The 56th JAIF ANNUAL CONFERENCE

Session 4「Maximizing and Deepening Uses of Nuclear Power toward 2050」

Toward social deployment and the possibility of multi-purpose utilization of next-generation nuclear reactor

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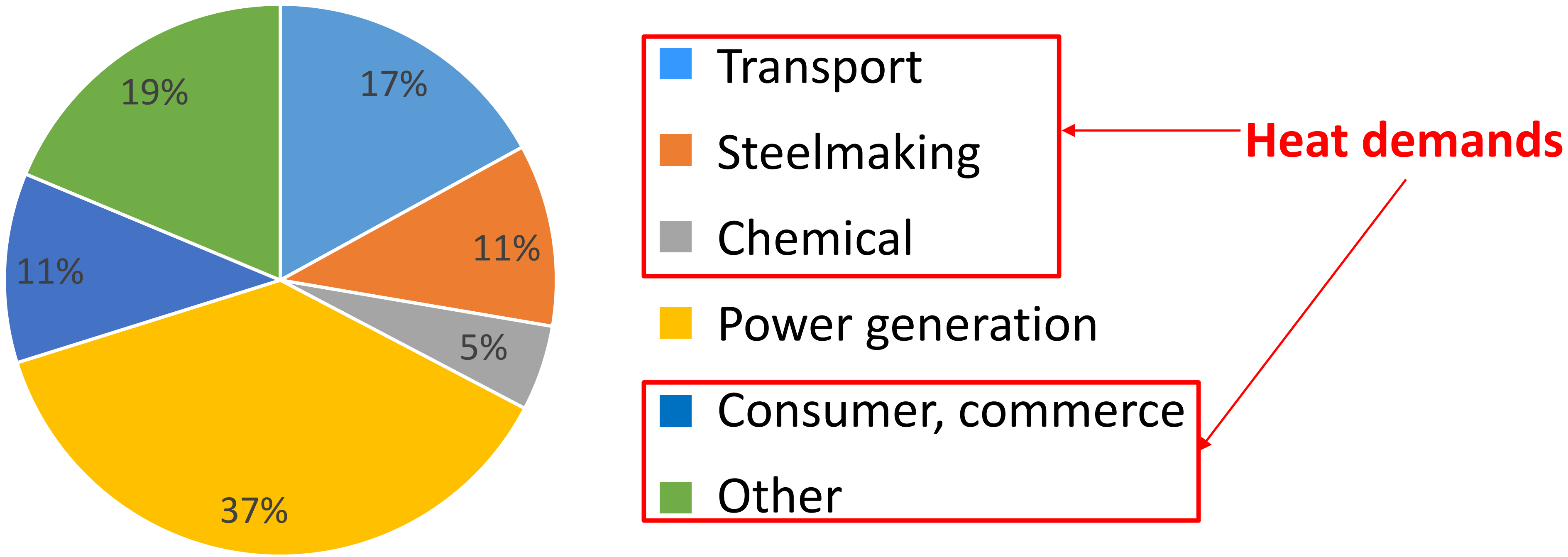
SeFARD

Breakdown of CO_2 emissions in Japan

- Decarbonization in the power generation sector dominating about 40% is indispensable. Japan needs the maximum use of both renewable energy sources and nuclear power.
- Up to 60% come from the use of thermal energy in non-power generation sectors (civilian use and industrial use). It is also necessary to make efforts to decarbonize heat sources for these demands.
- **Next-generation reactors or innovative nuclear power systems** will meet the heat demand in industry (non-power generation use) .



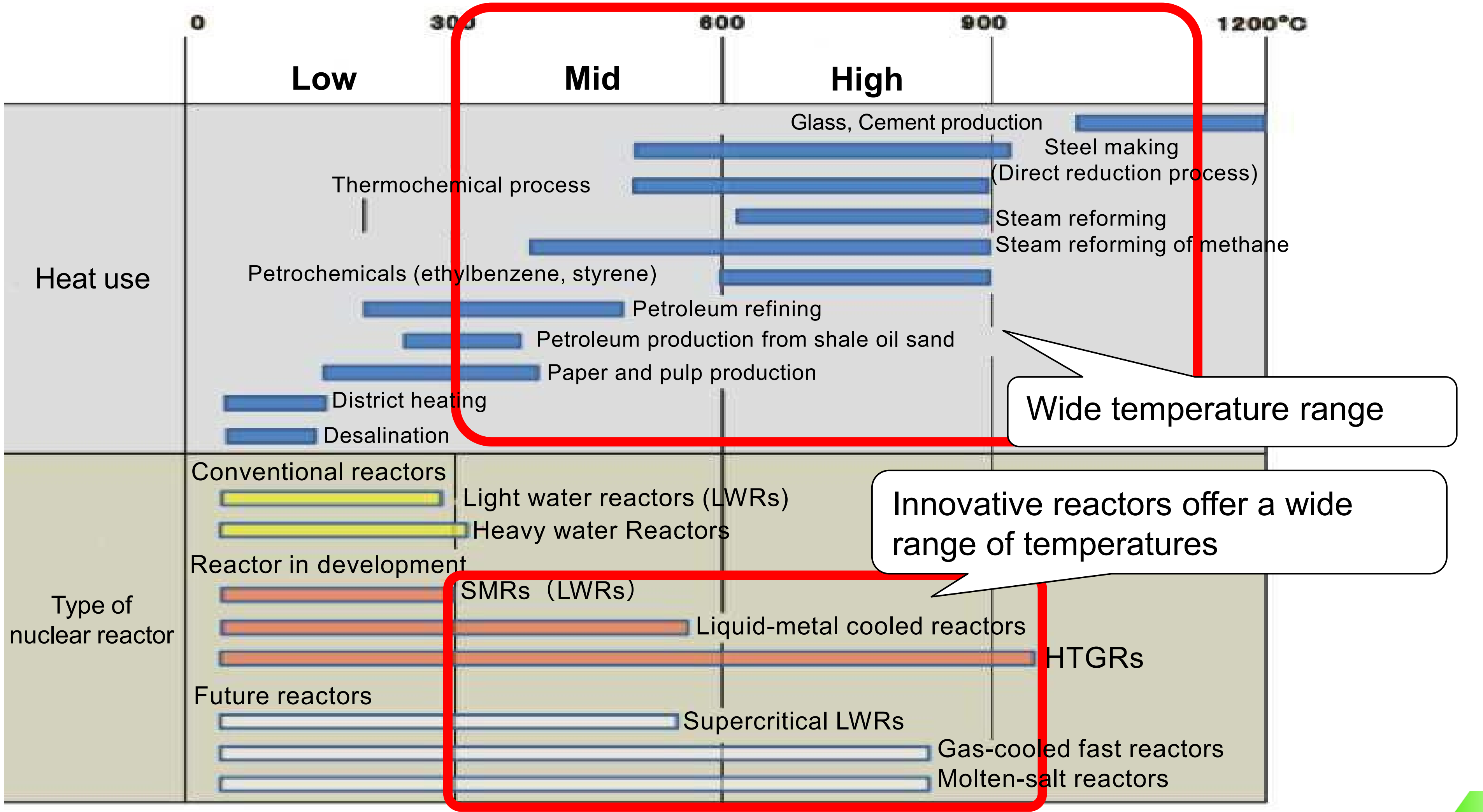
Breakdown of CO2 gas emissions in Japan (2020)

Ref:National Institute for Environmental Studies, Japan [Greenhouse Gas Inventory Office]

Heat demand and temperature range nuclear reactors can cover

Ref.: Agency of Natural Resources and Energy, Innovative Reactor WG 1st Meeting document 6 (Apr. 20, 2022)

- Innovative reactors have the potential to supply heat from low temperatures (up to 300℃) to high temperatures (up to 900℃) and can cover hydrogen production and industrial process heat (e.g., district heating, steel making).



（出典）IAEA Nuclear Energy Series, Opportunities for Cogeneration with Nuclear Energy

Japan's recent activities for next-generation reactor development

Nuclear Energy Subcommittee (METI)

- Innovative Reactor Working Group (WG) drafted the interim report on "Technical roadmap for advanced reactor (High temperature gas reactor, Fast reactor)" (July 2022)
- Policy and guidelines on actions for nuclear development (draft) (December 2022)

Council on fast reactor development (METI)

- Strategic WG discussed the way of fast reactor development after 2024. Discussion for revision of Fast Reactor Strategic Roadmap (Dec. 2018)
- Proposed a revision of the Roadmap (Dec. 22, 2022)

Decided by Ministerial meeting on nuclear energy (Dec. 23, 2022)

METI: Ministry of Economy, Trade and Industry
MEXT: Ministry of education, culture, sports, science and technology

"GX: Green Transformation Policy" Implementation Council (Cabinet Secretariat)

adopted a document at the 5th meeting (Dec. 22, 2022)

"GX Basic Policy–Roadmap for the next 10 years"

- Maximum utilization of nuclear power contributes to energy security and highly decarbonizing power sources.
- Making safety the first priority, promote resuming operation to achieve 20 to 22% of Japan's electricity produced by nuclear power in FY2030.
- Promote the development and construction of next-generation reactors to replace the reactors decided to be decommissioned

>> Cabinet decision (Feb. 10, 2023) <<

Japan Atomic Energy Commission

Basic policy for nuclear energy
(February, 2023, Committee decision on the revised draft)
Cabinet decision (Feb. 28, 2023)

Working Group on Development of R&D Infrastructure for Next-generation Reactors (MEXT)

Proposal for basic R&D toward the development primarily of fast reactors and high-temperature gas-cooled reactors, and development of base infrastructure (Mar. 28, 2023)

Requirements for next-generation reactors

- Ensure the safety, and
  - Supply stable power (in large quantities + advanced safety mechanisms + technological self-sufficiency, supply chains)
  - Achieve natural resource recycling (waste management + effective use of resources)
  - Be flexible (load-following + hydrogen and heat production + flexible siting)

Stable power supply

- As a carbon-free power source, contribute to stable, sustainable power supply across the nation.
- Achieve safety innovations for regaining the public trust.
- Innovate processes in manufacturing and procurement to stimulate nuclear supply chains, so that technological self-sufficiency will further improve.

Natural resource recycling

- As a carbon-free energy source, use innovative technology to recycle high-level radioactive waste
- Propose solution to limited natural resources
- Become a recyclable energy source through technological innovation

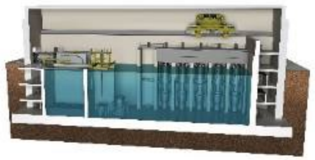
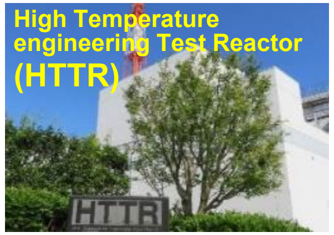
Flexibility

- Support variable renewables by adjusting nuclear power output (load-following)
- Produce hydrogen, achieve various heat application, and store heat when electricity demand is low
- Be flexible in site locations by reducing the sizes of emergency planning zones
- Contribute to improving national welfare through medical RI production

Further enhanced safety

- Develop and promote technologies for safer nuclear power by reflecting lessons learned from TEPCO's Fukushima Daiichi nuclear power plant accident.

Main categories of innovative reactors *1

Advanced Light-Water Reactor (LWR)	 Plant concept*2	Large-scale LWRs featuring new safety-enhancing technologies (e.g., a core catcher). The use of existing LWR technology allows existing LWR supply chains to actively participate in the development and us to easily predict when to start the operation.
Light-water Small Modular Reactor (SMR)	 SMR plant (source: NuScale Power)	Electricity output up to 300 MW. Production of units (modules) in a factory reduces time and cost of construction. Using existing LWR technology, SMRs are a practical option to reduce investment risk and to meet various future needs such as load sharing.
HTGR		Provides high temperature heat (over 900ºC) which can be used for various applications such as hydrogen production as well as highly efficient power generation. HTGR development is underway towards technology demonstration making the most use of international collaboration.
Fast reactor (FR)		Fast neutrons enable the nuclear fuel cycle to be achieved through the effective use of uranium resources and combustion of radioactive waste. FR development is underway using international frameworks, in which the experiences of Joyo and Monju are reflected.

Ref.
*1 https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/029.html
https://www.nikkei.com/article/DGXZQOUC246DB0U2A820C2000000
*2 https://www.meti.go.jp/shingikai/enecho/denryoku_gas/genshiryoku/kakushinro_wg/pdf/001_08_00.pdf

R&D on High Temperature Gas-Cooled Reactor and Heat Application

Characteristics of HTGR

- ○ Excellent **self-controllability and inherent safety** that enable rector design **with no severe accident**
- ○ Various heat use with high efficiency, such as **hydrogen production and desalination**

Contribution to carbon-free future

HTGR
- generates hydrogen for use
- serves as a heat source as an **alternative to coal-fired plants**
- can be deployed in small nuclear energy developing countries **(electricity, hydrogen production, heat use)**

→ Satisfies various needs

HTTR: the only facility available to technology development under international cooperation

- ○ **UK** (Clean Energy Innovation)
- ○ **Poland** (Strategic partnership)
- ○ **USA** (CNWG: Civil Nuclear Energy Research and Development Working Group)
- ○ **OECD/NEA HTTR project** (Japan, the U.S., France, Germany, Korea, Czech, Hungary)
- ○ **GIF VHTR project** (Japan, the U.S., France, Canada, Korea, China, EU, Switzerland)

JAEA and NCBJ signed the Implementing Arrangement (Nov. 2022)

HTTR
(reactor power: 30 MWth)

- ●Achieve reactor outlet coolant temperature 950℃ (Apr. 2004)
- ●50-day continuous operation at 950℃ (Mar. 2010)
- ●Safety demonstration test (loss of core flow test) (Dec. 2010)
- ●Permission of changes to reactor installation in conformity to the new regulatory requirements (Jun. 2020)
- ●Restart (Jul. 2021)
- ●Safety demonstration test (loss of core cooling test) (Jan. 2022)
- ●Tests for HTGR safety improvement

HTGR's contribution to decarbonization

Hydrogen production system

Hydrogen

© IWATANI

Recharging station

steel-making

Supplying hydrogen to

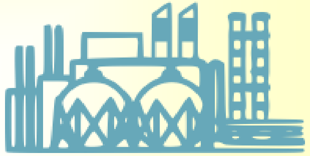
- Fuel-cell vehicles (FCVs)
- Hydrogen-reduced steel-making

Hydrogen, steam, electricity supply to chemical plants

Hydrogen

Steam

Electricity



Chemical plant

- Hydrogen → Ammonia production, petroleum refining
- Steam → Process heat supply (e.g., chemical plant)
- Electricity → Steam turbine power generation

Hybrid system with renewable energy

+

Electricity

Hydrogen

Compensating variable renewable energy sources by adjusting reactor power or amount of Hydrogen production

Hydrogen supply for CO_2 recycling

Hydrogen

Synthetic fuels
Methanation
Methanol synthesis

CO_2

CO_2 recycling (e.g., synthetic fuels, methanation, methanol synthesis)

Significant contribution to decarbonization and CO_2 recycling in industrial and mobility sectors by HTGR cogeneration systems (hydrogen production, steam, and power supply)

SeFARD

Hydrogen mass production using very high temperature of HTGR

JAEA started the **demonstration of hydrogen production technology using very high temperature (950℃) of HTTR** in FY2022.

JAEA and MHI are

Demonstrating supply of a large amount of hydrogen

- carbon-free hydrogen production methods using decarbonized high temperature heat sources at over 800℃ to achieve **a stable and affordable supply of a large amount of hydrogen by 2050, aiming at** industrial applications such as use in ironmaking and chemical plants.
- Developing **a techniques and devices** (e.g., high temperature isolation valves) **to safely connect HTTR and a hydrogen production plant.**
- Conducting **feasibility studies** of domestic and international various **carbon-free hydrogen production technologies** including IS method, methane pyrolysis method, high-temperature steam electrolysis; and investigating hydrogen production technologies suitable for using very high temperature heat sources.
- Conducting **feasibility and viability studies** of the above-mentioned technologies **on a practical application scale**.

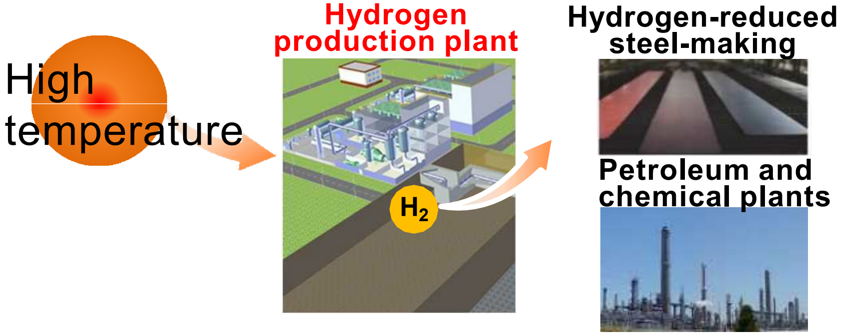
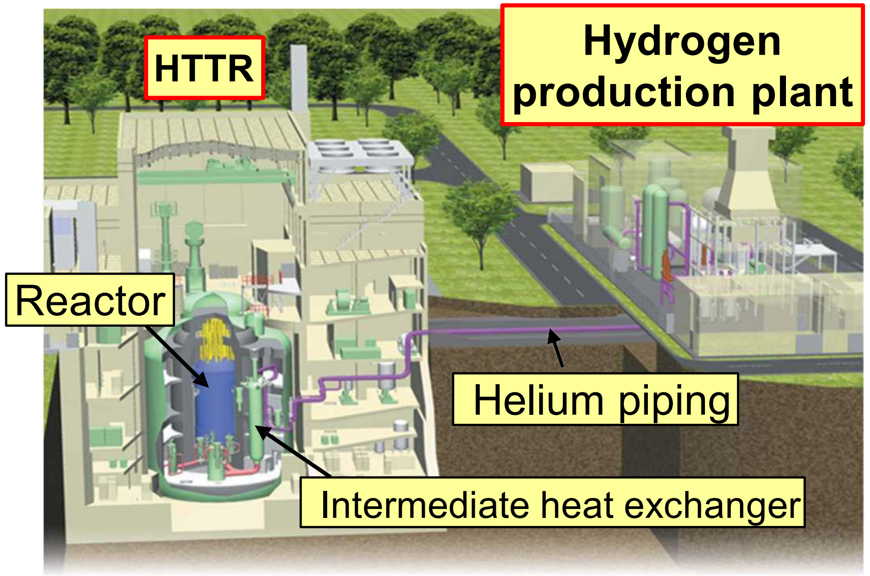


Image of industrial hydrogen application using high temperature heat

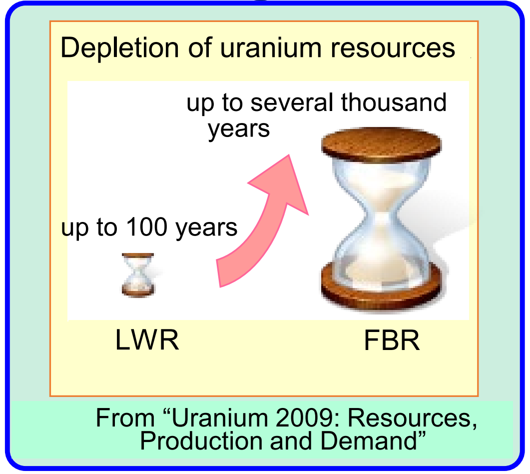


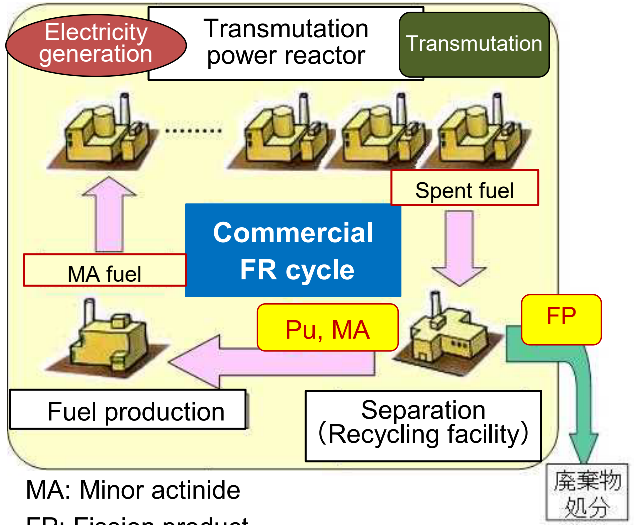
HTTR-hydrogen production system (image)

Significance of FR cycle

- Efficient use of uranium resources
  (Dozens of times larger than that of LWRs)
- Spent fuel recycling (no need for uranium import) and technological self-sufficiency (domestic production) ensure stable energy supply.
  ⇒ Effective use of finite resources, strengthening energy security
- Zero CO_2 emissions
- Recycling minor actinides (MAs) of spent fuel as nuclear fuel reduces the amount of radioactive waste
  ⇒ Reduction in environmental burden
- Find uses as a base-load as well as a dispatchable power source that complements variable renewables (solar and wind) in combination with thermal storage.
  ⇒ Carbon neutrality and coexistence with variable renewables
- High circulation capability of coolant in combination with air coolers enables long-term stable decay heat removal even under a total blackout. (already demonstrated by the experimental fast reactor Joyo)
  ⇒ Ensured safety
- Capable of producing medical radioactive isotopes using fast neutrons
  ⇒ Improving cancer treatment for public well-being

Achieving innovation according to the green growth strategy

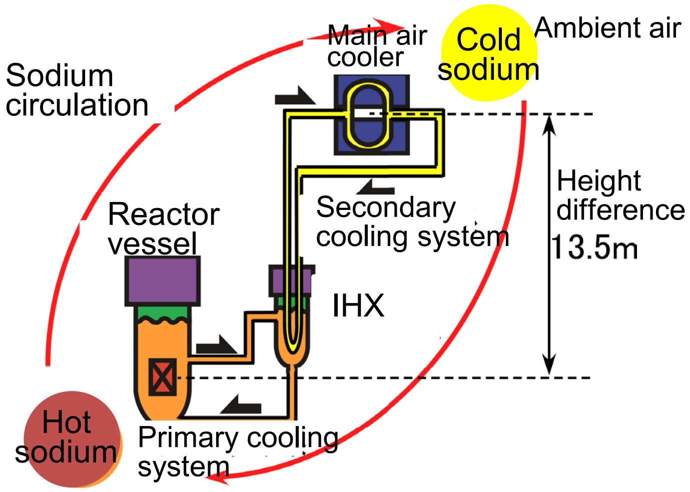




MA: Minor actinide
FP: Fission product

FR transmutation system for electricity generation

Reference https://www.mext.go.jp/content/20211104-mxt_genshi-000018772_3.pdf



Decay heat removal by natural circulation

Large effect in reducing both radioactive waste amount and radiotoxicity

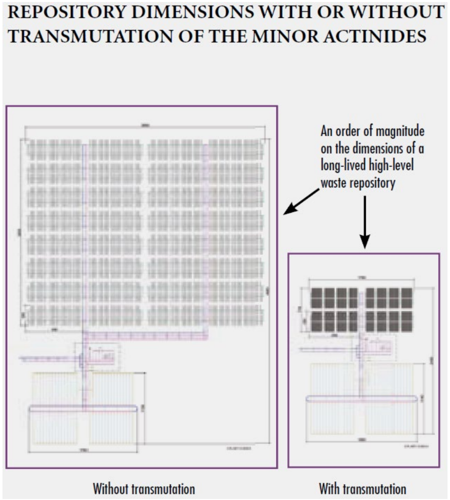
- Recycling minor actinides (MAs) in spent fuel as nuclear fuel reduces the amount of radioactive waste and significantly shortens the decay time of radioactive materials from 100,000 years to 300 years.

⇒ **Reduction in environmental burden**

- Plutonium (Pu) can be produced or burned through Pu management.

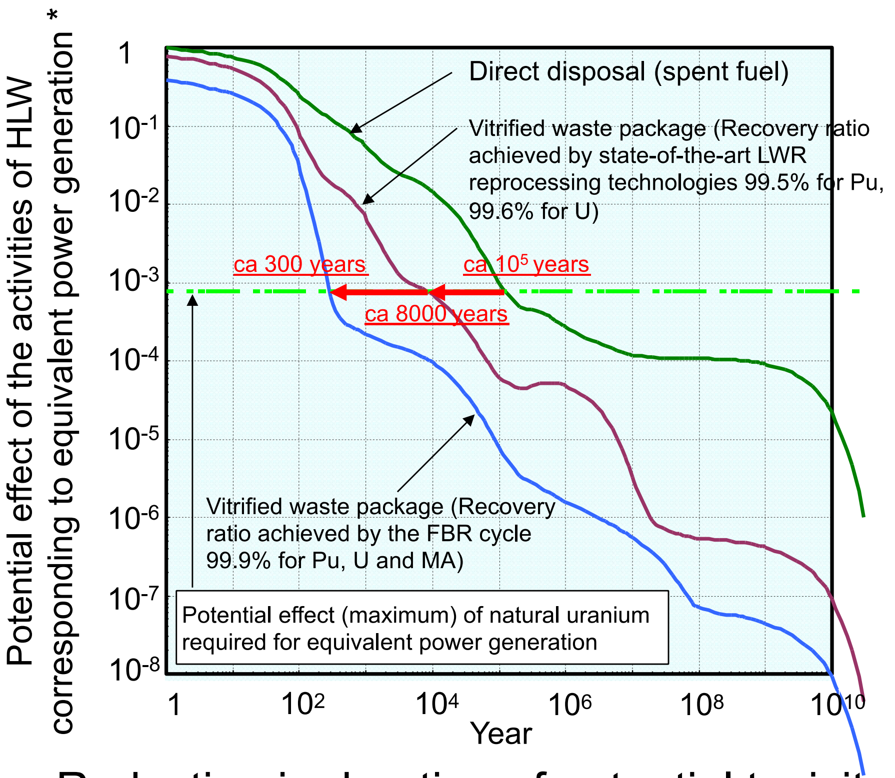
Reduction in the area for high-level radioactive waste requiring geological disposal

Americium	Transmutation	⇒ 1/7
Americium Neptunium Curium	Transmutation	⇒ 1/10



Referring the material "Report on Sustainable radioactive Waste Management " prepared by the CEA (2012)

*) A relative value assuming that the potential effect of spent fuel at the first year is 1.



Reduction in duration of potential toxicity

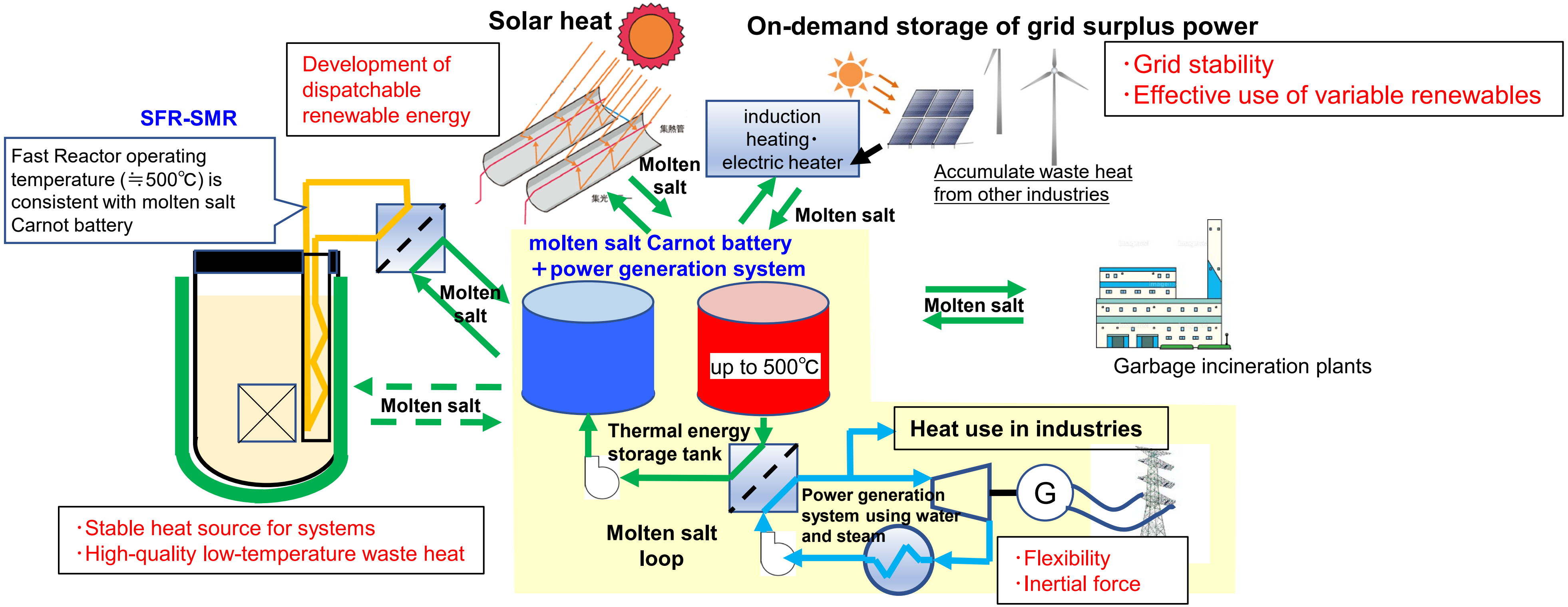
Possibility of various heat uses of FRs

■ For future energy

- Maximum use of renewable energy + stabile energy supply (low cost, stable grids by adapting to power fluctuation)
- Carbon-free energy sources with operational flexibility coexisting with renewable energy
  ⇒ One solution is energy supply that combines SFR-SMR and power generation using thermal energy storage with molten salt (molten salt Carnot battery)

■ Feature

- Enhanced safety against a severe accident achieved by a small core and various cooling methods for SFR-SMR
- SFR-SMR + Carnot battery enables operational flexibility, stable supply, and use of various heat sources, without emitting carbon dioxide



Contribution to non-energy fields by FRs

Referring the meeting material "Agency of Natural Resources and Energy, 23rd Nuclear Energy Subcommittee document #5 (Apr. 14, 2021) "

- The experimental fast reactor Joyo will serve not only for FR development but also medical radioisotope (RI) production. Although the RIs are crucial for advanced medical treatment, Japan is relying on imported RIs.

RI production using Joyo

Mass production: High neutron density allows mass production of RIs at a lower cost than using accelerators.

	Production (μg)	Cost (yen/μg)
Reactor (JRR-3) *per year	3,900	1,000
Accelerator *per irradiation	42	33,000

Comparison of molybdenum (Mo-99) production using nuclear reactors or accelerators

Mo-99
Used in nuclear medicine imaging to detect cancer metastasis

Rare RIs: Fast neutrons can be used to produce rare RIs such as Actinium (Ac-225)

With moderators, FRs can produce RIs that are similar to those obtained from an LWR.

Ac-225
Used in alpha internal therapy for cancer treatment

High expectations for domestic production of medical RIs by using JAEA's test and research reactors

- Submissions of requests for domestic RI production
  - from seven medical societies to MEXT* (Aug. 2020), and to ministers of relevant ministries and the chairman of Nuclear Regulation Authority (Jul. 2021)
  - from cancer patient associations and related organizations to MEXT (Aug. 2020).
  - from Japan Federation of Cancer Patient Groups to ministers of relevant ministries and the New Komeito (May 2021).
- Discussion on increasing medical RI production (the Committee on Audit of the House of Councilors, May 2021)
- Description on medical RI production using Joyo (the Green Growth Strategy, Jun. 2021)
- Establishment of the expert committee on RI production and use (the Atomic Energy Commission, Nov. 2021)
- Discussion on domestic production of medical RI (the Committee on Budget of the House of Councilors, Mar. 2022)
- An action plan (the expert committee of the Atomic Energy Commission, May 2022

Summary

■ Versatility of next-generation reactors can meet the public's demands

- HTGRs can generate high temperature heat for carbon-free hydrogen production, meeting various public needs such as reduction of greenhouse gas emissions in the industry and transportation sectors.

- The FR cycle system can reduce the waste amount, radiotoxicity, and decay time of radioactive materials through MA recycling. Also, it can produce or burn plutonium, depending on future energy situations.
  → Contribution to both stable energy supply and global sustainable development.

- To achieve sustainable carbon-free electricity, Japan needs dispatchable power sources that can support variable renewables and offer decarbonized energy. HTGRs and FR systems combined with heat storage technology can play this role, using their load-following capabilities.

- FRs will also contribute to non-power generation fields like medical RI production, which serves the public's health.