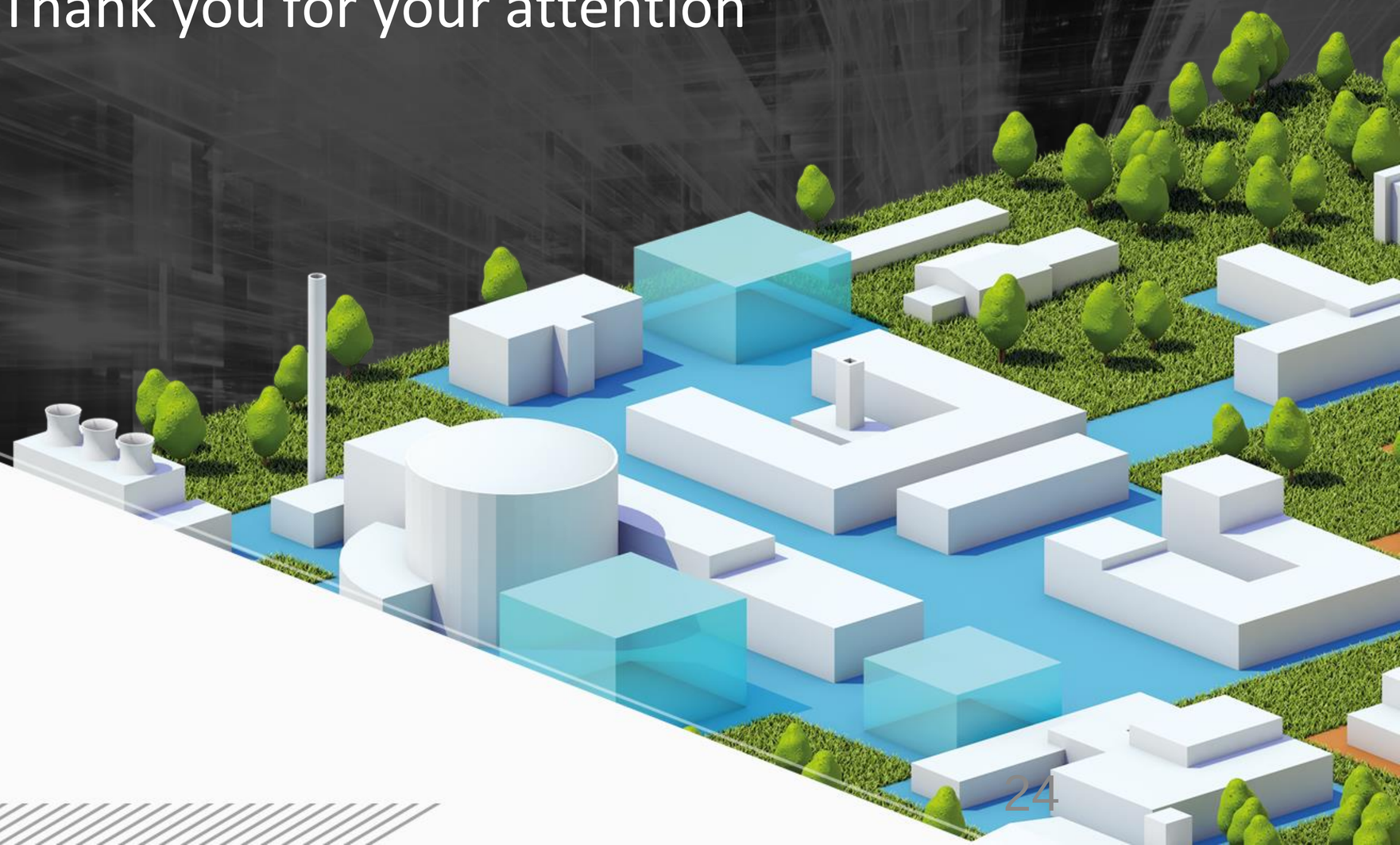
Take away

- GEMINI+ design will be improved and optimised
  - Revised version of SOR
  - We invite students to participate in the CFD benchmark
  - Codes and standards – review of applicability
- Decarbonisation through nuclear poly-generation with GEMINI+ HTGR
  - Readiness for deployment
- TRISO Fuel for HTGRs
  - The plan for establishing independency of European countries
- Licensing
  - Support to countries for early demonstration (Poland, UK, …?)
- Enhanced communication with stakeholders and public

GEMINI+ 4.0

Technology	TRL start	TRL end
Licensing readiness	6	7
Coupling	4	5
Core design	7	8
Codes & standards	6	7
New qualified fuel manufactured in Europe and reference fuel cycle defined (as an alternative from the purchase on international market)	3	4

Thank you for your attention



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