Development of HTGR for industrial heat supply towards carbon neutral by 2050 in Japan

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1. The Significance of Nuclear Hydrogen Production in a Hydrogen Society
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Requirements for Hydrogen Supply in Decarbonized Society

1 Large-scale and Stable Hydrogen Production

- Industrial processes need long-term continuous operation to be cost-effective
- Carbon neutrality requires large-scale hydrogen supply

(Current status) 2 Mt/year

(2050) **20 Mt/year**

National Hydrogen Strategy

2 Carbon-free Hydrogen Production

- Industrial decarbonization is driving competition in hydrogen technologies
- Carbon pricing is being widely implemented worldwide

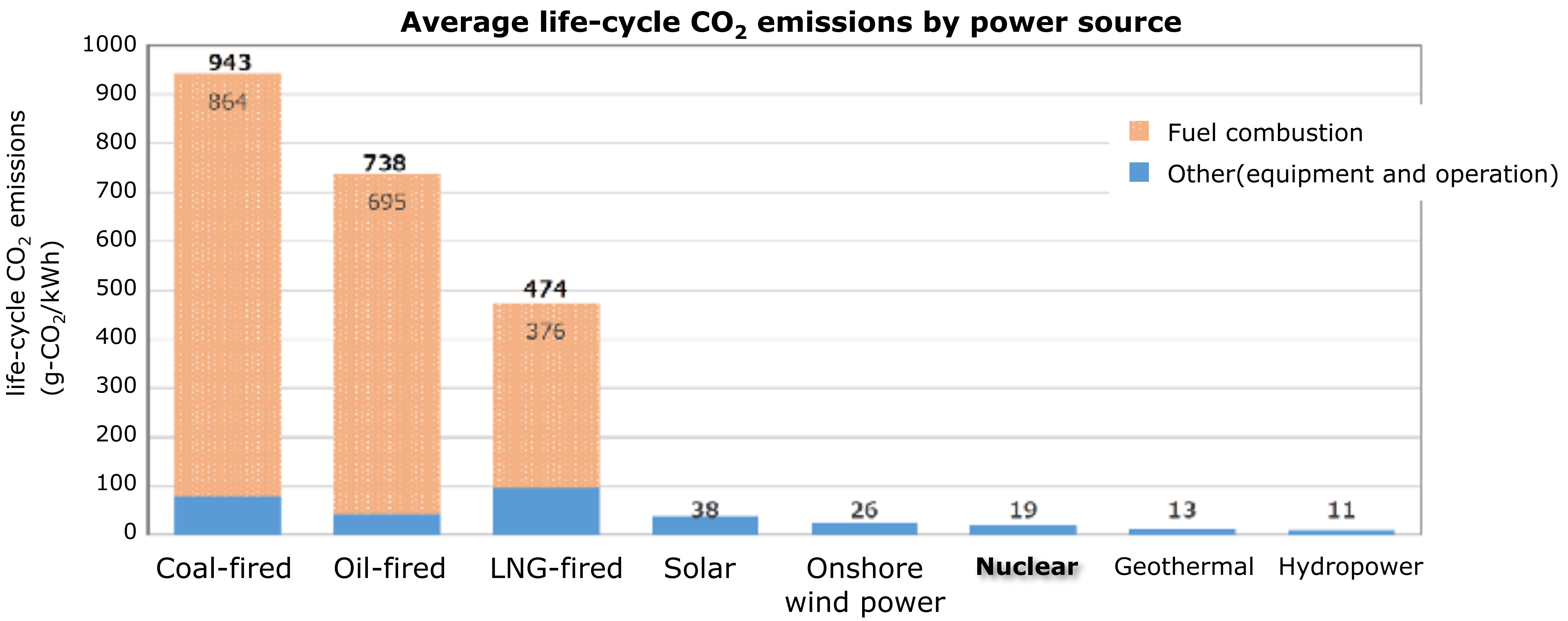
\32,500/tCO_2

(IEA Estimates of Carbon Pricing in Advanced Economies)

JRI: Challenges in Promoting Carbon Pricing — Domestic Framework Development and International Coordination

Advantages of Producing Hydrogen with Nuclear - Low CO_2 Emission

Nuclear power is a sustainable energy source because it emits very low levels of CO_2 during operation and has the third-lowest lifecycle CO_2 emissions of all power sources

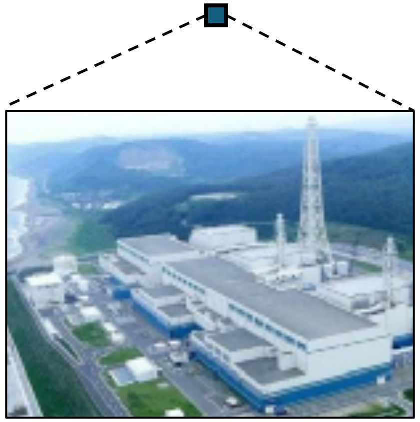


Excerpt from Material 1 "Decarbonized Energy Sources" of the 58th Meeting of the Strategic Policy Committee, Advisory Committee on Energy and Natural Resources
https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2024/058/058_004.pdf (accessed on May 8, 2026)

Advantages of Nuclear Hydrogen Production - High Energy Density

Nuclear energy offers high energy density, enabling large-scale and stable energy production with minimal space requirements.

Nuclear Power Plant
1 GW
(approx. 0.6 km²)



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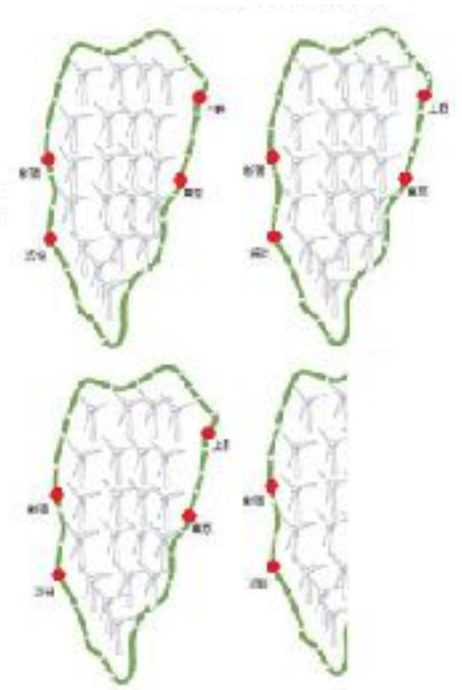
Solar Power
Yamanote Line Loop-sized Area
(approx. 58 km²)

=

Wind Power
3.4 × Yamanote Line
(approx. 214 km²)



資源エネルギー庁　原発のコストを考える（一部修正）
https://www.enecho.meti.go.jp/about/special/tokushu/nuclear/nuclearcost.html（accessed on January 9,　2025）

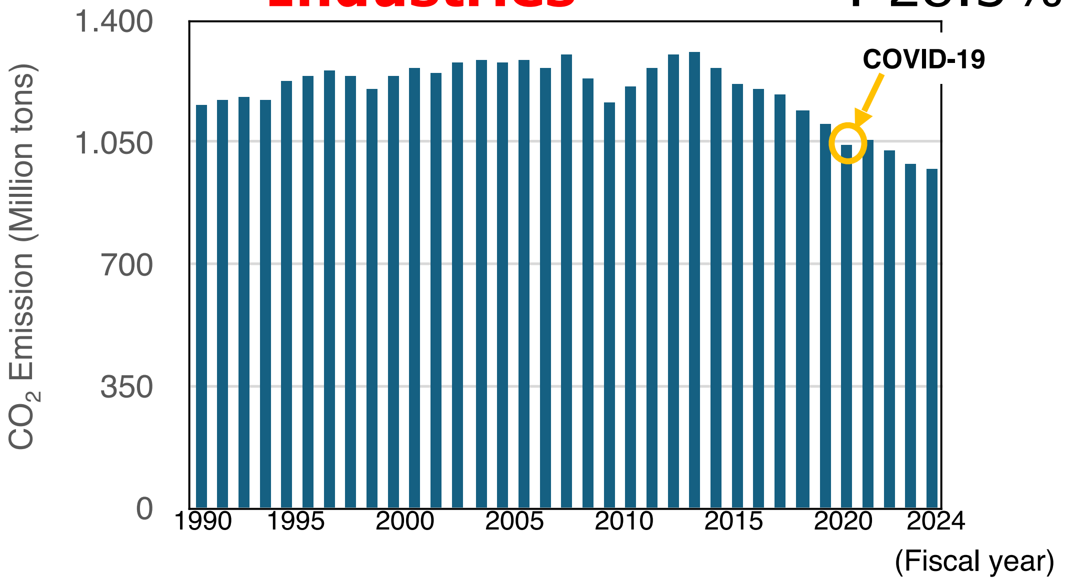
Japan's CO_2 Emission (Total & Sectors)

- Japan's CO_2 emissions have decreased since 2013 due to energy conservation and expansion of low-carbon electricity.
- Further reduction is necessary to achieve carbon neutrality by 2050.

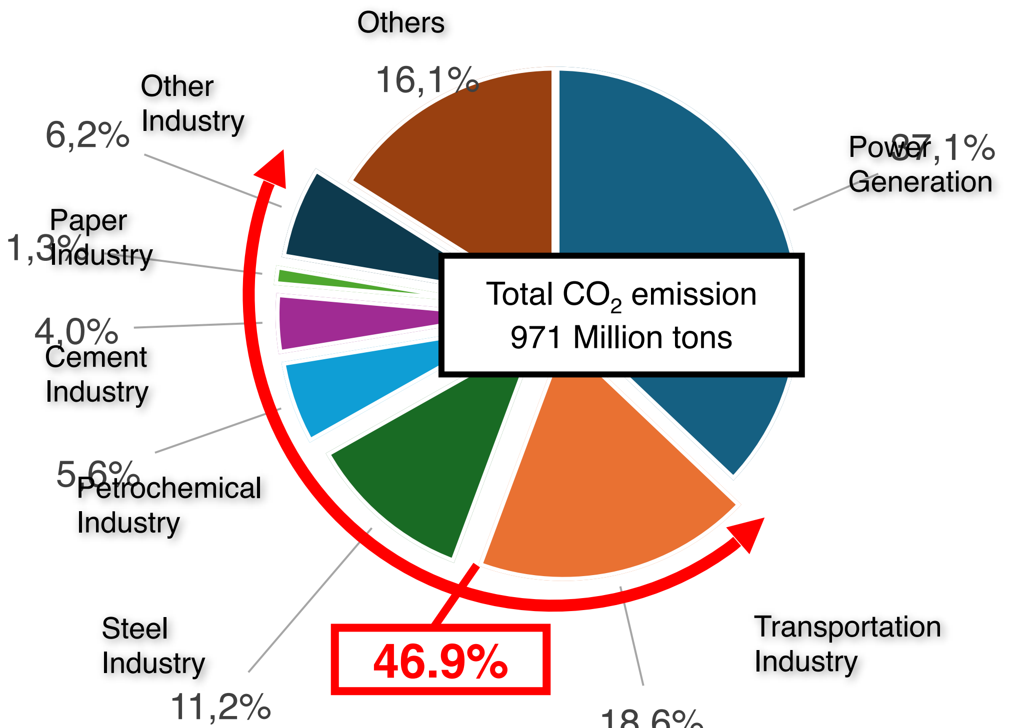
[Sectors with high CO_2 emission]

- ➢ Power generations : 37.1%
- ➢ **Transportations** : 18.6%
- ➢ **Industries** : 28.3%

Reducing CO_2 emissions in these three areas is essential to achieving carbon neutrality



Transition of CO_2 emission in Japan
(1990-2024)

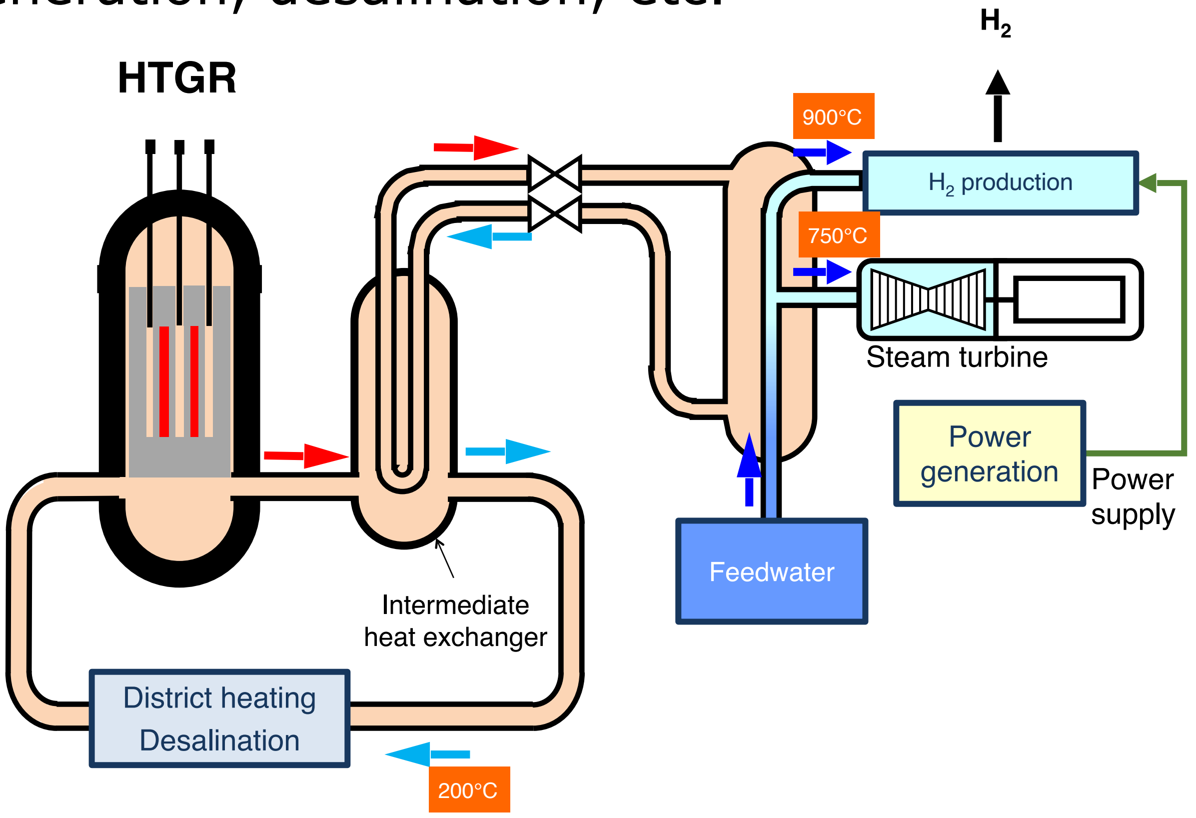


CO_2 emission by sectors in Japan
(2024)

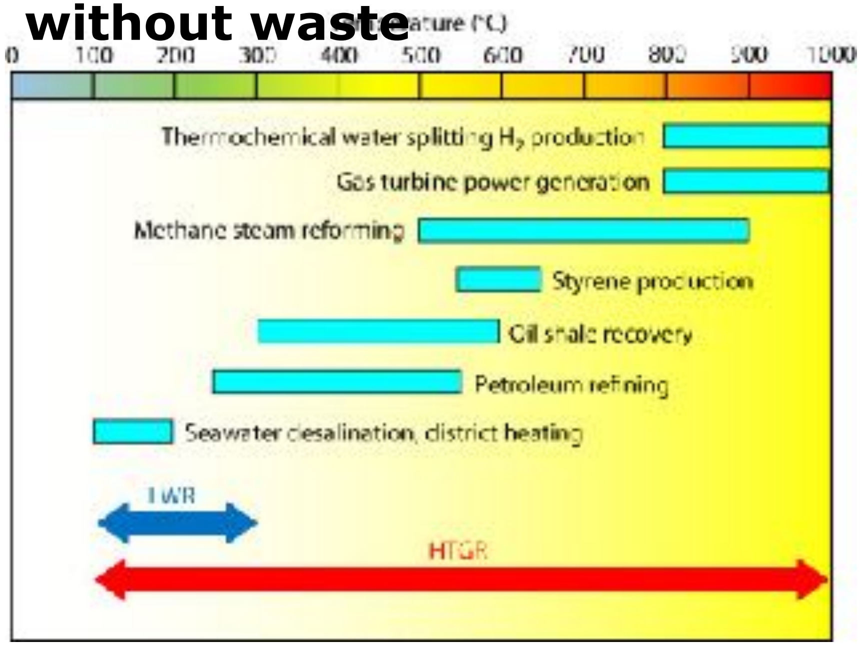
https://www.nies.go.jp/gio/aboutghg/index.html (accessed on May 14th, 2026)

HTGR Features – Heat Supply Capability

HTGR can supply high-temperature heat above 900ºC and support various applications, including hydrogen production, process heat supply, power generation, desalination, etc.



Efficient use of heat from high to low temperature without waste



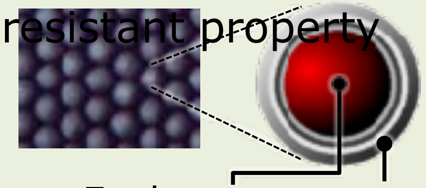
Clean, diversified energy enables substantial CO_2 reductions outside the power sector.

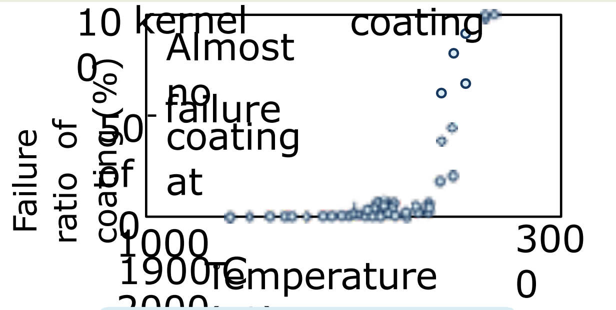
J. Iwatsuki et al., Overview of high temperature gas-cooled reactor, in High Temperature Gas-Cooled Reactors, JSME Series in Thermal and Nuclear Power Generation, vol. 5, Elsevier, pp. 1–16 (2021).

HTGR Features – Safety Characteristics

Ceramic coated fuel particle

Inability to melt due to heat-resistant property

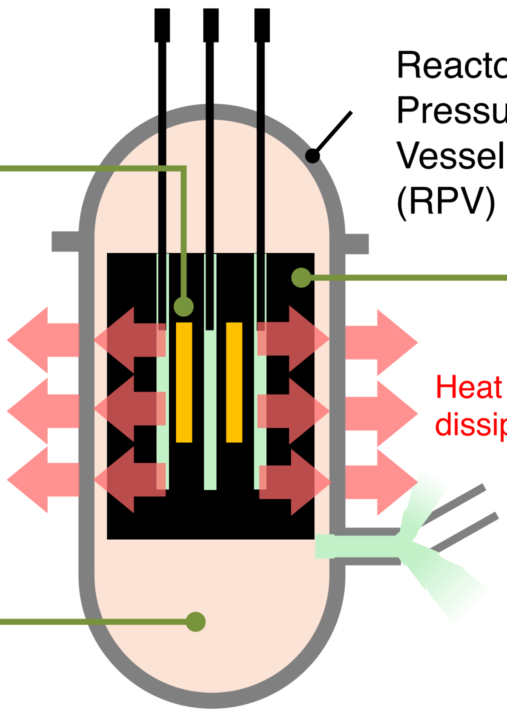




Experimental result for coated fuel particle

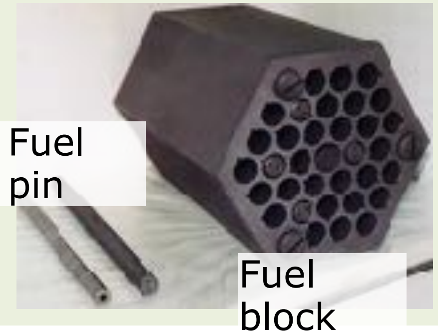
Helium coolant

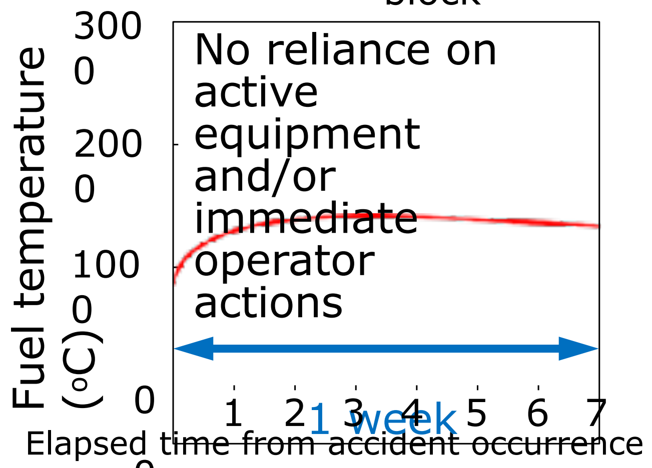
No explosion or decomposition risk – chemically inert.



Graphite moderator

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



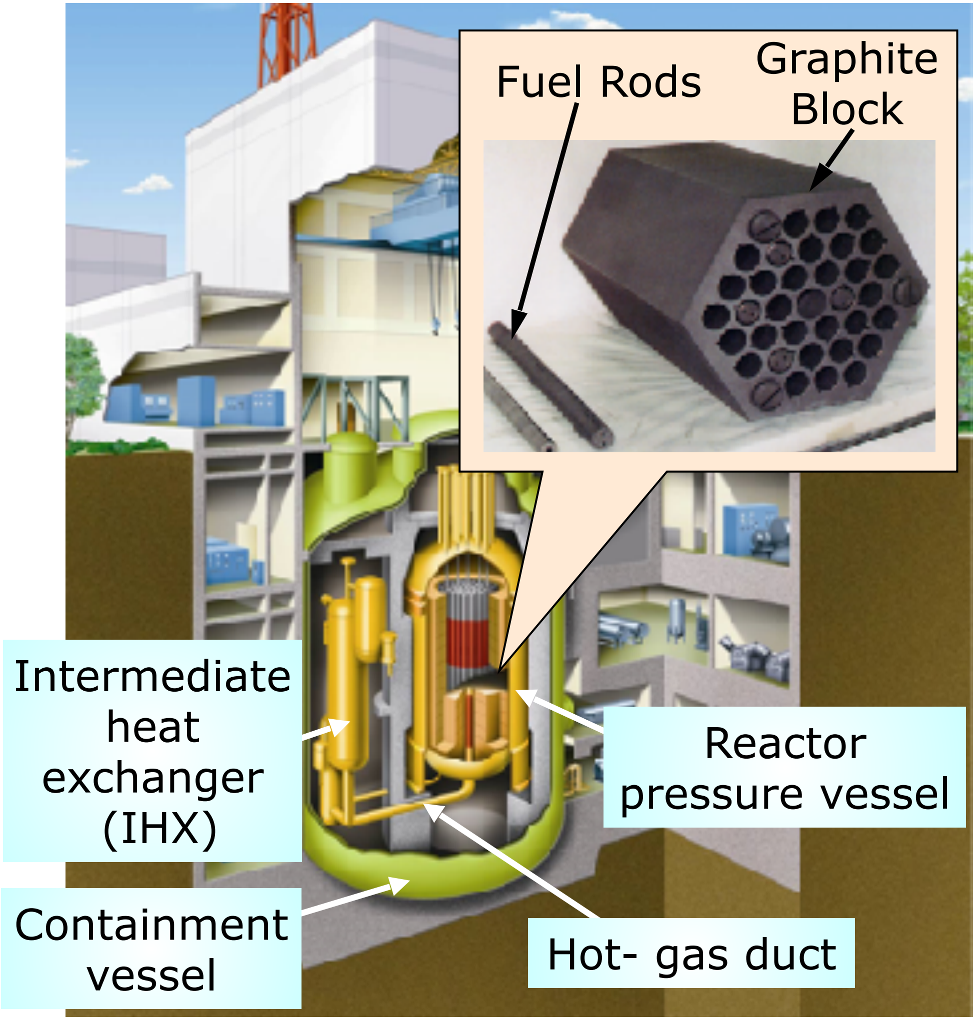


Fuel temperature during loss-of-core cooling accident (Simulation)

H. Sato, Role of High Temperature Gas-cooled Reactor Technologies to Attain Carbon Neutrality, Technical Meeting on the Role of Nuclear Cogeneration Applications Towards Climate Change Mitigation, October 11-13, Online

HTGR Development in Japan

High Temperature Engineering Test Reactor (HTTR) is the only prismatic-type HTGR in operation in the world.



Major Specifications

Thermal power	30 MW
Fuel	Coated fuel particle / Prismatic type
Core material	Graphite
Coolant	Helium
Inlet temperature	395°C
Outlet temperature	950°C
Pressure	4 MPa

Major Achievements

First criticality	: November, 1998
Full power operation	: December, 2001
50 days continuous 950°C operation	: March, 2010
Obtain permission of changes to reactor installation in conformity to New Regulatory Requirements	: June, 2020
Restart operation	: July, 2021
Station black out test	: January, 2022
LOFC test at 100% reactor power	: March, 2024

HTGR Development History at JAEA

Major Specifications	
Thermal power	30 MW
Fuel	Coated fuel particle / Prismatic type
Core material	Graphite
Coolant	Helium
Outlet temperature	950°C
Pressure	4 MPa

Approximately £784m was invested.

H_2 Production Demonstration

Establishment of fundamental technologies

- 2024 — Loss of forced cooling test at full power
- 2022 — Station blackout test
- 2021 — Restart operation
- 2014 ～ 2020 — Conformity review on the new regulatory requirements
- 2010 — Start of loss of forced cooling test; 950ºC/50 days operation
- 2007 — 850ºC/30 days operation
- 2004 — Reactor outlet coolant temperature 950ºC

First in the world

- 2002 — Safety demonstration test (control rod withdrawal test)
- 2001 — Reactor outlet coolant temperature 850ºC (30MWt)
- 1998 — First criticality

Construction of reactor

- 1991 ～ 1997 — Construction
- 1989 ～ 1990 — Application and permission of construction
- 1985 ～ 1988 — Detail design

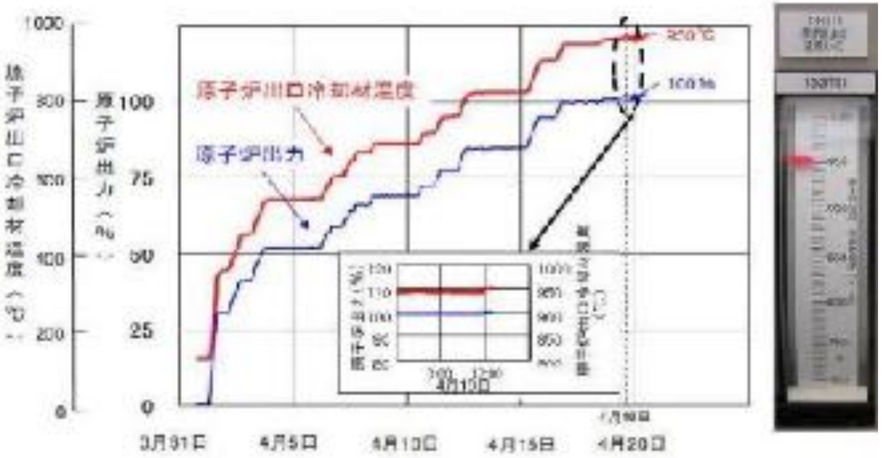
HTTR

- 1981 ～ 1984 — Basic design
- 1974 ～ 1980 — System integrity design
- 1969 ～ 1973 — Conceptual design

Multi-purpose experimental Very High Temperature Reactor (VHTR)

Research and development and design

Attainment of reactor outlet temp. 950ºC



Research and development

Fuels · Materials

In-pile helium loop (OGL-1)

Reactor physics

Very High Temperature Reactor Critical assembly (VHTRC)

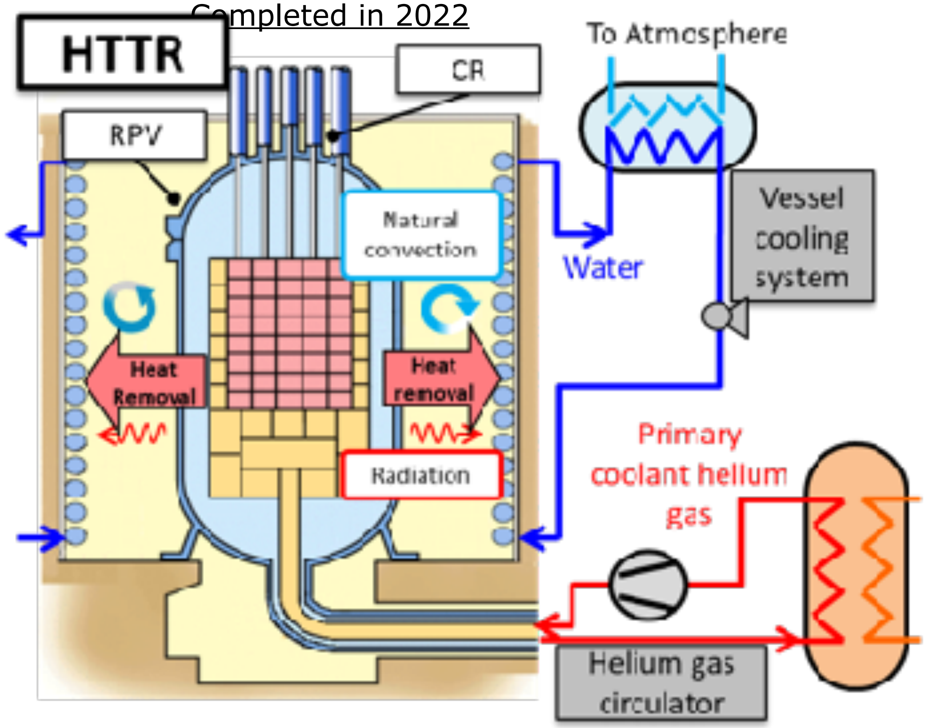
Thermal hydraulics

Helium Engineering Demonstration Loop (HENDEL)

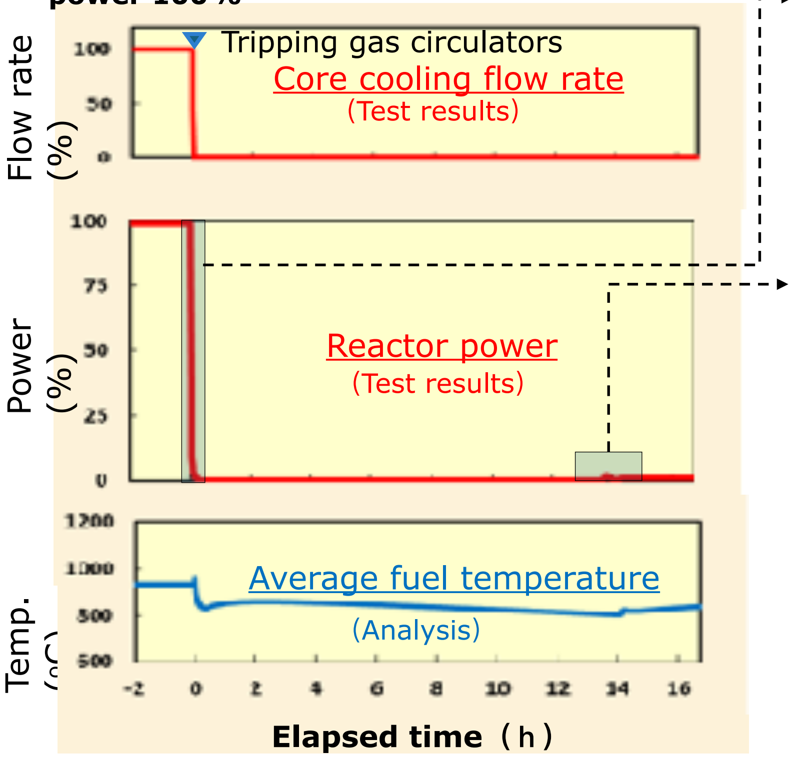
HTTR Safety Demonstration Test

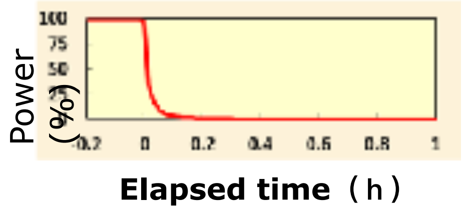
Safety demonstration tests are being carried out to confirm inherent safety features of HTGR using the HTTR under OECD/NEA framework

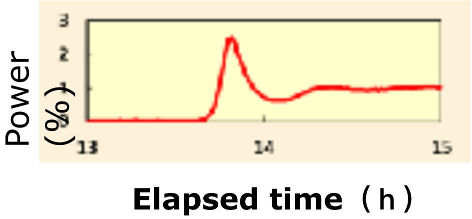
- Loss of forced cooling test (9MWt) — All HGC stopped at 30% — Completed in 2011
- Loss of forced cooling test 100% (30MWt) — All HGC stopped at 100% — Completed in March 2024
- Station blackout test — All HGC + VCS stopped at 30% (9MWt) — Completed in 2022



Loss of forced cooling test at reactor power 100%







- Initial power 100% (30MWt)
- Stop all helium gas circulators and core flow rate become zero
- VCS operation maintained
- No scram operation (No CR insertion)

The reactor intrinsically shut down as soon as the core cooling flow rate approaches zero.
The reactor is kept stable long after the loss of core cooling.

E. Ishitsuka, "Experience of HTTR Licensing for Japan's New Nuclear Regulation," GIF Webinar Series 52, April 21,

Loss of Forced Cooling Test from Reactor Power at 100%

27th March 2024

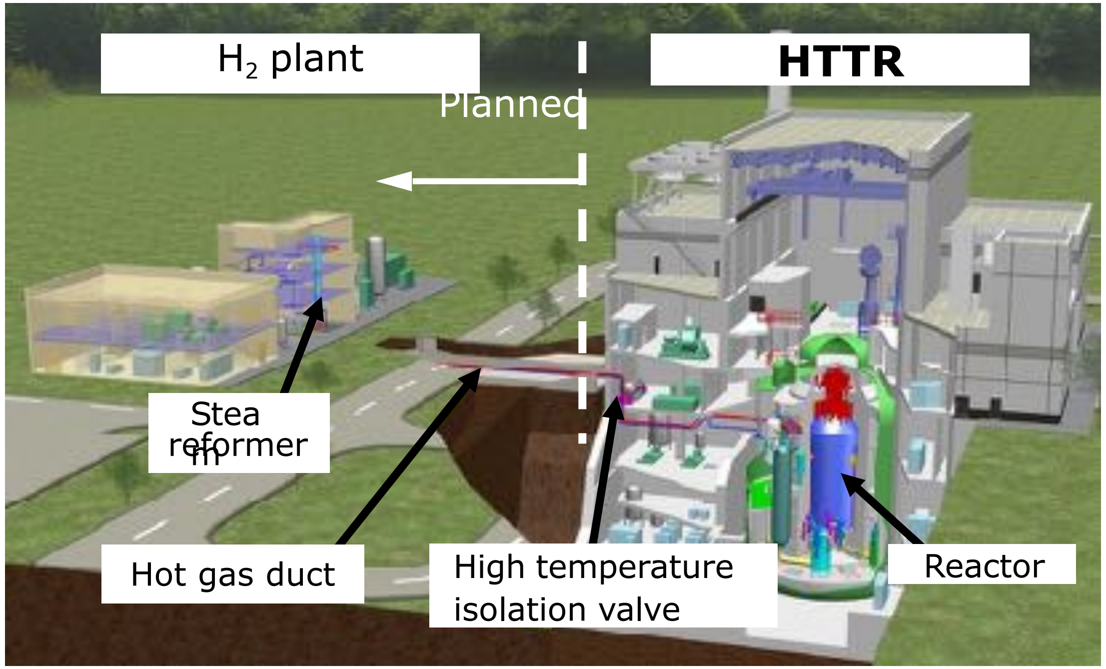
Safety Demonstration Test Commemorative Ceremony

March 27, 2024

Hydrogen Production Demonstration Using HTTR

Objective

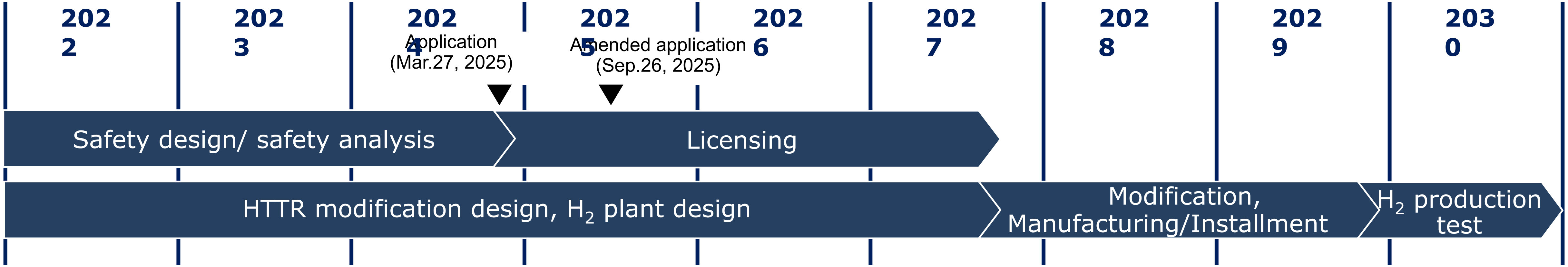
- Establish a safety design for coupling HTGR and H_2 plant through the licensing by the Japanese Nuclear Regulation Authority.
- Demonstrate the performance of components required for coupling between HTGR and H_2 plant.
  - ✓ High temperature isolation valve
  - ✓ Hot gas duct, etc.



Tasks

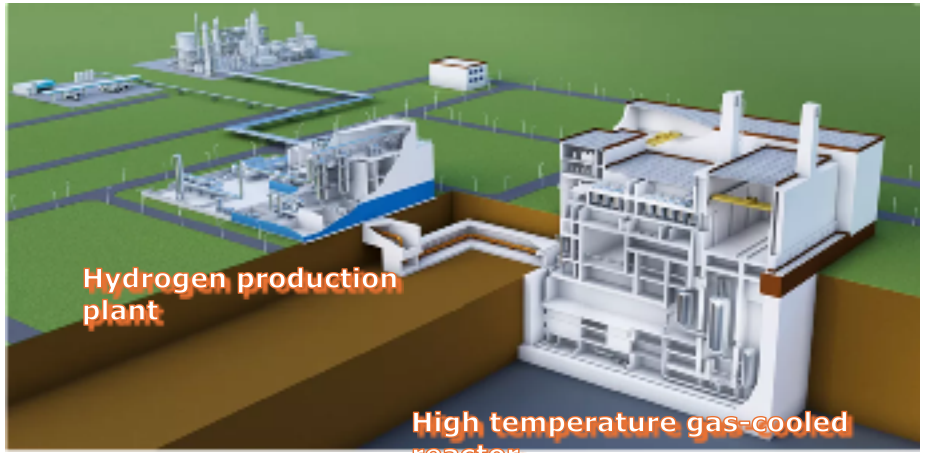
- Construct a steam methane reforming H_2 plant and connect to the HTTR.
- Conduct a continuous H_2 production test and plant dynamic tests.

Schedule (JPFY)

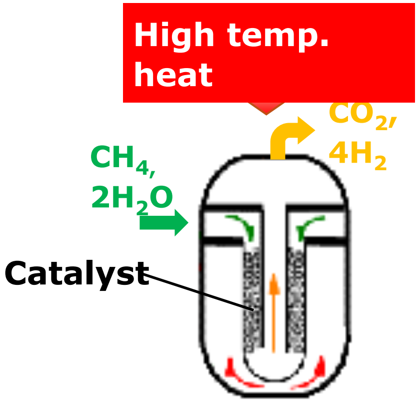
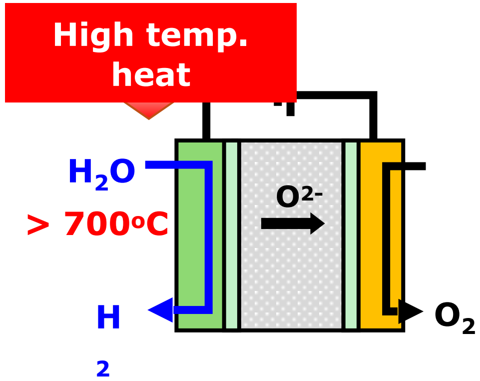
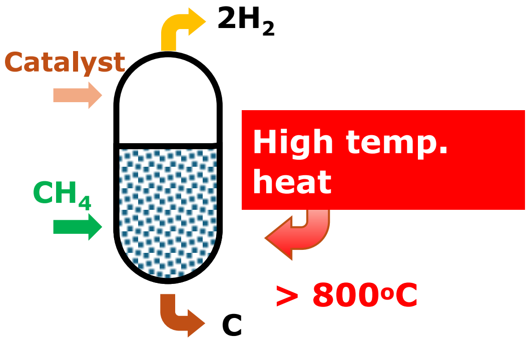
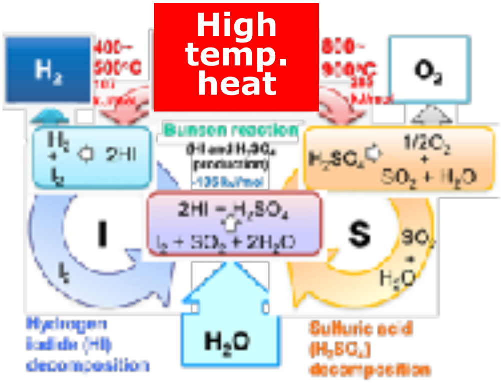


HTGR Demonstration Reactor Project in Japan

- Target of operation in the late 2030s.
- Mitsubishi Heavy Industries is responsible for the design and construction as a lead company.
- A reactor power range from 150 MW-250 MW*1.
- Supply a very high temperature above 800°C to H_2 plant*2.
- Combination with a carbon-free H_2 production technology enables large-scale, low cost, carbon-free

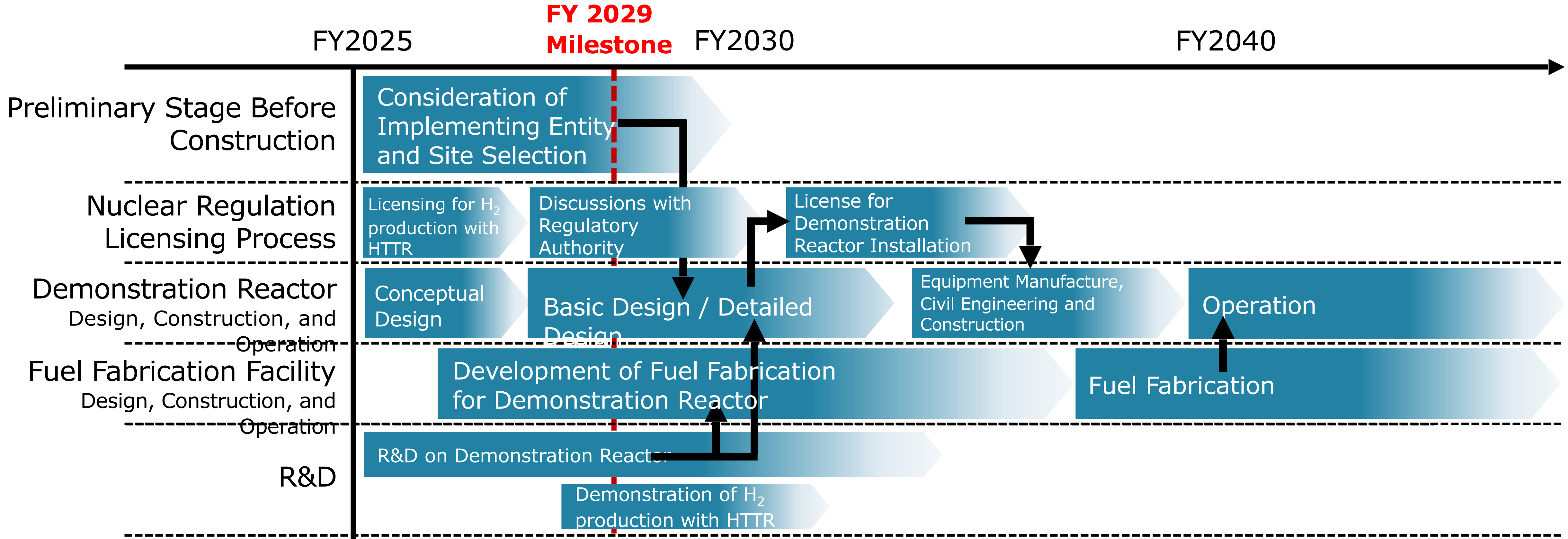


Bird's-eye view of HTGR demonstration reactor*3

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

*1 Y. Usui, et al., Development of High Temperature Gas-cooled Reactor by Mitsubishi Heavy Industries, The 19th Lecture Meeting of the Japan Society of Maintenology, C-1-1-4 (2023).
*2 METI, www.enecho.meti.go.jp/appli/submission/2022/0222_01.html, accessed on January 19, 2024.
*3 https://www.mhi.com/jp/business/products-services/energy-environment/nuclear-power-generation/high-temperature-gas-cooled-reactor(Accessed on May 11th 2026)

A Technology Roadmap for Developing



Key points

*1 : In order to proceed with the design of the demonstration reactor, the selection of an implementing entity and the determination of a site are prerequisites. Furthermore, the understanding of the local government and other relevant parties is necessary to begin concrete planning. The timing of the start of operations will vary depending on when the implementing entity is selected and the site is determined.

*2 : First, licensing procedures for hydrogen production at the HTTR, which are currently underway, will be addressed. Following this, the approach to safety assurance based on HTGR's inherent safety will be examined. Dialogue will be engaged with regulatory authorities, and the results will be reflected in the design as necessary.

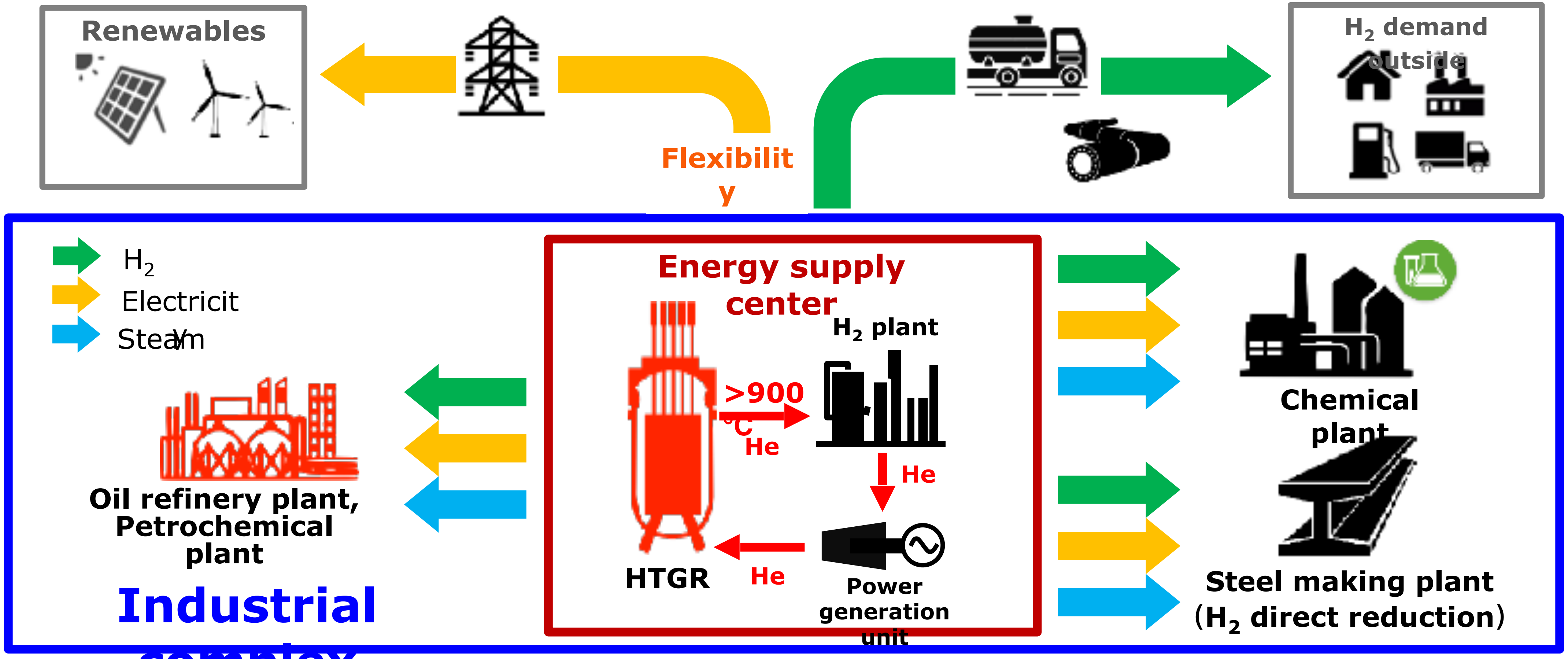
*3 : The conceptual design is scheduled to be completed in FY2026. Subsequently, the process will be shifted to the basic and detailed design phases of the demonstration reactor

*4 : Regarding fuel production, specific options, including domestic production and overseas procurement, will be further examined.

*5 : The design of the demonstration reactor, key technology development, and nuclear fuel cycle technology development will be implemented through the demonstration reactor project. Additionally, hydrogen production with HTTR will be commenced around FY2028, and the results will be reflected in the development of the demonstration reactor.

*1 JAEA translated a roadmap based on Working Group on Next-Generation Innovative Reactors, Subcommittee on Nuclear Energy, Electricity and Gas Business Basic Policy Subcommittee, Advisory Committee for Natural Resources and Energy

Contribution of HTGRs to Net-Zero Emissions



Economical Value

- Reduction of high energy procurement cost in carbon neutrality
- Improvement of profitability by the

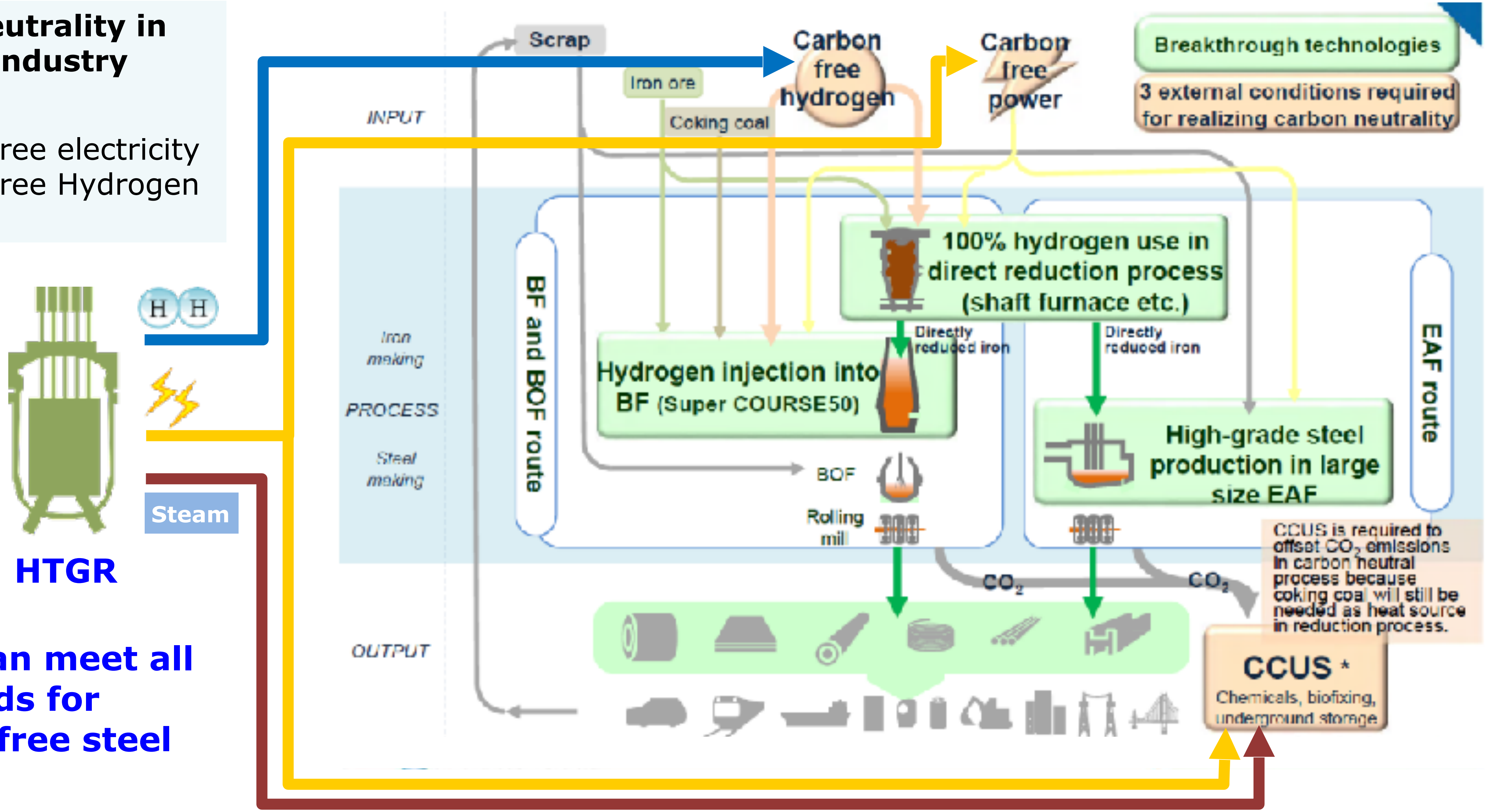
Social Value

- Achieving carbon neutrality in Hard-to-Abate industries
- Reinforcement of resilience for carbon neutral society

HTGR-based Energy Supply: Steel Industry

Carbon neutrality in the steel industry requires

1. Carbon-free electricity
2. Carbon-free Hydrogen
3. CCUS



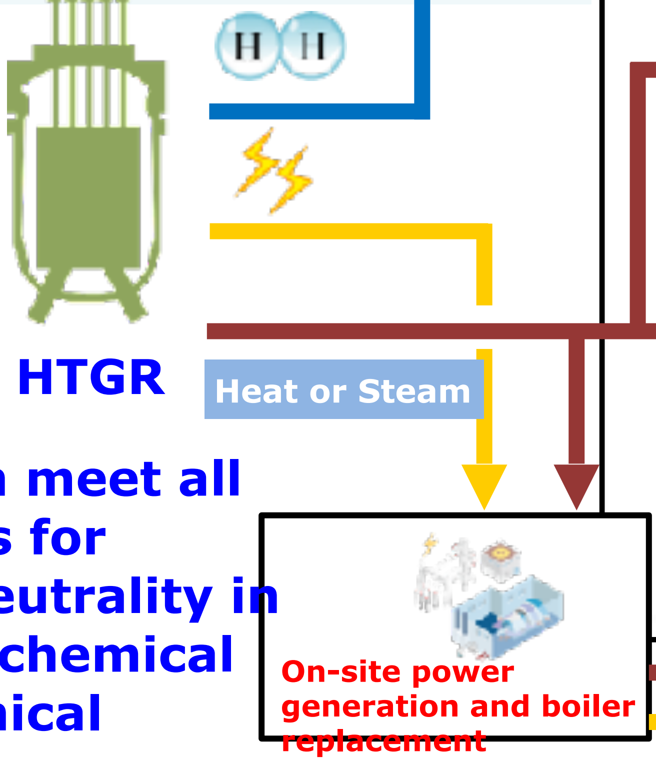
HTGR can meet all the needs for carbon-free steel making

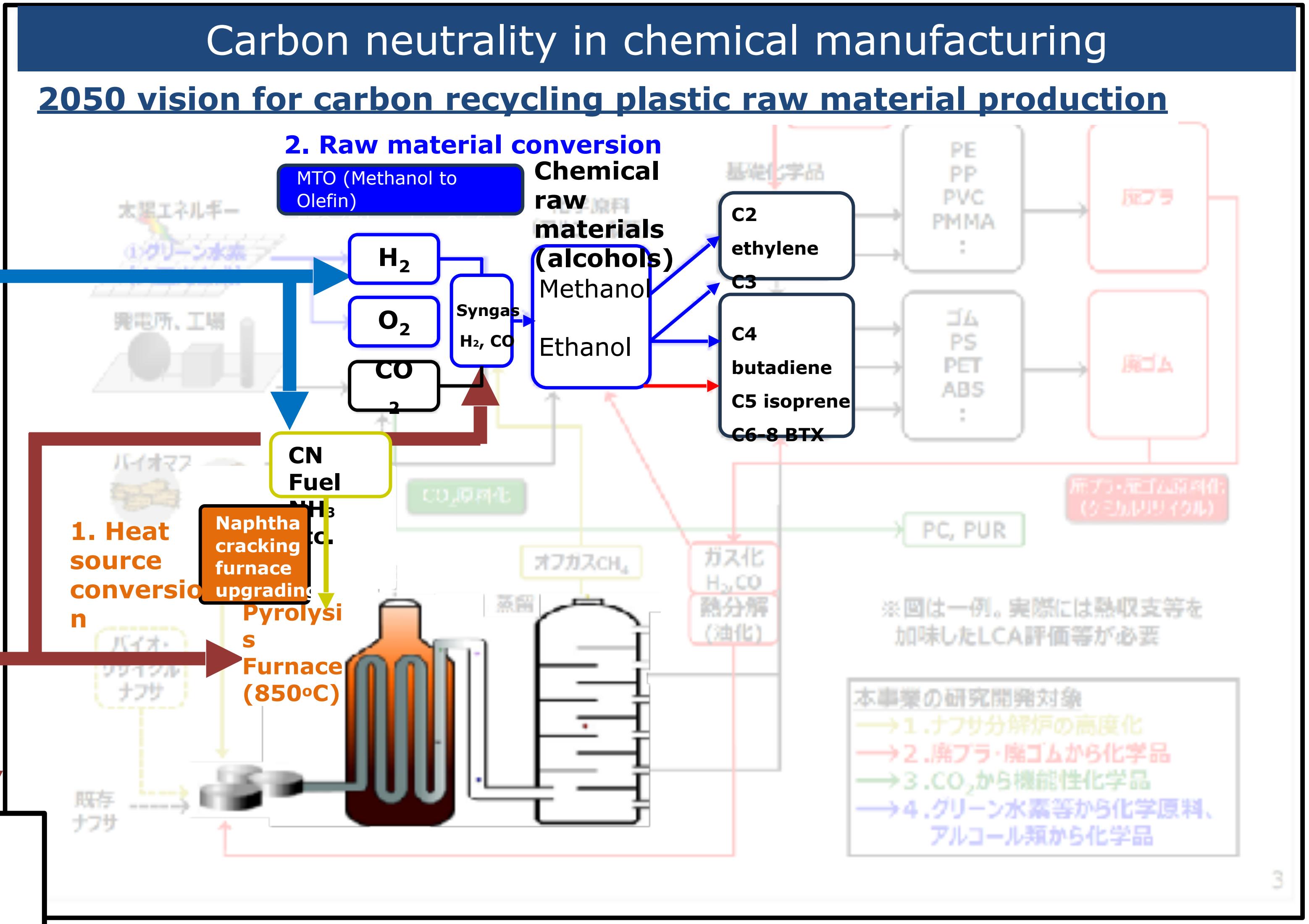
The figure is referred from Nippon Steel, Nippon Steel Carbon Neutral Vision 2050, March 30, 2021. (https://www.nipponsteel.com/en/ir/library/pdf/20210330_ZC.pdf (Accessed on May 22, 2023.)), and JAEA added the information about HTGR

HTGR-based Energy Supply: Chemical Industry

Carbon neutrality in the petrochemical and chemical industry efforts

1. **Heat source conversion**
   → High-temp. heat and steam supply to naphtha cracking furnaces, conversion to hydrogen
2. **Raw material conversion**
   → Hydrogen supply for MTO
3. Raw material recycling

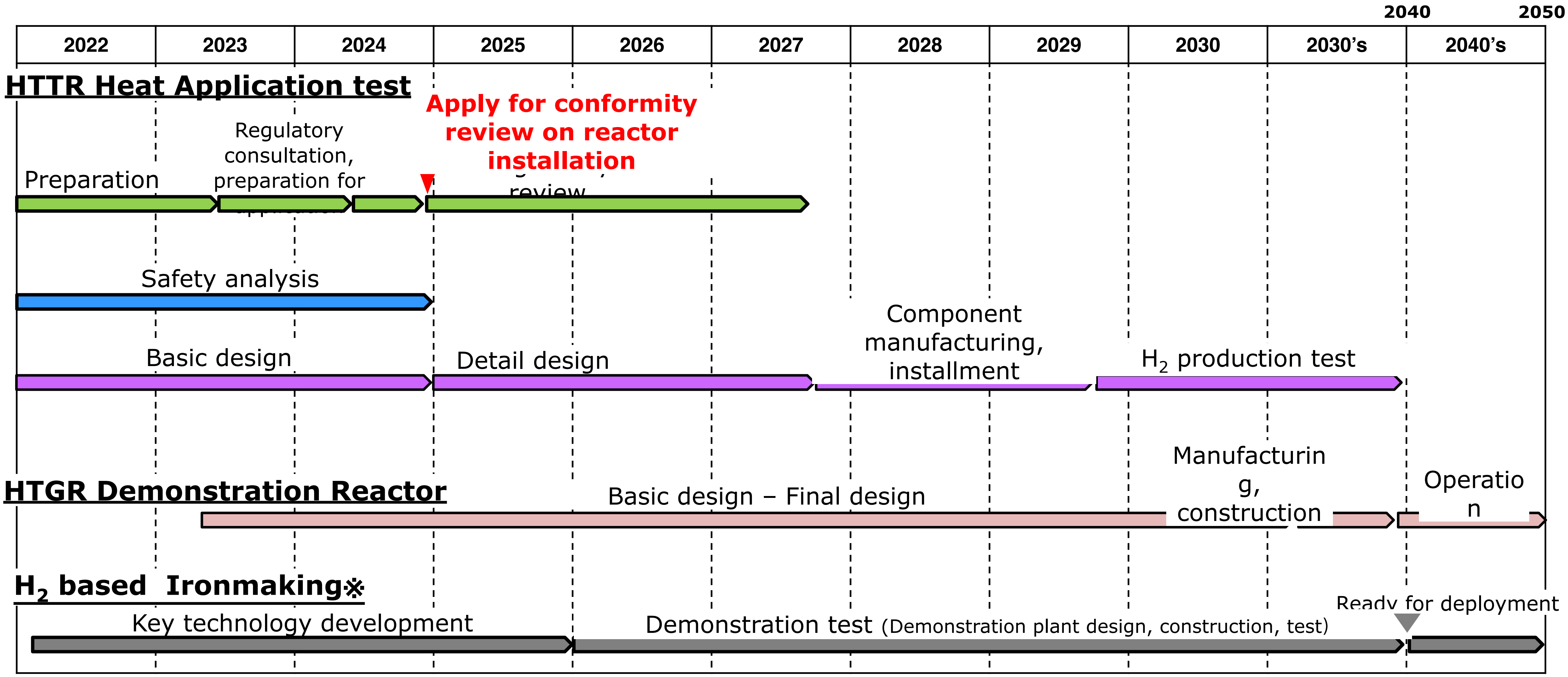




HTGR can meet all the needs for carbon neutrality in the petrochemical and chemical industry

The figure is referred from the document(https://www.city.shunan.lg.jp/uploaded/attachment/79293.pdf (accessed on December 19, 2024)), and JAEA modified and added the information about HTGR.

Future Plans for HTGR Demonstration



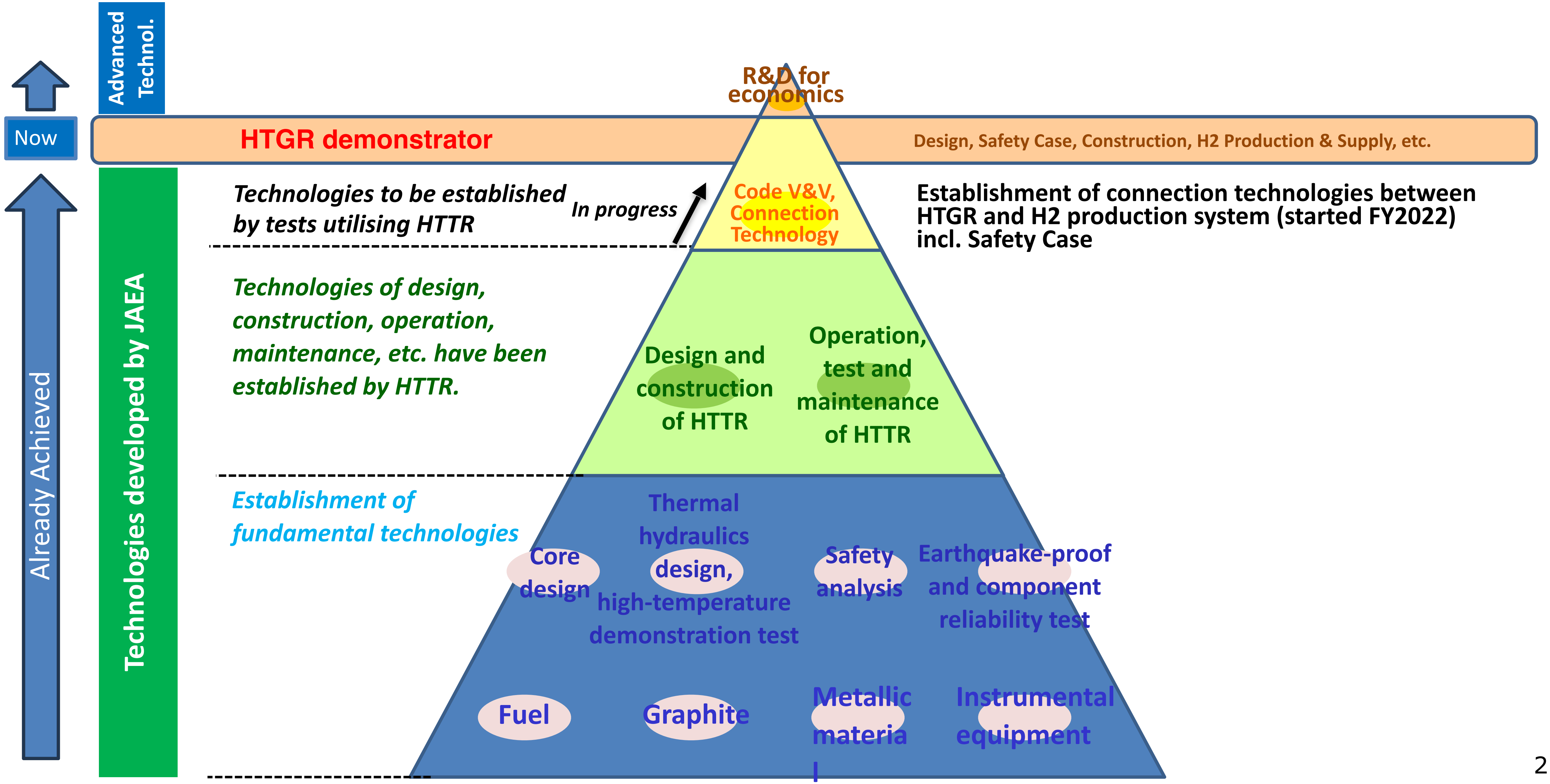
*GREiNS, https://www.greins.jp/research/research02/ (accessed on July 30, 2025)

Summary

- HTGRs enable large-scale, stable hydrogen production, supporting Net Zero goals, especially in hard-to-abate sectors such as steel and chemicals.
- Japan operates the HTTR (950 °C heat), demonstrating suitability for hydrogen production, and is advancing commercialization with a HTGR demonstration reactor targeted the late 2030s.
- Leveraging Japan's HTGR expertise can accelerate early HTGR deployment and contribute to decarbonization in both countries.

Appendix

Japan's HTGR Technology Capabilities



Challenges and Approaches for HTGR Commercializatio

Policy

Project predictability

- Early engagement with regulator, use of PRA for regulatory process

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

→ **HTGR demonstration on reactor development**

→ **HTTR-heat application test**

Regulatory Demarcation Boundary

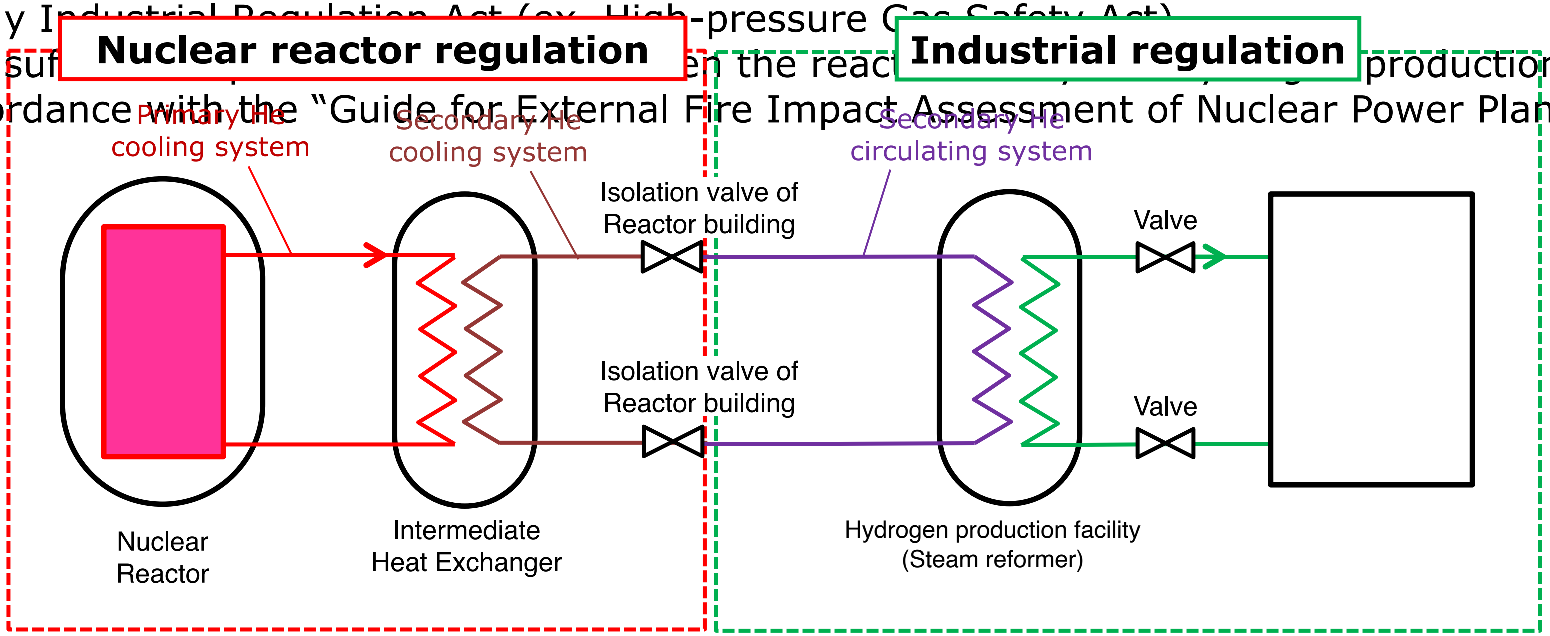
Application coverage of the Nuclear Reactor Regulation Act would extend only to isolation valves of reactor building, and that the hydrogen production facility would be excluded from the scope of the review

Nuclear Reactor Regulation Act: Equipment necessary for safely shutting down a reactor and maintaining that state (red dotted line)

- ✓ Apply the Reactor Regulation Act
- ✓ The isolation valves of reactor building is a demarcation boundary between the reactor facility and industrial facility. The isolation valves close in the event of an abnormality in the general industrial facilities to isolate it from the reactor facility. (green dotted line)

Industrial Regulations Act: Equipment not necessary for the safe shutdown of the reactor or maintaining that state

- ✓ Apply Industrial Regulation Act (ex. High-pressure Gas Safety Act)
- ✓ The suf [illegible] en the reac [illegible] production equipment must be ensured in accordance with the “Guide for External Fire Impact Assessment of Nuclear Power Plants.”



Regulatory demarcation boundary

JAEA, Amended application for changes to reactor installation of the High Temperature Engineering Test Reactor to demonstrate hydrogen production technology by high temperature gas-cooled reactor (Notice), https://www.jaea.go.jp/02/press2025/p25092603/ (Accessed on May 11, 2026).