Contribution towards H_2 Society

～Achieving Carbon Neutrality by HTGR with Inherent Safe Characteristics～

November 15, 2023

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Requirements to H_2 Supply Source in H_2 Society

1 Domestic H_2 production

- International H_2 supply chain requires large-scale H_2 transportation
- Transportation of Liquified H_2 is expensive at present

162 JPY/m^3

（Roly transport+Liquification+loading+Marine transportation cost）

Estimation by METI at 2020

2 Large-scale, stable H_2 production

- Continuous operation is mandatory for economical industrial process
- Large-scale H_2 supply is required to achieve carbon neutrality

200万t/yr （Present） ▶ 2,000万t/yr （2050）

Basic H_2 Strategy

3 Carbon-free H_2 production

- Increased competition in technology development of industrial process for the use of H_2 towards carbon neutral society
- Full introduction of carbon pricing expected in international trades

32,500JPY/tCO_2

（Developed nations' carbon tax in 2050 estimated by IEA）

JRI, https://www.jri.co.jp/MediaLibrary/file/report/researchreport/pdf/14069.pdf (accessed on November 14, 2023)

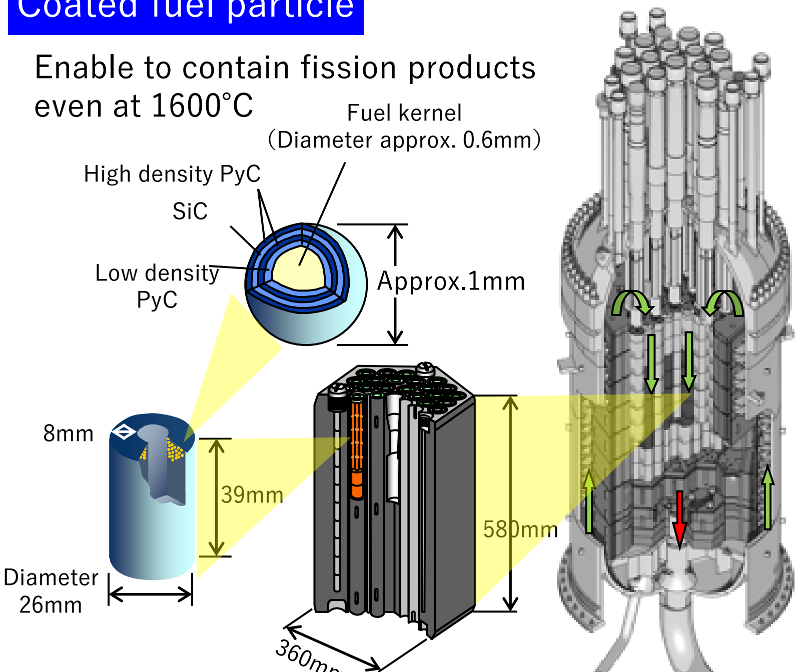
What is HTGR?

●Superior safety

Feasible to design a reactor that would not melt down due to inherent safe characteristics

Coated fuel particle

Enable to contain fission products even at 1600°C



Graphite components

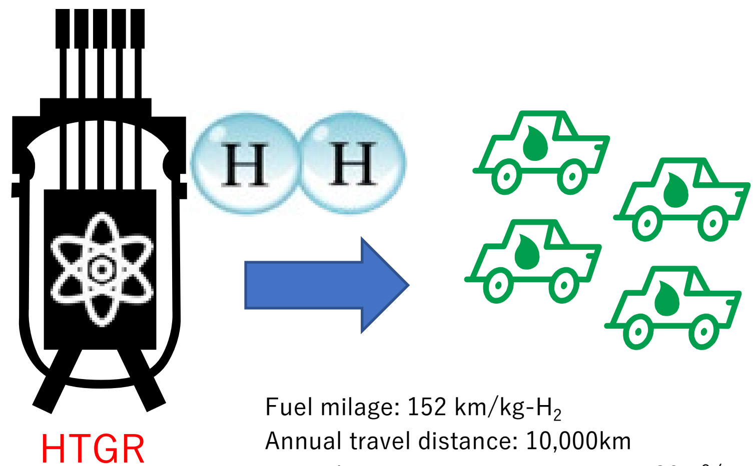
Allowable temperature limit 2500°C

Helium

Stable at high temperature (No temperature limits, chemically inert)

●Great versatilities in applications

HTGR can supply high temperature heat above 900°C and provide for great versatility in the applications including H_2 production, power generation, desalination, etc.



Fuel milage: 152 km/kg-H_2
Annual travel distance: 10,000km
Annual H_2 consumption：Approx. 730m^3/unit

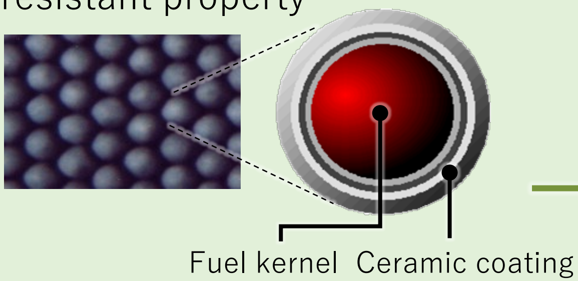
One unit of HTGR* (Reactor thermal power 250MW) can provide H_2 for 300,000 FCVs

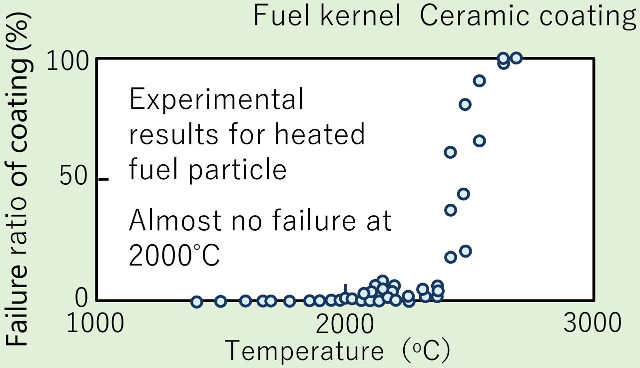
*H_2 production efficiency 50%, plant availability 80%

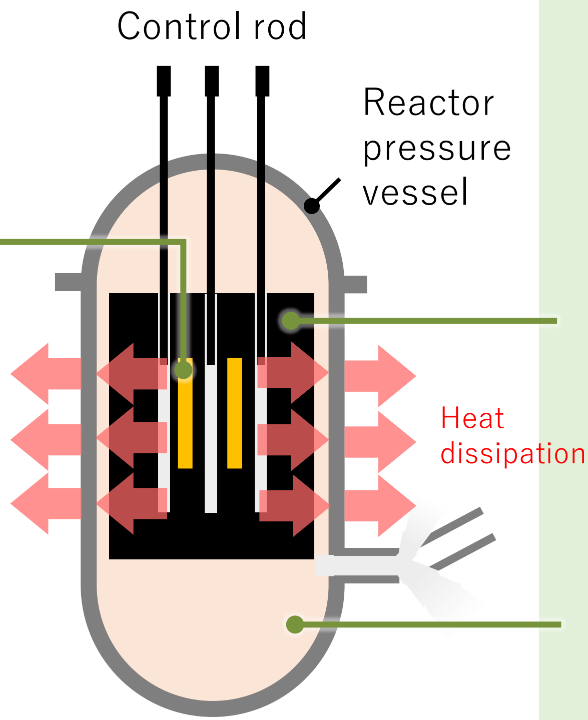
HTGR Features －Superior safety－

Ceramic coated fuel

Inability to melt due to heat-resistant property

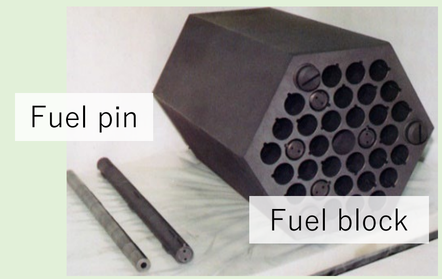






Graphite structure

Capable to remove heat passively from RPV outside due to high heat capacity and large thermal conductivity



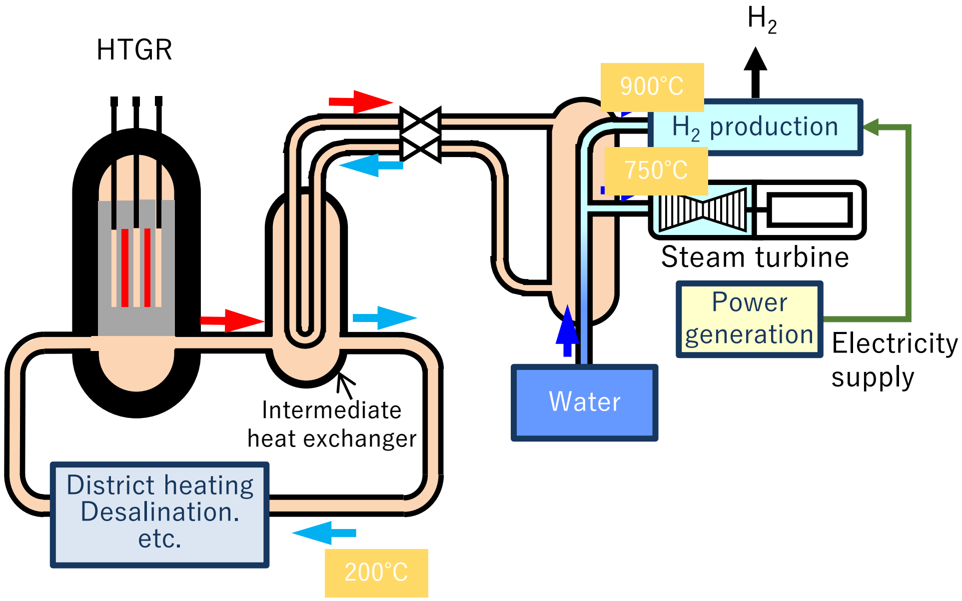
Helium coolant

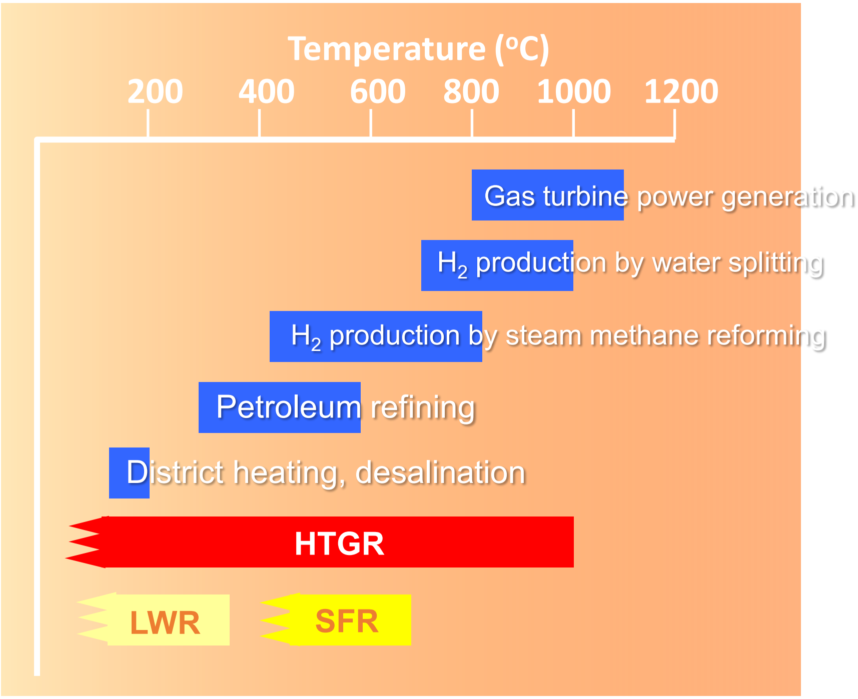
No explosions of H_2 and vapor due to chemical inertness and phase change inability

Reactor can be shut down and cooled intrinsically, as well as contain radionuclides under abnormal conditions such as loss of offsite power and coolant

HTGR Features　－Versatile heat application－

HTGR can provide for great versatility in application of non-electric field including H_2 production, district heating, desalination, etc.

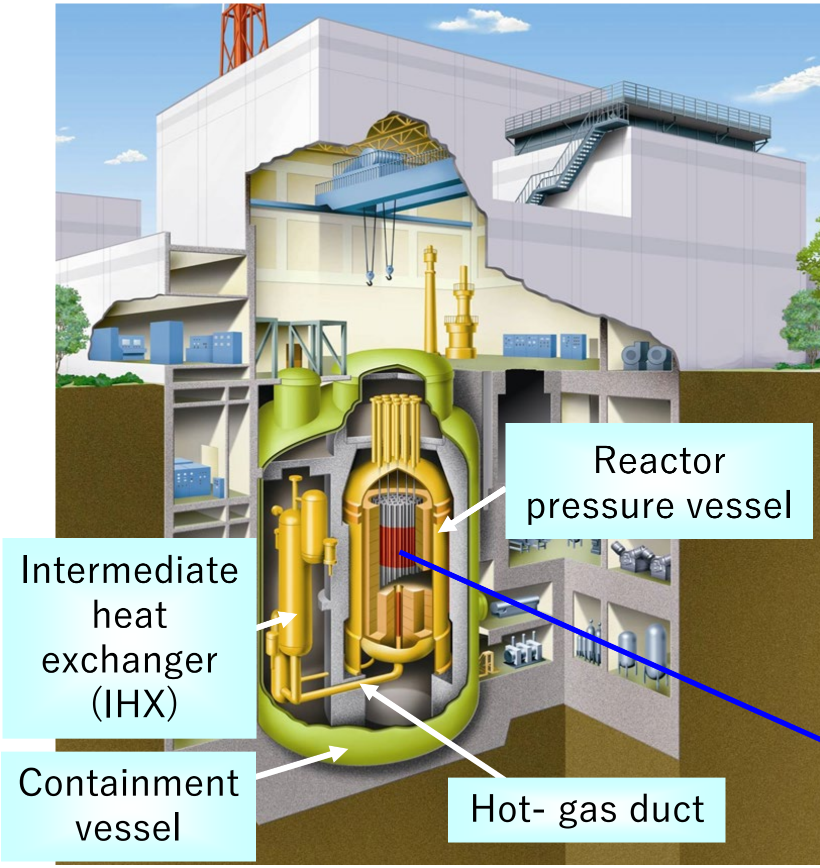




HTGR can contribute to reduce a large amount of CO_2 emission from non-electric field by supplying carbon-free, versatile energy

Japan's HTGR Technologies － HTTR, HTGR test reactor－

HTTR

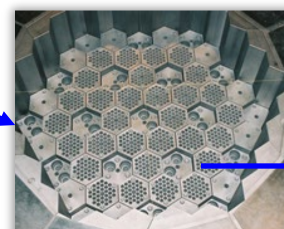


Japan's first HTGR

● Reactor thermal power	30MW
● Coolant	Helium gas
● Reactor temp. inlet/outlet	395/850,950°C
● Coolant pressure	4MPa
● Reactor structural material	Graphite

Nov., 1998	First criticality
Mar., 2010	50 days 950°C operation
Dec., 2010	Safety demonstration test*
Jul., 2021	Restart operation following permission of changes to reactor installation in conformity to New Regulatory Requirements
Jan., 2022	Safety demonstration test*

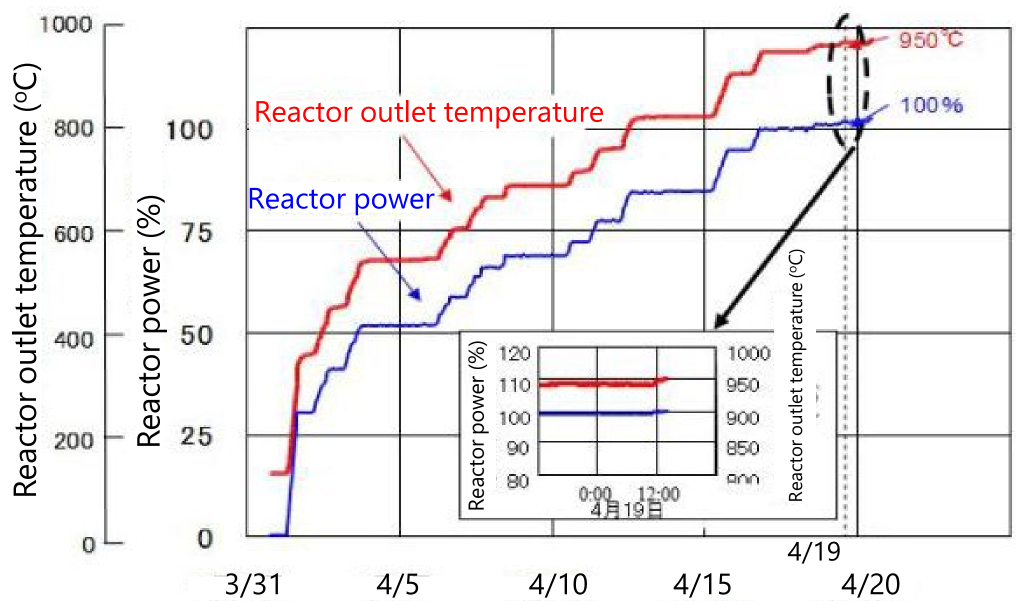
*OECD/NEA LOFC project


Reactor core


Core graphite block

HTTR achieved world's highest reactor outlet temperature of 950°C

Japan's HTGR Technologies
－High temperature heat supply demonstrated by the HTTR－



Capability of high temperature heat supply above 900ºC was demonstrated by HTTR operation

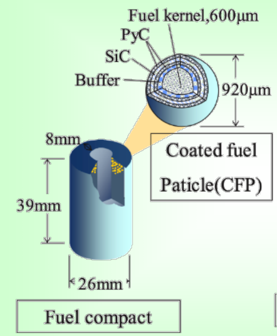
Japan's HTGR Technologies
－Technologies owned by Japanese entities－

■HTTR design, construction, operation experience
（MHI, Toshiba/IHI, Hitachi※1, Fuji Electric, KHI, etc.）

Large amount of HTGR technology data accumulated in vendors

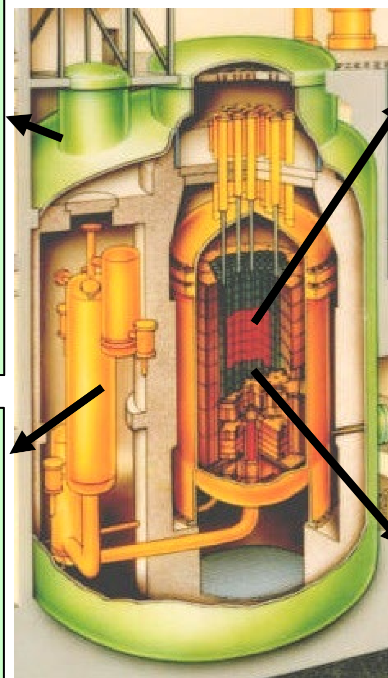
Enables an optimized commercial reactor design

■Fuel, co-developed with NFI



Ceramic coating with high fission product containment performance

Coating is stable for long period of time
（Three times higher burnup than LWR）



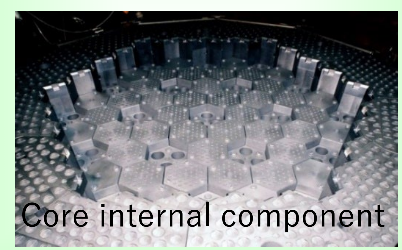
■Heat resistant alloy Hastelloy XR, co-developed with Mitsubishi Materials※2

Metallic material used as structural material at world's highest temperature of 950°C

Capable to supply high temperature heat above 900°C

■Graphite IG-110, co-developed with Toyo Tanso

World's highest quality graphite (isotropic high density graphite)

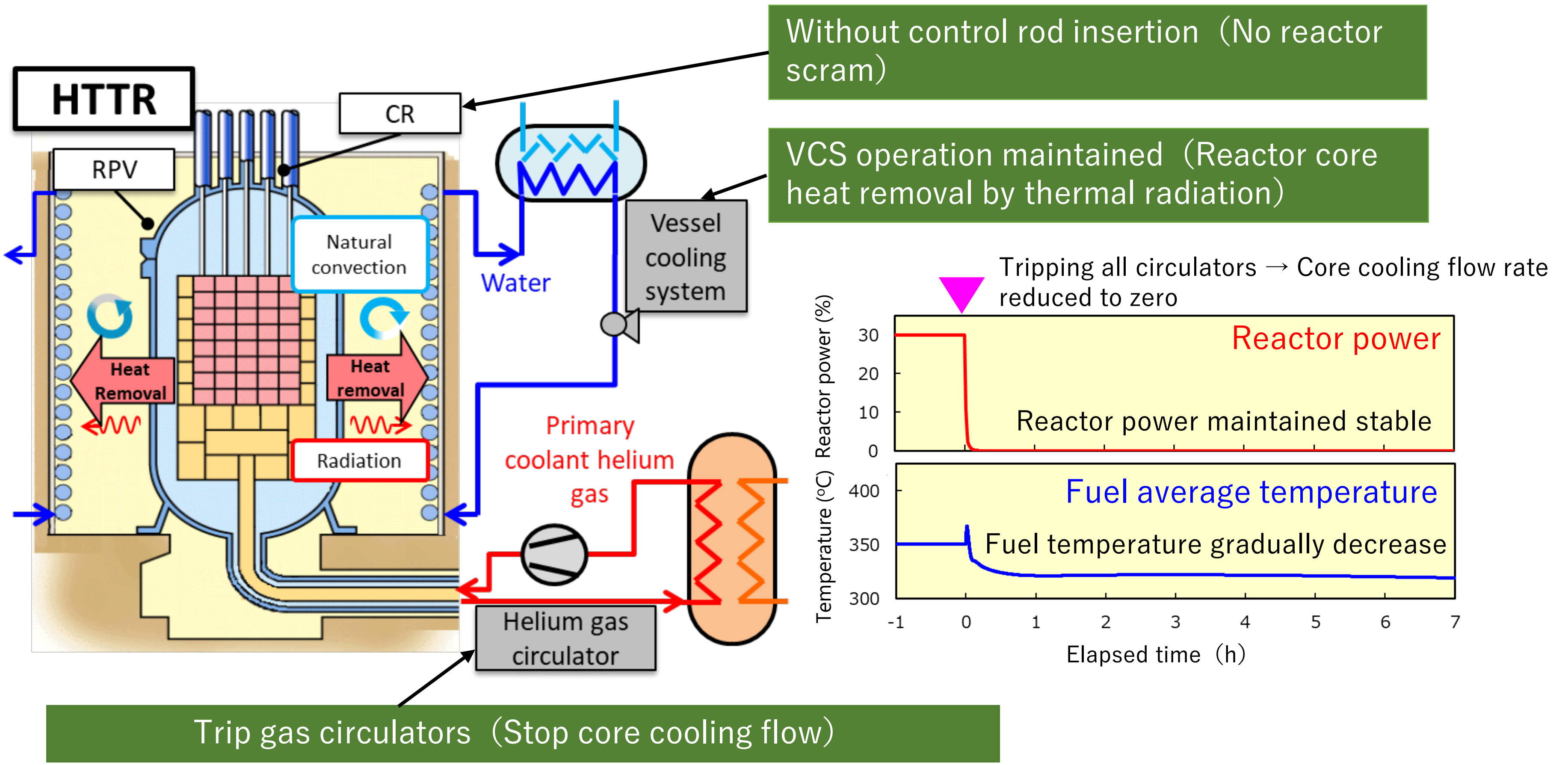


Superior strength, high thermal conductivity, superior resistance to irradiation

HTGR can be constructed using domestic technologies

※1 Participated at the time of HTTR construction, withdrawn from the business
※2 Participated at the time of HTTR construction, technology transferred to other company

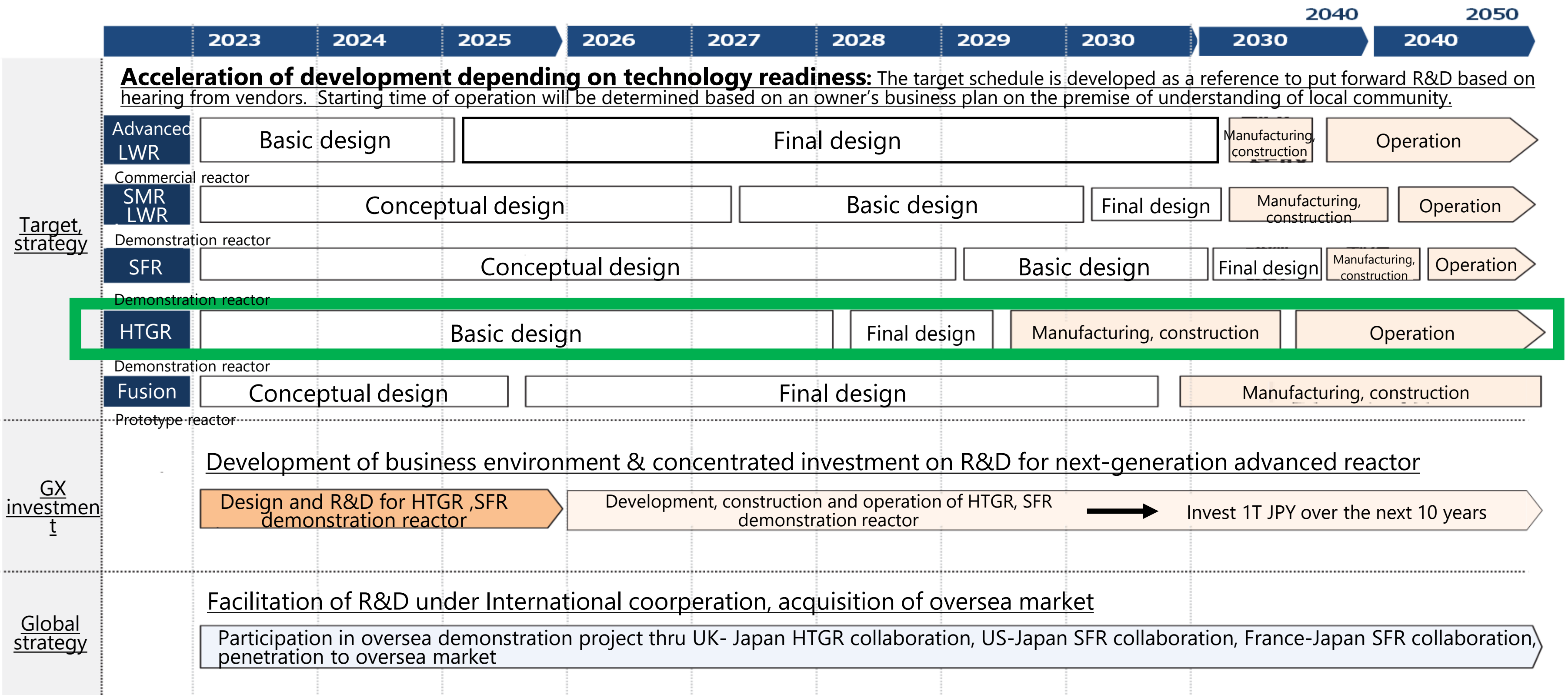
HTGR Features －HTTR Safety Demonstration Test－



HTTR test demonstrated that reactor can be shut down and cooled intrinsically without control rod insertion and active core cooling

HTGR Demonstration Reactor Development Plan
－Basic Policy for GX Implementation－

Develop a HTGR demonstration reactor to be operated in 2030's.



HTGR Demonstration Reactor Development Project

Enacted: JPFY2023 48B JPY （JPY2023-JPY2025 431B JPY）

Request: JPFY2024 256B JPY （JPY2023-JPY2026 1279B JPY）

Basic Policy for GX Implementation
https://www.meti.go.jp/press/2022/02/20230210002/20230210002_3.pdf

Challenges and Approaches towards HTGR Commercialization

Society

Site selection, Business scheme development

- Obtain social acceptance, development of business model
  ：Interaction with stakeholders, UK HTGR demonstrator project

Technology

Development of reactor technologies

- Reactor core：Scale-up
- Component：Scale-up, performance improvement
- Fuel：Development of spent fuel reprocessing technologies
- Codes and standards：Establishment of safety standards/design codes

Development of heat application technologies

- Coupling：Establishment of demarcation boundary and between HTGR and H_2 plant, components required for coupling
- H_2 production：Development of carbon-free H_2 production technologies

Policy

→ HTGR demonstration reactor development

→ HTTR -heat application test

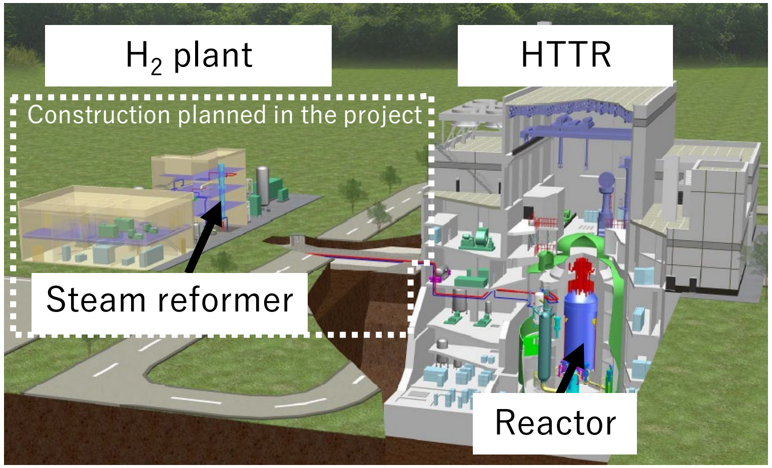
Development of Coupling Technology between HTGR and H_2 plant －HTTR-heat application test－

【Tasks】

- Use the HTTR as a heat source which demonstrated 950ºC heat supply capability
- Establish safety design and evaluation technologies for coupling between HTGR and H_2 plant
- Demonstrate performance of components required for coupling between HTGR and H_2 plant

【Expected results】

Develop safe coupling technologies between HTGR and H_2 plant



Bird's eye view of the test

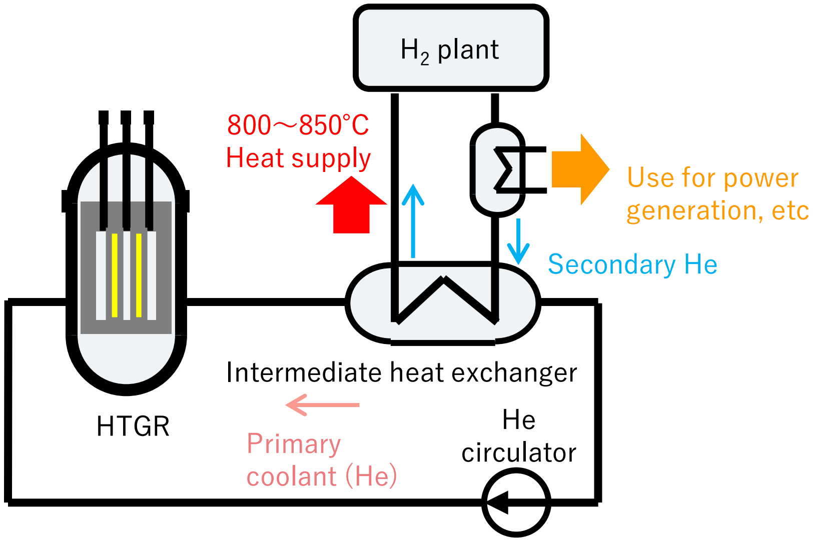
- ✓ Develop coupling technologies by connecting a steam methane reforming H_2 plant to the HTTR
- ✓ H_2 plant with carbon-free H_2 process will be connected to the HTTR in the future

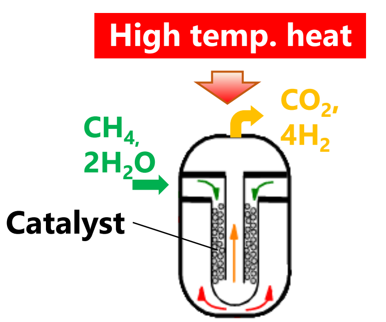
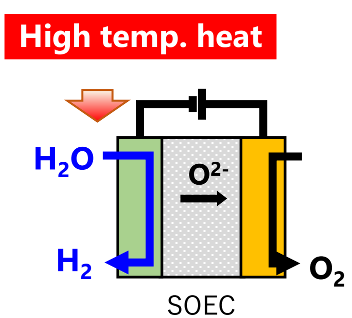
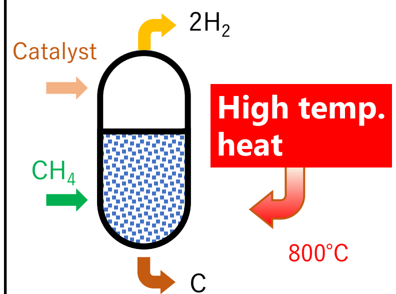
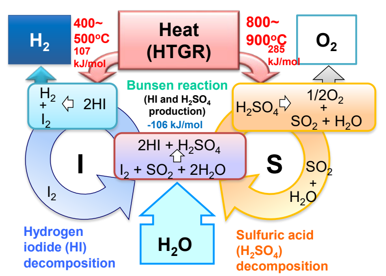
Draft test schedule

	R4 2022	R5 2023	R6 2024	R7 2025	R8 2026	R9 2027	R10 2028	R11 2029	R12 2030
HTTR-heat application test	Safety design・evaluation		Application ▼	Licensing					
	HTTR modification/H_2 plant design (steam methane reforming process)				HTTR modification/H_2 plant manufacturing, installation			H_2 production test	

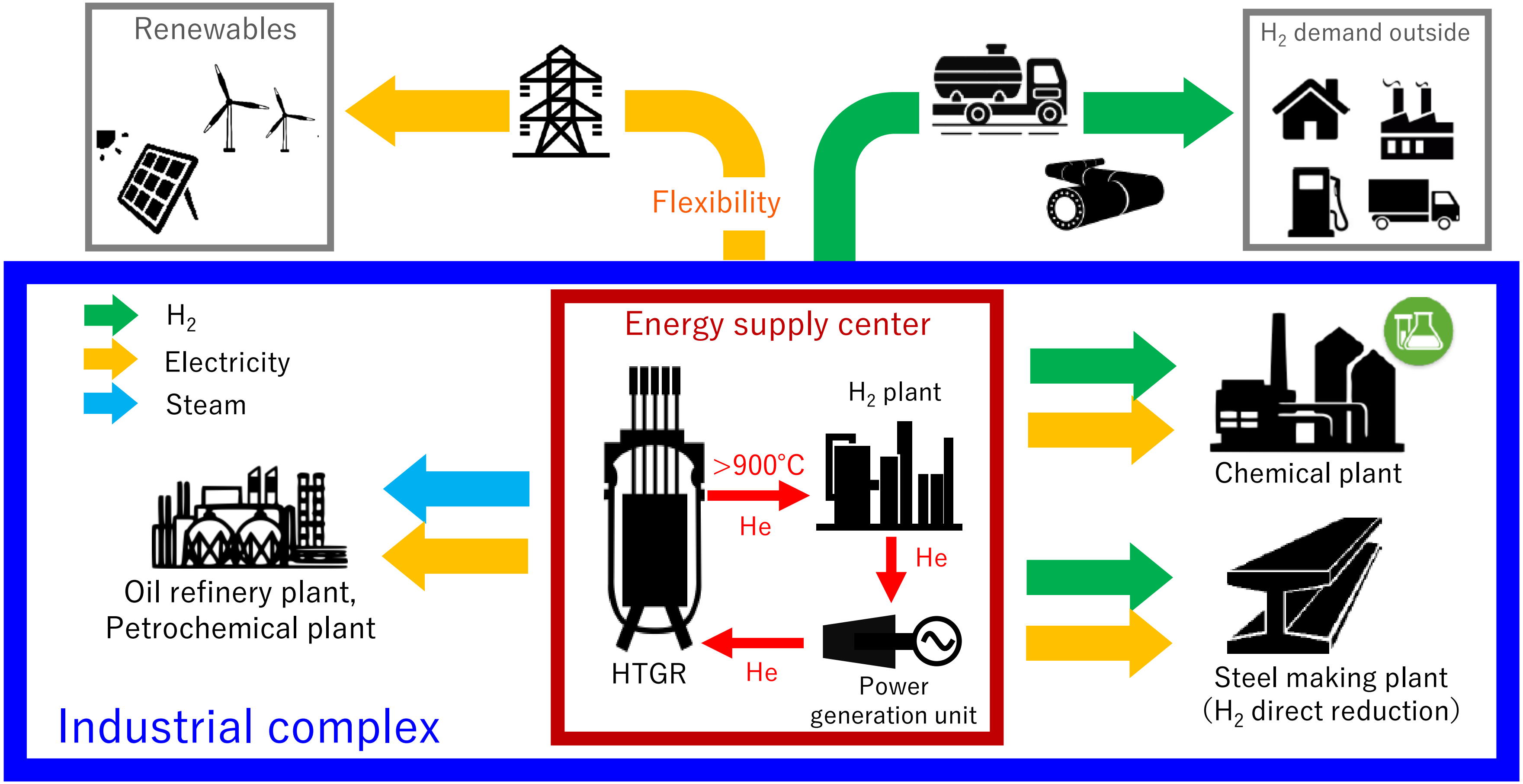
Selection of H_2 production Technology

- Reactor thermal power 150MW～250MW
- Supply high temperature above 800°C to H_2 plant
- Waste heat can be used for power generation to be supplied to internal load of steel making plant
- Combination with a carbon-free H_2 production technology enables large-scale carbon-free H_2 production
- A carbon-free H_2 production technology will be selected considering technology readiness



	Steam methane reforming	High temperature steam electrolysis	Methane pyrolysis	IS process
概要				
	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$	$H_2O \rightarrow H_2 + 1/2O_2$	$CH_4 \rightarrow 2H_2 + C_{(s)}$	$H_2O \rightarrow H_2 + 1/2O_2$

HTGR Commercial Deployment Model



Adding new social value

Achieving carbon neutrality in Hard-to-Abate industries

Reinforcement of resilience for carbon neutral society

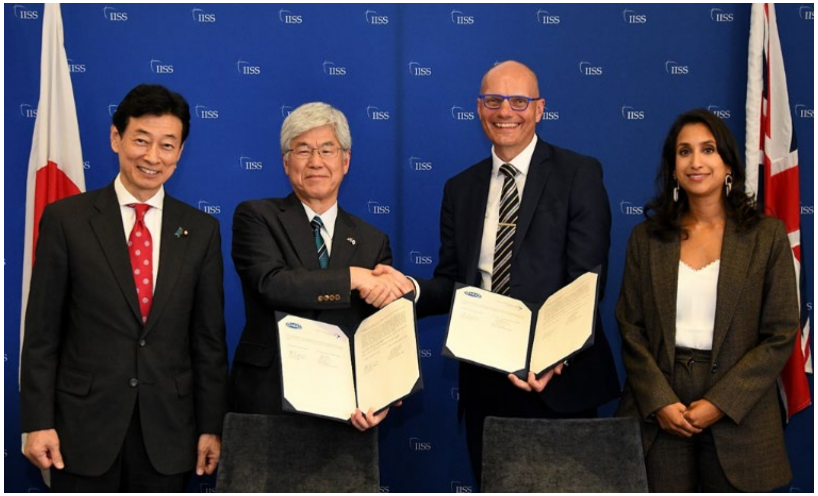
※Figures in the following report is used
METI, https://www.meti.go.jp/shingikai/energy_environment/suiso_nenryo/pdf/027_01_00.pdf (accessed on November 14, 2023)

Expectation to Japan's HTGR Technology －UK－

- Department for Energy Security and Net Zero (DESNZ) selected National Nuclear Laboratory (NNL) and JAEA team as project entities to implement the Phase B reactor project

- JAEA and NNL signed comprehensive Memorandum of Co-operation in the field of HTGR under the attendance of Ms. Coutinho, Secretary of State for DESNZ and Mr. Nishimura, Minister of Economy, Trade and Industry

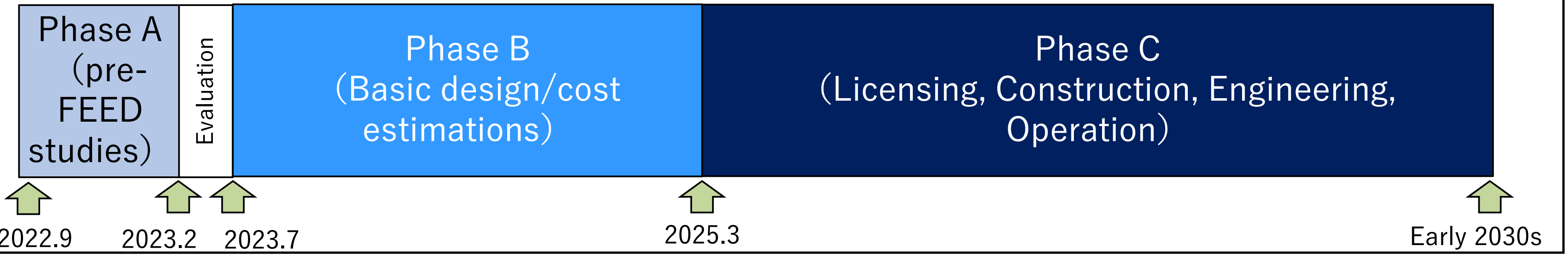
- JAEA will collaborate with NNL to accelerate early deployment of HTGRs in order to contribute to the achievement of carbon neutrality by 2050.



(From left to right) Mr. Nishimura, Minister of Economy, Trade and Industry, Mr. Koguchi, President of JAEA,
Mr. Howarth, CEO of NNL, Ms. Coutinho, Secretary of State for DESNZ
(September, 2023, London, UK)

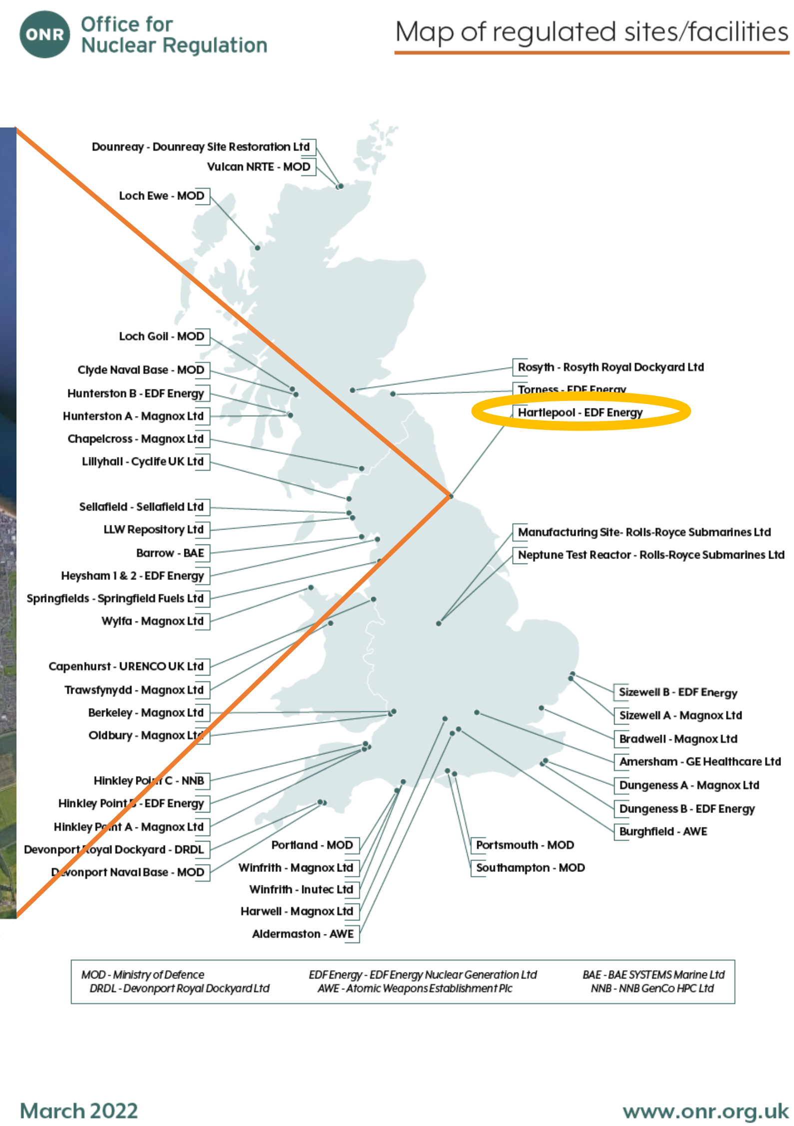
UK HTGR Demonstration Reactor Programme

- Phase A：pre-FEED studies (2022.9～2023.2)
- Phase B：Basic design, cost estimations (2023.7～2025.3)
- Phase C：Licensing, Construction, Engineering, Operation

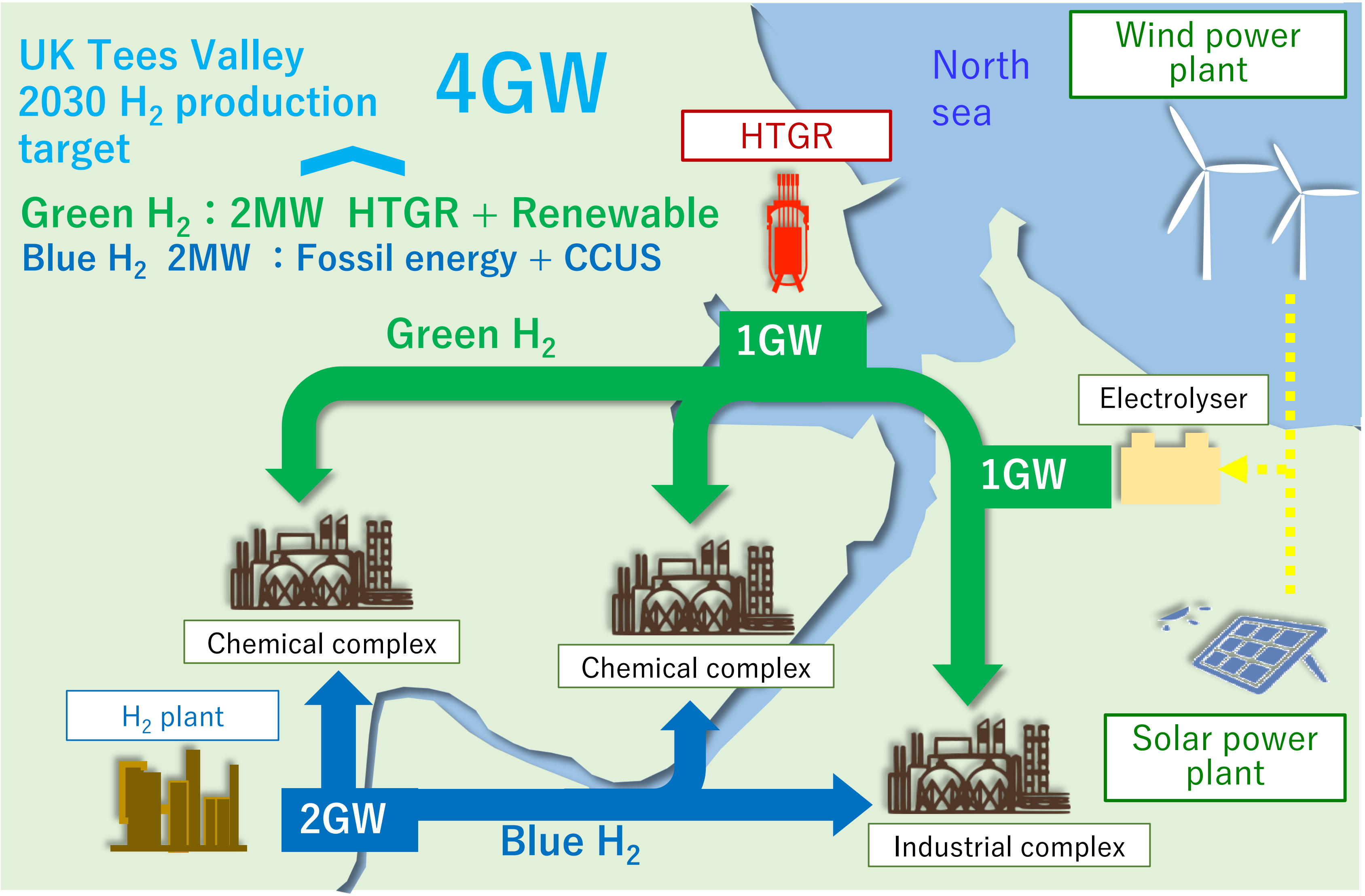


UK HTGR Demonstrator Potential Site

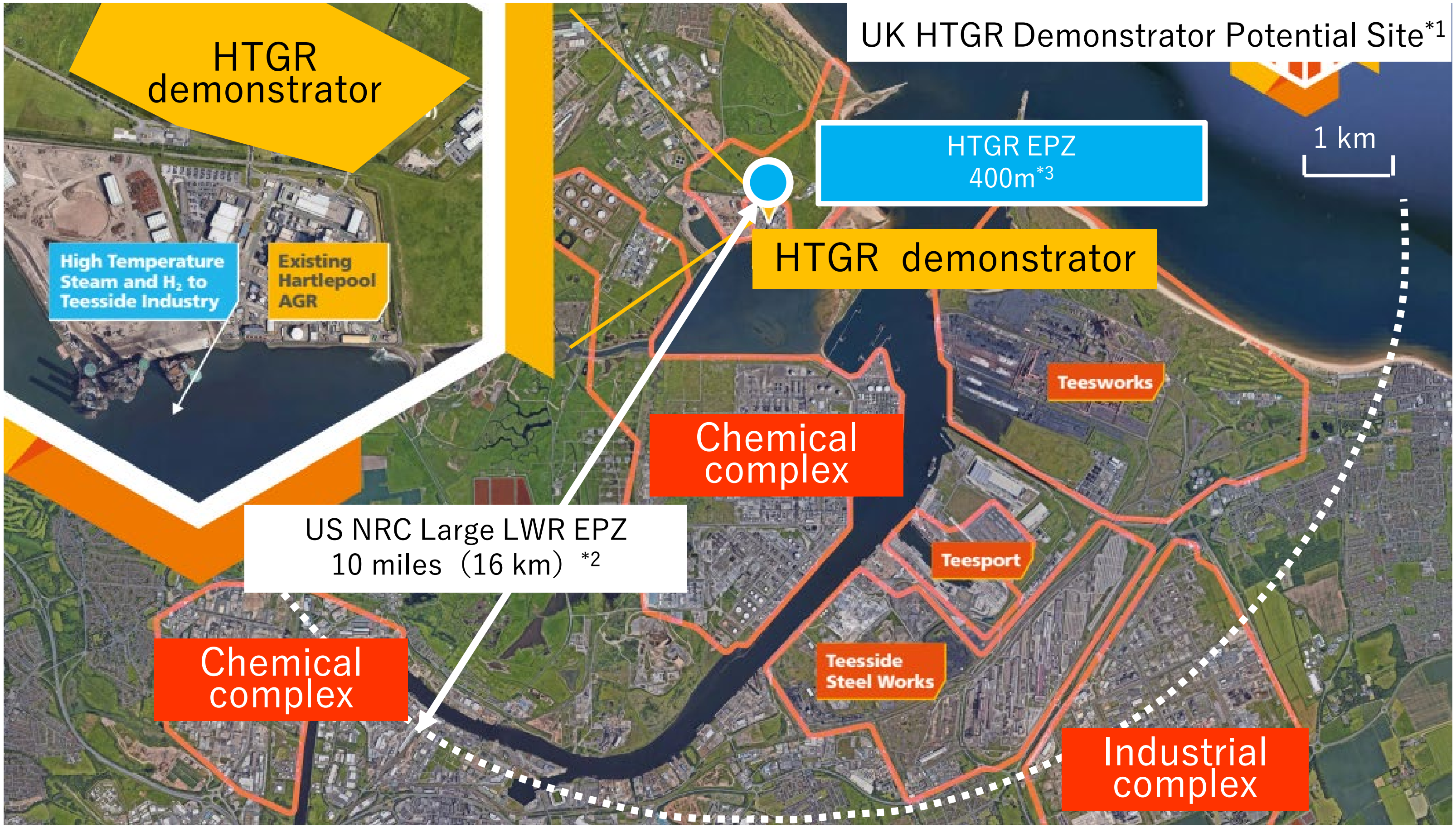
EDF-Energy flyer



HTGR Commercial Deployment Model －HTGR×Renewable－



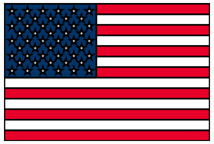
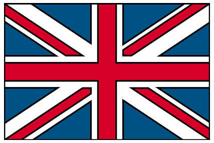
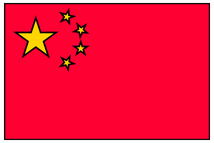
Towards Collocation of HTGR with Industrial Complex



Superior safety enables collocation of HTGR with industrial complex

*1 EDF energy, https://www.edfenergy.com/energywise/amr (accessed on November 7, 2023)
*2 US NRC
*3 X-energy, X-energy's Xe-100 Reactor Design Status, National Academy of Sciences, May 26, 2021.

HTGR Development Projects around the World

USA		**DOE support for HTGR development** (Advanced Reactor Demonstration Program, 2020～) • Support construction of advanced reactors to have an operation by 2028 (750°C, Electric power 80MW)
UK		**DESNZ support for HTGR development** (Advanced Modular Reactor R&D, demonstration program, 2022～) • UK government selected HTGR as a advanced modular reactor, and will have demonstration by the beginning of 2030s
Poland		**Poland government support for HTGR project** • HTGR research reactor (750°C, Reactor thermal power 30MW) basic design started (2021)
China		**China Energy Technology Innovation Action Plan 2016-2030** • R&D using research reactor (700°C) • Demonstration reactor (750°C, Electric power 210MW) in operation (Grid connection : Dec. 2021, Full power operation, 2022)

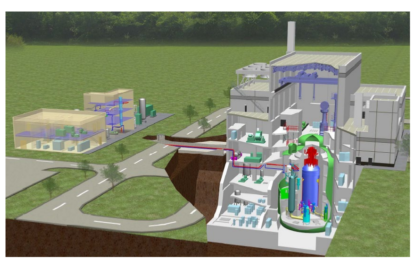
- Increasing momentum in development projects worldwide towards HTGR commercial deployment
- No other project in the world aims to supply high temperature heat above 900°C that enables efficient H_2 production

Summary

1	Domestic H_2 production	**Collocation of HTGR with industrial complex**
2	Large-scale, stable H_2 production	**High temperature heat supply above 900°C by HTGR**
3	Carbon-free H_2 production	**HTGR ＋Carbon-free H_2 plant**

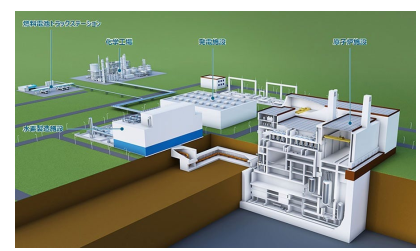
HTTR-heat application test

Establish coupling technologies between HTGR and H_2 plant



Demonstration reactor development

Demonstration of technical and economical feasibility



MHI　www.mhi.com/jp/news/230725.html