Recent Trends Surrounding Fusion Energy Power Generation

The path to commercialization of fusion energy power generation

Innovative Technology Series*

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Research & Consulting Unit
Mizuho Financial Group

* Series of reports highlighting areas of technology and innovation that can contribute to strengthening the competitiveness of Japanese industry and to solving social issues.

Contents

Summary

- Fusion energy research has been undertaken by public institutions in particular for some time, but in recent years, there has been a certain degree of success in areas, including the generation and maintenance of high temperature plasma required for fusion energy and reduced costs through technological progress. This is one reason for the increase in development by the private sector and the funding from the private sector
- As a result of certain research outcomes, research and development in areas not just for fusion energy but also in fuel extraction, breeding, and efficient heat recovery needed for fusion energy power generation is now in a state that can be finally be incorporated for further steps. However, there are numerous technical challenges for all methods, and while the commercialization of power generation in the 2030s will be challenging, technical innovation could make this feasible
- Looking at overseas developments, the US Government and the UK Government have announced strategies for construction and operation of fusion reactors in 2035 and 2040 respectively. In addition, fusion start-ups in the US and Europe that have raised enormous funds in the order of 100s of billions of yen have issued targets for commercialization that are earlier than the government targets. At the current point, demonstration reactors are being constructed, and depending on their success, power generation commercialization could be closer
- Behind the statements from major start-ups about commercialization of power generation in the 2030s, is the indication of more ambitious goals for the timing of commercialization than before, with the intent to attract investment from investors and companies that place importance on social demands, including 2050 Carbon Neutrality and energy security
- The Japanese Government's focus is on responding based on the progress of the ITER project, an international project. The aim is to commence construction of a prototype reactor immediately following the 2035 combustion experiment, and to demonstrate power generation from the prototype reactor in 2045. In addition, Japan as formulated its "Fusion Energy Innovation Strategy" as an independent initiative and has also started supporting fusion start-ups based on that strategy.
- Given the uncertainty about which fusion energy power generation method will be successfully commercialized, it is important to promote not only fusion reactors but the fusion industry, including periphery areas that are Japan's strength. In addition, looking ahead to the commercialization of power generation, Japan's industrial sector needs to strengthen its involvement through means, including investment and alliances with start-ups engaged in fusion reactors, which will also accelerate research and development in fusion reactors

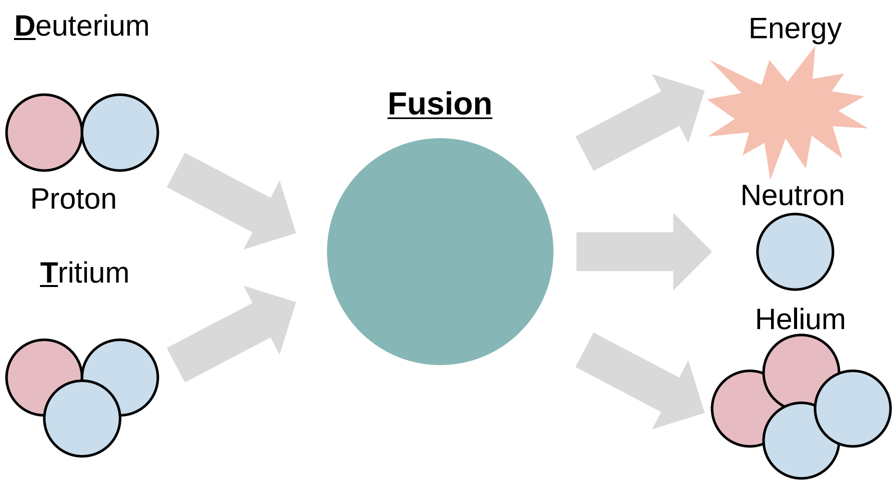
Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd.

1. Outline of fusion energy power generation

Energy generation processes differ between fusion energy power generation and commercialized nuclear power

- Fusion energy power generation refers to the fusing of light nuclei such as Deuterium and Tritium and changing them into a heavy nucleus in a power generation method that uses the difference between the total mass before and after fusion to generate enormous energy
  - The D-T reaction[Note] is said to have the highest feasibility of achieving fusion, known as the sun on earth, since low temperatures and pressure are needed for a reaction, the probability of reaction is high, and the energy generated is large
- On the other hand, nuclear fission used in nuclear power involves neutrons hitting Uranium 235, using the energy that is generated when the heavy nucleus is split into light nuclei, which differs from the process of fusion energy power generation

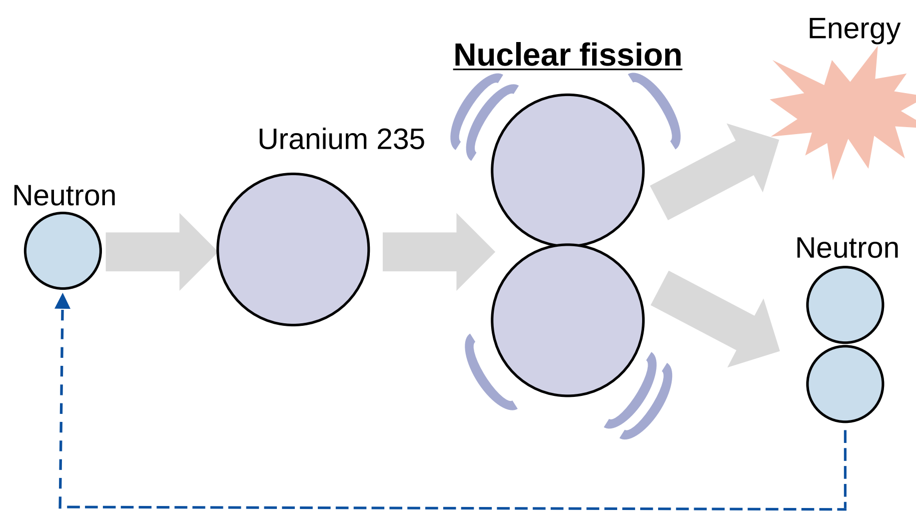
Fusion energy power generation framework (D-T reaction)



Note: Fusion reaction from Deuterium and Tritium. There are also fusion reactions that use other fuels

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Nuclear fission framework in nuclear power

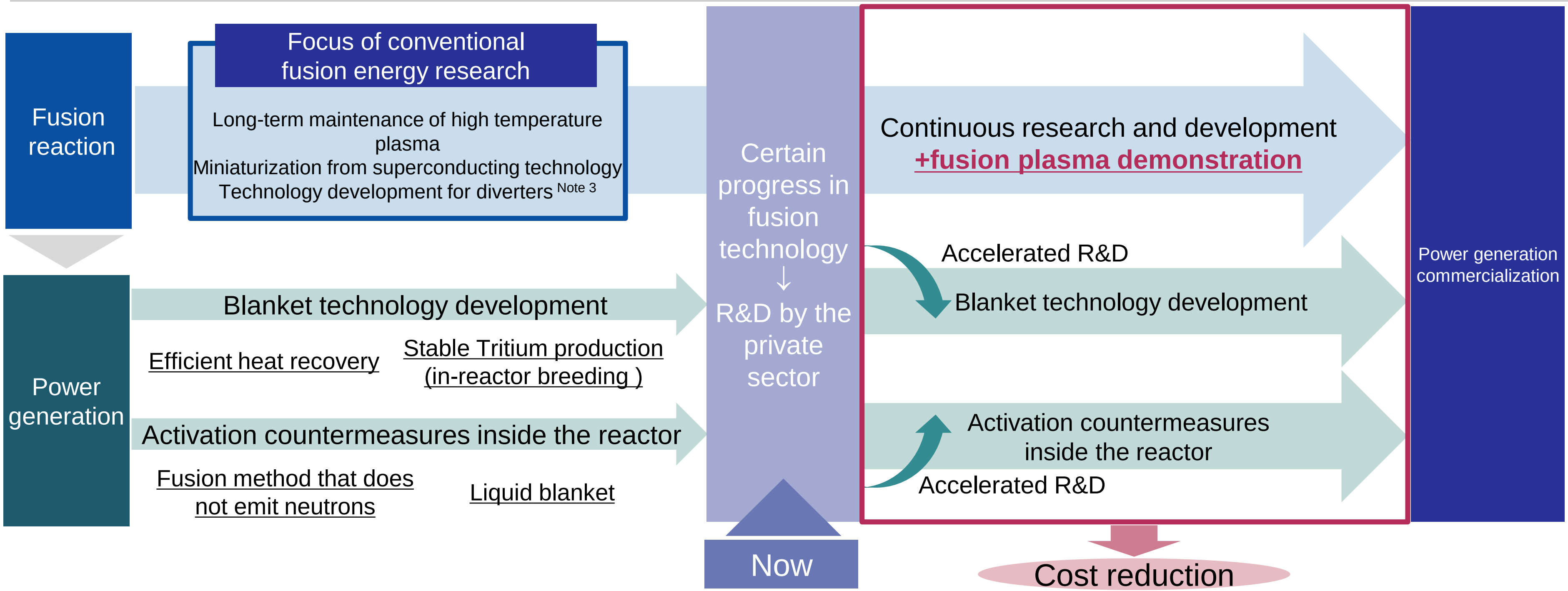


Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

The research stage for the commercialization of fusion energy power generation through certain technological progress

- The long-term maintenance of high temperature plasma [Note 1] had been the biggest challenge for fusion energy research. However, in addition to the certain technological progress made through many years of research and development, the progress in areas, including miniaturization, have resulted in achieving levels in which the private-sector can invest
- The improvement in readiness levels of fusion technology has enable initiatives to be carried out in research and development for the commercialization of power generation, including heat recovery technologies not only for demonstration of fusion plasma but also heat technologies, including blankets[Note 2], fuel procurement, including stable Tritium production inside the reactor, and activation countermeasures inside the reactor

Image of major technological progress towards the commercialization of fusion energy power generation



Note 1: High temperature high density state of ionized electrons and ions that make up matter
Note 2: Converter that generates thermal energy. Requires features that stops neutrons, cools the emitted heat, and creates fuel
Note 3: High heat removal equipment responsible for improving particle exhaust, heat removal, and plasma confinement performance
Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd.

Reference: Major fusion energy power generation methods

Major method	Magnetic confinement				Inertial confinement (Laser method)	Compound methods (Magnetic ＋Inertial confinement)
	Tokamak method	Helical method	Magnetic field-reversed configuration type (FRC)	Sheared flow stabilization Z-pinch		
Category	■ Conventional	■ Conventional	■ Innovation confinement method	■ Innovation confinement method	■ Conventional	■ Innovation confinement method
Feature	■ High plasma confinement performance ■ Cost of reactor design and manufacture can be suppressed due to simplicity of coil shape	■ Easy to maintain magnetic field with steady operation forecast ■ No need for plasma current as magnetic field generated from coil	■ Plasma confinement is possible with a weaker magnetic field than required for the Tokamak method (contributes to miniaturization) ■ Very safe with no emission of neutrons in fusion ■ Ability to generate power without using a steam turbine	■ Does not use super conducting magnets and miniaturization is possible ■ The magnetic field that creates the current that flows in the plasma compressed the plasma itself, creating a high temperature high density state	■ The power generation volume can be adjusted with the reaction frequency, and can respond to load fluctuation ■ Laser and reactor are independent, and activation can be suppressed	■ Magnetized plasma is compressed with compressed air piston not a laser, so cost can be reduced ■ Fuel density is lower than for inertial confinement, and can be ignited at low density
Issue	■ Plasma stability is an issue ■ Requires plasma current to generate a magnetic field ■ Large equipment is required to create a magnetic field	■ Coil shape is complicated compared to the Tokamak method	■ Plasma temperature needs to be at least 1B℃ ■ Power is generated through electromagnetic induction by passing plasma through the coil, and power generation efficiency is uncertain	■ A higher current is required for net energy to be positive	■ Improving the reaction rate of fusion ■ Continuous laser irradiation and laser control technology ■ Large equipment is required for irradiation with laser light	■ Improving plasma confinement performance ■ Controlling compression timing ■ Piston equipment durability
Major firms	■ Commonwealth Fusion Systems (US) ■ Tokamak Energy (UK)	■ Helical Fusion (Japan)	■ TAE Technologies (US) ■ Helion Energy (US)	■ Zap Energy (US)	■ EX-Fusion (Japan)	■ General Fusion (Canada)

Note: Major methods are the categories reflected in the Fusion Industry Association, The global fusion industry in 2023. The Ministry of Education, Culture, Sports, Science and Technology refers to Tokamak method, Helical method, Laser method as typical confinement methods and others as innovation confinement methods. This report refers to the typical confinement method as conventional

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Fusion energy power generation is hoped to provide decarbonization and stable power supply

Challenges facing the world following the situation in Ukraine

Securing energy security while transferring from fossil fuels to clean energy, including breaking away from Russian fuels

Main features of fusion energy power generation	
(1) Carbon neutrality	■ The products from the fusion process are Helium, and Carbon Dioxide and other greenhouse gases are not generated during the fusion reaction
(2) Abundant fuel	■ The fuel used in D-T reaction (Deuterium and Lithium), said to have a high possibility of realization, exists in seawater and, once extraction technology is established, can be generated nearly inexhaustibly, and a huge amount of energy can be produced by a small amount of fuel
(3) Inherently safe	■ If the heating and fuel supply to maintain plasma stop, there is no fusion reaction, and no need to suppress the reaction, so it is possible to stop safely even if there is a loss of power supply
(4) Environmental preservation	■ Only a low level of radioactive waste is generated, which can be processed with existing technology
(5) Base load power supply	■ Fusion energy power generation does not depend on external environmental factors as do wind power generation and solar power generation for the volume of power generation, and can be operated continuously as needed

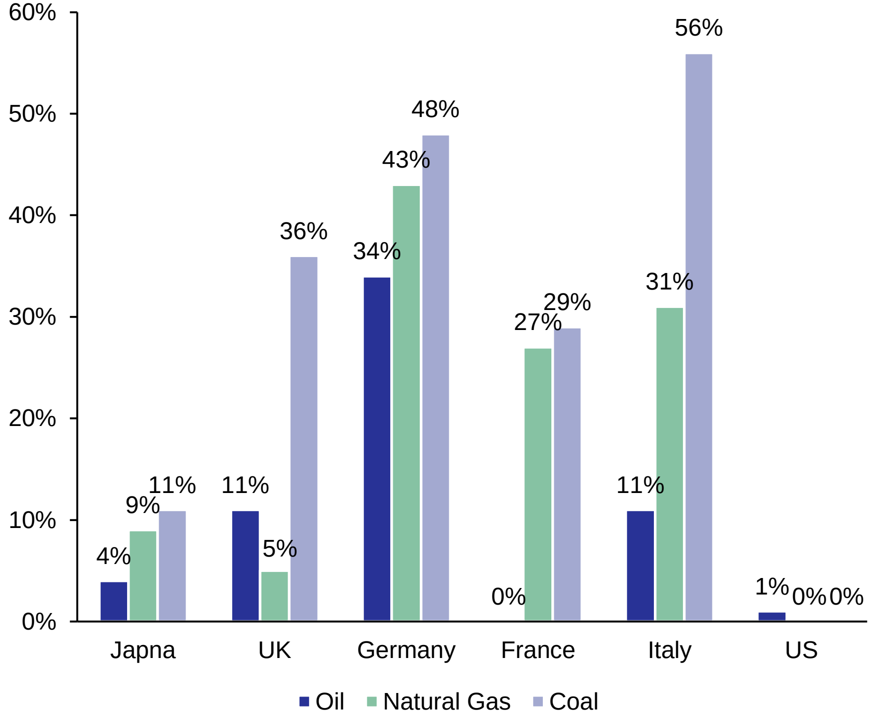
Since seawater, the source of the fuel, covers two-thirds of the surface of the Earth, numerous countries can produce the fuel as long as they have the technology, so there are growing hopes that it will resolve the problem of unequal distribution of energy resources as an energy that contributes to the stable supply of energy

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. Based on Japanese Government and UK Government materials

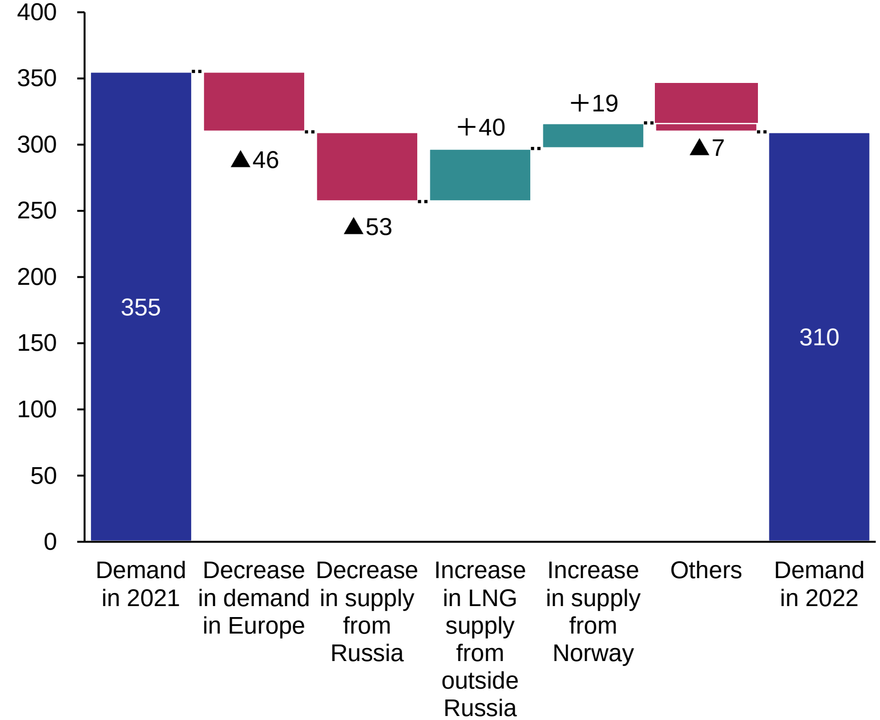
Partial dependency by Japan and Europe on fossil fuel imports from Russia

- It is not just in Japan; Europe's fuel procurement structure also relies on procurement of fossil fuels from Russia
- Due to the situation in Ukraine, Europe is moving to break away from Russian fossil fuels, through measures, including increasing supply within Europe and procuring US LNG
- If fusion energy power generation is commercialized, Japan and Europe could ensure energy security without depending on the procurement of fuel from Russia

Major countries' dependency ratio on Russia for fossil fuels (2020, Japan shows preliminary figures for 2021)



Change in Europe's demand and supply structure for natural gas(2021-2022)

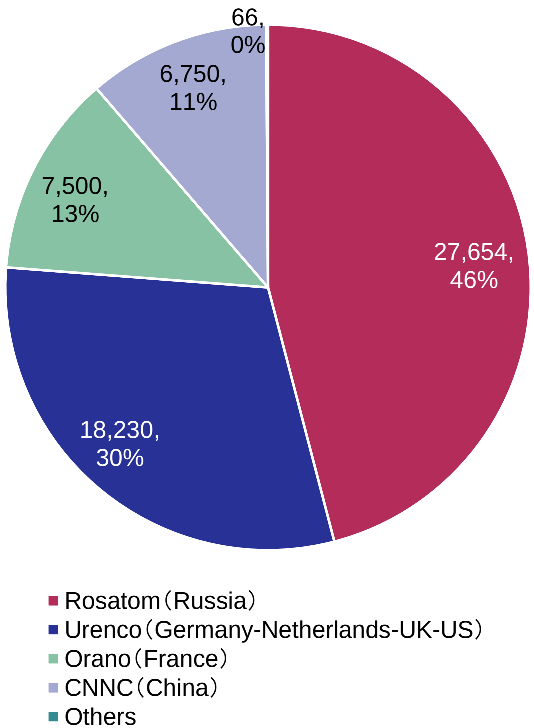


Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on materials from the Agency for Natural Resources and Energy

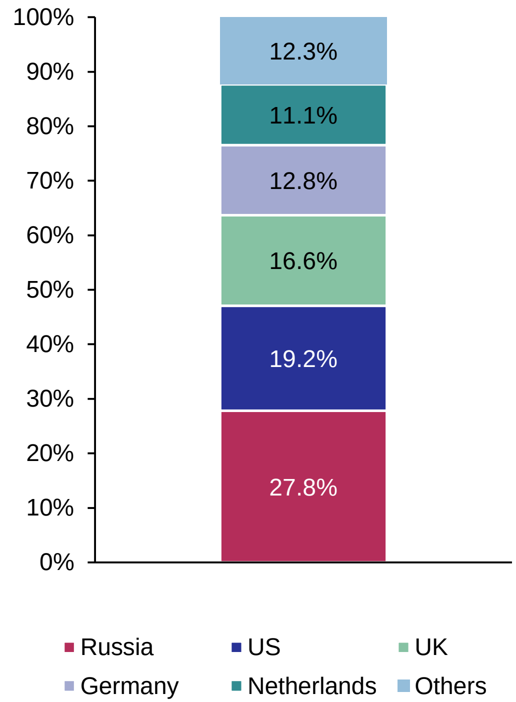
Commercialization of fusion energy power generation has a direct connection not only to breaking away from fossil fuels but from Russian-sourced nuclear fuel

- Russia accounts for 46% of the global manufacturing capacity for enriched uranium needed for nuclear power. The EU procures more than 30% of its enriched uranium from Russia and even the US, which does not rely on Russia for fossil fuels, procures 28% of its enriched uranium from Russia
- The realization of fusion energy power generation without the need for enriched uranium and without the possibility of fuel depletion if there is seawater would greatly contribute to strengthening energy security in the US and countries in Europe
  - Even innovative reactors, including SMR (Small Module Reactor) require enriched uranium technology, and it is difficult to break away from Russian fuels under the current circumstances

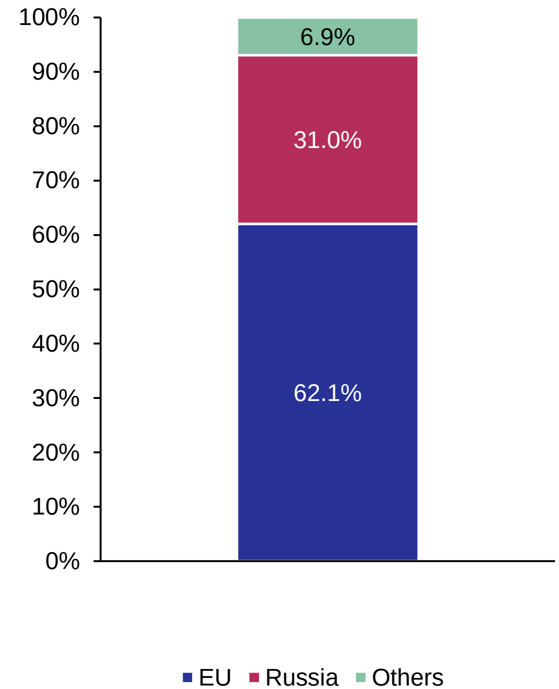
Share of global uranium enrichment manufacturing capacity by company (2020, thousand SWU/year)



Countries sourcing US enriched uranium (2021)



Countries sourcing EU enriched uranium (2021)

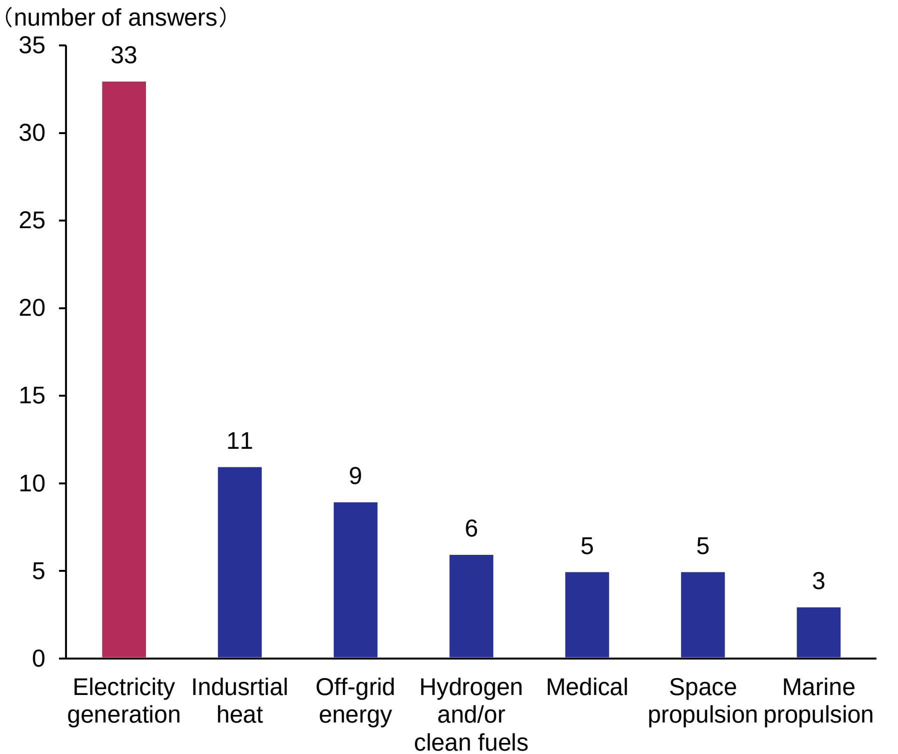


Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. Based on U.S. Energy Information Administration (EIA) materials and Euratom Supply Agency materials

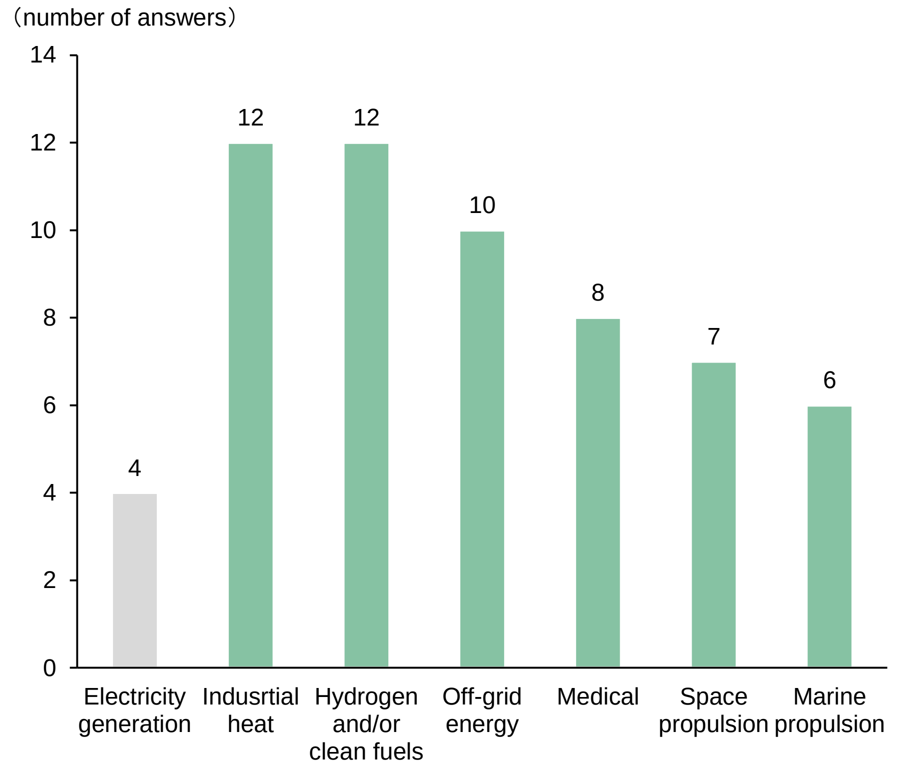
Fusion technology is not only for power generation, but can be utilized in other industries

- The major markets for fusion technology are dominated by power generation, followed by hopes for areas, including industrial heat demand, off-grid energy, and the manufacture of clean fuels, including Hydrogen
- As potential markets, in addition to industrial heat demand and the manufacture of clean fuels, there is the possibility of utilization in non-power generation sectors of space, ocean, and medical

Major markets for fusion technology anticipated by fusion start-ups



Potential spin-off markets for fusion technology anticipated by fusion start-ups

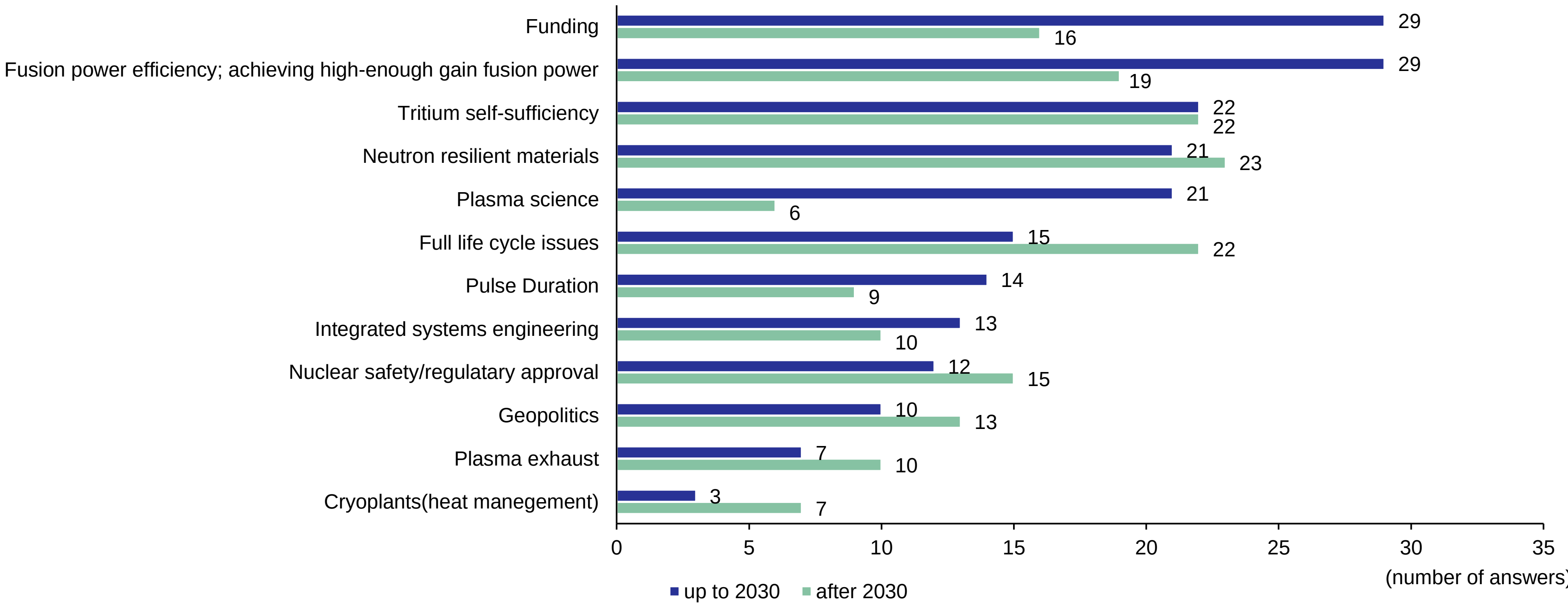


Note: Multiple responses allowed
Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Fusion Industry Association, *The global fusion industry in 2023*

Challenges for fusion energy power generation vary from funding to the types of technology development

- In addition to funding, major challenges for fusion energy up to 2030 raised by fusion start-ups are fundamentals of fusion technology, including improving the efficiency of fusion energy and Tritium self-sufficiency
- Even after 2030, start-ups anticipate ongoing need for initiatives involving technology development and life-cycle issues, and also anticipate problem solving requirements on the software side, including regulations

Challenges for the commercialization of fusion energy power generation raised by major start-ups



Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Fusion Industry Association, *The global fusion industry in 2023*

2. Major countries' initiatives for fusion energy power generation

Japan not only has a financial burden for ITER, but is also contributing through product supply

- International Thermonuclear Experimental Reactor (ITER) is a fusion demonstration reactor using the Tokamak method being developed by Europe, Japan, the US, Russia, China, South Korea, and India
  - The plan is to commence operations in 2025, with demonstration of fusion reaction in 2035. It is currently under construction, but there have been delays
  - Japan's financial burden is 9.1% of the total in the construction phase and 13% of the total in the operational phase

Outline of ITER

Technical goals	■ Generation of a burning plasma that produces at least 10 times as much fusion output as the external input in 300 to 500 seconds ■ Demonstration of super conducting coils and heating devices, and equipment testing, including blankets
Outline of facilities	■ Construction location: France ■ Output: 500,000kW (No power generated for ITER)
Schedule	■ 2025: Operations commence ■ 2035: Fusion operations (First Plasma)

Financial burden of ITER members

Europe	Japan	US	Russia	China	South Korea	India
Construction period						
45.5%	9.1%	9.1%	9.1%	9.1%	9.1%	9.1%
Operating period						
34.0%	13.0%	13.0%	10.0%	10.0%	10.0%	10.0%

Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

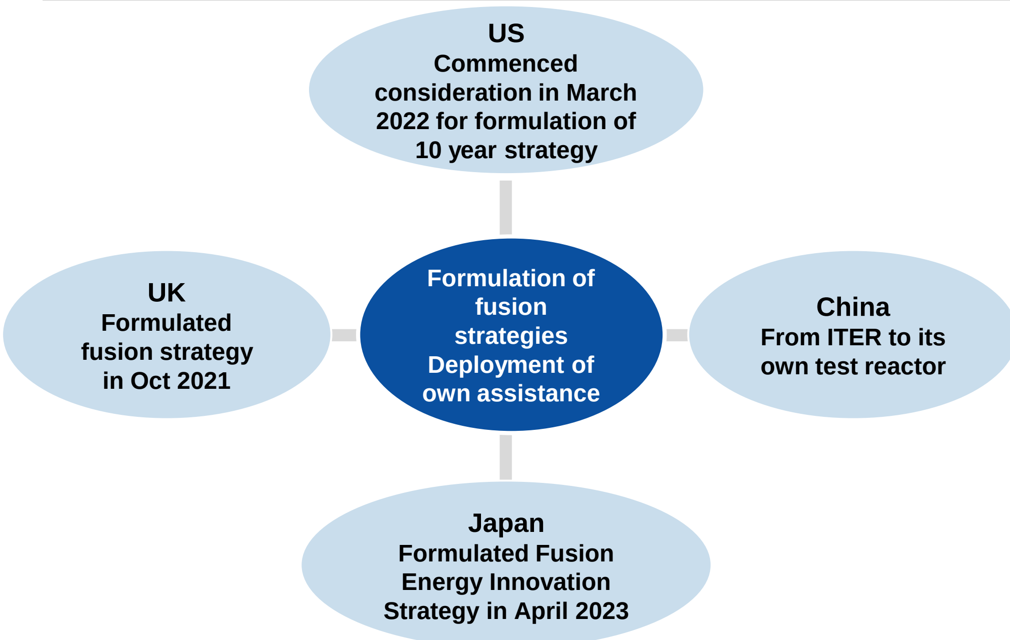
Japanese companies involved in ITER

Major companies	Major production equipment, etc.
Canon Electron Tubes & Devices	Gyrotron
Metal Technology Co.	Diverter cassette Providing metal bonding technology
The Furukawa Electric Co.	Central solenoid components
Japan Superconductor Technology	Toroidal field coil High performance Nb3Sn used in central solenoid Magnet for gyrotron
Daido Steel	Special stainless steel
Toshiba Energy Systems & Solutions	Toroidal field coil Blanket remote maintenance device Neutron measurement system
Toyama	Matching optics unit for gyrotron
Nippon Steel Engineering	Toroidal field coil conductor Central solenoid conductor
Hitachi	Outer vertical target for diverter
Mitsubishi Heavy Industries	Toroidal field coil Outer vertical target for diverter
Mitsubishi Electric	Toroidal field coil winding wire

Fusion development shifts from international cooperation to international competition

- Major countries are formulating their own strategies and roadmaps towards the commercialization of fusion energy power generation, while monitoring the progress in the plans for the international project known as ITER. Fusion development, including support for national government funded development is not only for international cooperation under the ITER Projects; there are aspects of international competition with each country undertaking its own initiatives
  - In addition to government assistance, private-sector investment has also surged, with initiatives of major fusion start-ups in areas, including research and development targeting commercialization earlier than the government targets
- Japan formulated the “Fusion Energy Innovation Strategy” in April 2023, and we expect additional government assistance in preparation for commercialization

Trends of major countries in the commercialization of fusion



Aiming for commercialization earlier than the government target

Country	Target for commencing operations at government pilot plant		Commercialization target for start-ups
US	2035-2040	⇒	2028 (Helion Energy) Early 2030s (Commonwealth Fusion Systems, TAE Technologies)
UK	2040	⇒	2030s (Tokamak Energy)
Japan	2045	⇒	2034 (Helical Fusion) 2035 (EX-Fusion)
China	2030s	–	– (Target year unknown)

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

[Japan] Own support also deployed towards the commercialization of fusion energy power generation

- The Cabinet Office formulated the "Fusion Energy Innovation Strategy" in April 2023, putting forward a vision for the commercialization of fusion energy in a national strategy that incorporates specific action likely to pump-prime private-sector investment
- The Ministry of Education, Culture, Sports, Science and Technology has deployed support based in ITER progress. When considering the action plan towards the construction of the DEMO reactor announced in October 2022, it noted the possibility of commencing construction of the DEMO reactor immediately following the demonstration of the ITER fusion reactor, and bringing the demonstration of the DEMO reactor power generation forward by about 5 years to 2045
- In addition, there is support not only for ITER. The FY2022 supplementary budget provided support of up to JPY 6.5B to fusion start-ups for demonstration of fusion technologies in preparation for fusion prototype reactors

Outline of Fusion Energy Strategy from the Cabinet Office

Developing the fusion industry	Strategies for developing technologies
■ Clarify targets through creation of technology and market opportunity maps ■ Matching at the Fusion Industry Council of Japan intended to be established in FY2030 ■ **Strengthen support to close the gap between the technological seeds possessed by private companies and the industrial needs**	■ **Strengthening technology support measures such as potentially game-changing miniaturization and high-performance technologies** ■ Acquire key technologies through ITER Project/BA Activity[Note] ■ Accelerating R&D in anticipation of the development of the DEMO reactor ■ Advancing the Action Plan for the DEMO reactor development

Framework for promoting Fusion Energy innovation Strategy

- **Frameworks for the implementation of R&D by bringing together**, centering on the QST, **academia and private companies** for the development of the prototype reactor
→Establish hubs for fusion technology innovation
- Strengthening the fostering of human resources in Japanese universities and acquiring excellent human resources from other fields and other countries
→Provision of fusion energy educational programs

Note: BA = Broader Approach
Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Outline of support for fusion from the Ministry of Education, Culture, Sports, Science and Technology

ITER-related budget

ITER Project	➢ Activities of ITER Organization (share of expenses) ➢ Production testing for ITER equipment at the National Institutes for Quantum Science and Technology (QST) and secondment of personnel, etc.
BA Activity, etc.	➢ Operation and development of advanced super conducting Tokamak device ➢ Development of continuous operations for Japan Atomic Energy Agency accelerator ➢ Prototype reactor design activities and computer simulation activities

Promote the approach for development of prototype reactor from Conventional ITER Project/BA Activity

Consider action plan for construction of prototype reactor

- ✓ Promote technology development, and commence construction of prototype reactor immediately following the ITER burning experiment in 2035
- ✓ Conclude **the technical viability of power generation demonstration from a prototype reactor in 2045**

➕

Support for fusion start-ups (FY2022 Supplementary Budget)	■ MiRESSO: Up to JPY 2.0B ■ Helical Fusion: Up to JPY 2.0Bt ■ LiSTie: Up to JPY 1.5B ■ Kyoto Fusioneering: Up to JPY 1.0B

[Japan] Support for challenging fusion research considered while keeping the Moonshot R&D Development Program in mind

- The Ministry of Education, Culture, Sports, Science and Technology has convened the *Working Group on Supporting Challenging Fusion Research* since June 2023, and commenced considering the necessary fusion research themes through backcasting, setting new targets for fusion energy

Working Group on Supporting Challenging Fusion Research – Final Report (October 19, 2023)

Draft 2050 Moonshot Goal

Achieve a vibrant society unleased from resource constraints that is in harmony with the global environment through multifaceted utilizing of fusion energy by 20250

	2035	2050
Milestones	■ Proof of principle for innovative fusion energy systems (systems that integrate confinement method and core technologies based on innovative ideas) for early realization of fusion energy ■ Demonstration of purpose for diverse commercialization of fusion energy (proof of principle for technologies looking ahead to new deployment of portable devices, and advanced space and ocean devices, etc.) ■ Build an industrial base at the same time as multisided applications for fundamental innovation technology that can take on the challenge	■ Realize innovative fusion energy systems that enable innovative commercialization, including small power sources
Research and development to attain milestones	■ Strategically build the portfolio towards attaining the goal and advance systematically, challenging in various areas of research and development	■ Development of core technologies that implement innovative fusion energy systems ■ Investment in research and development that secures resources to enable mass production of fusion reactors and reduces costs
Examples of ripple effects	■ Medical technologies and environmental technologies that use particles generated with fusion reactions, etc. ■ Applications for aircraft propulsion superconducting motors and generators that use high temperature superconducting technology, etc. ■ Applications for materials in high heat removal equipment (diverter) and the structural space and ocean sectors ■ Applications for aircraft production in manufacture technology, etc.	■ Application for heat sources other than fusion reactors in plant technology
Attainment goals	■ Demonstrate the use of diverse energy sources, not exclusively electrical energy ■ In addition to the use as an energy source, demonstrate the application of fusion energy from multisided use, including particles generated from fusion reaction and core technologies	■ Attain social systems that implement fusion energy in various opportunities

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Reference: [Japan] Process chart for the nuclear industry in Japan's Green Growth Strategy

●Introduction phase: 1. Development phase → 2. Demonstration phase → 3. Expansion of introduction/cost reduction phase → 4. Freestanding commercial phase

	2021 – 2025	-2030	-2040	-2050
Fast reactor	❑ Development based on the strategic roadmap Step 1 • Foster competition between diverse technologies utilizing innovation in the private-sector Step 2 (from 2024) • Narrow down technologies gained from collaboration with the government, JAEA (Japan Atomic Energy Agency), users and manufacturers	Step 2 (continued)	Step 3 ・Embody the process	For example, expect the start of operations for a realistic scale fast reactor at the appropriate time around the mid 21st century
	• Efficient development utilizing international cooperation • Japan-France cooperation (improve safety and economics), Japan-US cooperation (multipurpose test reactors ,etc) (2021 to 2040)			
Smal reactor (SMR)	Commercialization by about 2030 in places, including the US and Canada →Japanese companies participate in overseas demonstration projects	Japan companies gain position as major suppliers	Reduce costs through expansion of sales channels and mass production framework	Global deployment to regions, including Asia, Eastern Europe and Africa
High temperature gas-cooled reactor **Hydrogen cost: Possibility of 12 yen//Nm³ in 2050**	Reactivation of HTTR (High temperature engineering test reactor) (2021) Test to confirm "specific safety" of using HTTR (2022–2023) Technology development needed for carbon free hydrogen manufacture (from 2024)	Technology development needed for carbon free hydrogen manufacture (continued)	Demonstration of connecting carbon free hydrogen manufacturing facilities to high temperature gas-cooled reactor	Reduce costs through expansion of sales channels and mass production framework
	Promote international cooperation utilizing HTTR able to deliver output at the world's hottest temperature of 950℃ (2021 to 2030)			
	Establish carbon free hydrogen manufacture technology that utilizes high temperature heat (IS (Iodine sulfur) method, methane heat solution, etc.) (2021 to 2030)		Testing needed for commercialization scale	
Fusion Reactor	Construction of fusion demonstration reactor (ITER) and production of various equipment under international cooperation	ITER operations commence • Plasma control test for fusion reaction		ITER fusion operations commence • Burning control engineering test through Deuterium-Tritium combustion • Demonstration of fusion engineering technology
	• ITER complementary experiment utilizing JT-60SA • Prototype reactor concept design and element technology development	Engineering design and development of actual scale technology for prototype reactor (2025 to 2040)		Testing needed for commercialization scale
	Promote human resource development, academic research (2021 to 2050)			
	Commercialization goal of about 2030 for venture companies in the US and UK, etc.			
	Japanese venture companies, etc. participate in research and development and as suppliers, delivering equipment for overseas projects equipment			

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Ministry of Economy, Trade and Industry materials

Reference: [Japan] Future path for next-generation innovative reactors in the basic policy to achieve GX

- Involvement in the development and construction of next generation innovative reactors that incorporate new safety mechanisms, with ensuring safety a major premise

Future path for next-generation innovative reactors in the basic policy to achieve GX

Goals/ strategies

Acceleration of development in line with technological maturity *Formulated as the "target period with the advancement of research and development" in light of individual interviews with businesses, etc. (The timing for commencement of operations if there is actual construction, etc., assumes an understanding of the site location, which is determined based on the plans formulated by businesses)

Reactor	2023	2024	2025	2026	2027	2028	2029	2030	2030s	2040s
Innovative light-water reactor *commercial	Basic design		Detailed design						Production/ construction; Operations	
Small light-water reactor *demonstration	Concept design				Basic design			Detailed design	Production/ construction	Operations
Fast reactor *demonstration	Concept design						Basic design		Detailed design; Production/ construction	Operations
High temperature gas-cooled reactor *demonstration	Basic design					Detailed design	Production/construction		operations	
Fusion reactor *prototype	Concept design		Detailed design					production・construction		

GX investment

Improve the business environment for next generation innovative reactors and concentrated research and development investment

- Improve the business environment for the development and construction of innovative light water reactors and improve the research and development base for the development and construction of next generation innovative reactors
- Research, development, and design of demonstration reactors for high temperature gas-cooled reactors and fast reactors
- Development, construction, and operations of demonstration reactors for high temperature gas-cooled reactors and fast reactors, etc. ➡Invest about JPY 1T in next 10 years

Regulations/ systems

Promote the introduction through energy-use related regulations

- Introduce long-term decarbonization power supply auctions
- Promote the introduction through improvements to the business environment, including steady operations of long-term carbonization power supply auctions
- Promote the introduction through the advanced method of the "Obligation to achieve a ratio of non-fossil fuel power supply"

International strategies

Promote development through international tie-ups and acquire overseas markets

- Participate in overseas demonstration reactor project through collaborations, including Japan-UK high temperature gas-cooled reactor cooperation, Japan-US fast reactor cooperation, and Japan-France fast reactor cooperation
- Expand overseas through highly competitive suppliers and expand base of suppliers capable of overseas expansion
- Acquire overseas market

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on GX Implementation Council materials

[Japan] Japanese start-ups also involved in various fusion methods

- There has been increase in the establishment of Japanese start-ups since 2019 involved in the innovation confinement methods such as FRC in addition to conventional methods of the Tokamak method, Laser method, and Helical method, as well as the development of core technologies

Initiatives of Japanese fusion start-ups

Company	Fusion power generation method	Target year for commercialization	Funds raised	Major initiatives	Major investors
Kyoto Fusioneering (Founded 2019)	—	N/A	JPY 12.2B	■ Fusion plant engineering — Development and design of gyrotron, blanket, and diverter — Fusion reactor design support	JIC Venture Growth Investments, INPEX, SMBC Venture Capital, MOL PLUS, K4 Ventures (Kansai Electric Power Group), Coral Capital, Sumitomo Mitsui Trust Investment, JAFCO Group, DBJ Capital, J-Power, JGC, Global Brain, Mitsui & Co, Mitsubishi Corp, Mitsubishi UFJ Capital, MUFG Bank
EX-Fusion (Founded 2021)	Laser method	2035	JPY 1.9B	■ Building laser fusion control systems ■ Technology development for continuous ignition to continuously generate energy	ANRI, Nissay Capital, Delight Ventures, MITSUI SUMITOMO INSURANCE Venture Capital, Nikon-SBI Innovation Fund, Osaka Shoko Shinkin Bank, Mitsubishi UFJ Capital, SMBC Venture Capital, Shizuoka Capital, Kyoshin Social Capital, Germination Fund No. 1
Helical Fusion (Founded 2021)	Helical method	2034	JPY 800M+	■ Design fusion reactors ■ Development of core technologies, etc. — Development of liquid metal blankets — Development of high temperature super conducting magnets — Development of non-magnetic low activation materials	SBI Investment, KDDI, Nikon, Sony Innovation Fund, Nissay Capital, Mitsui Mining & Smelting, AIZAWA Investments, SMBC Venture Capital, Mitsubishi UFJ Capital
Blue Laser Fusion (Founded 2022)	Laser method	2030	USD 25M	■ Laser fusion method from light hydrogen and boron, which do not generate neutrons	WASEDA University Ventures, SPARX, JAFCO, Itochu Corp, SoftBank
LINEA Innovations (Founded 2024)	FRCxtandem mirror	N/A	JPY 70M	■ Using fuels that do not generate neutrons, including light hydrogen and boron to generate a fusion reaction with FRC and using tandem mirrors for beam ion confinement	ANRI

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on materials published by each company

[Japan] Japan companies are strengthening their involvement, including through investment, in US and European start-ups

- Japanese companies are not only expanding their involvement in Japanese fusion start-ups but in leading overseas business through measures, including investment in US and European start-ups and business alliances
  - Sumitomo Corporation invested in the US fusion start-up TAE Technologies in June 2022. In July 2023, it announced a collaboration with the UK fusion start-up Tokamak Energy for the commercialization of fusion energy
  - Furukawa Electric invested in Tokamak Energy in January 2024

Background to investment in US and European fusion start-ups

	Reason for investment
Sumitomo Corp ↓ TAE Technologies	■ Further advance the realization of a carbon neutral society by deepening the knowledge and being involved in commercialization of the fusion sector, which will reportedly be a trump card for decarbonization and energy problems ■ Contribute to the realization of a carbon neutral society by deepen the understanding of cutting-edge technologies and sector trends in fusion energy power generation and also utilize the knowledge and experience of Sumitomo Corp. Contribute to the realization of a carbon neutral society by aiming for the commercialization of fusion energy power generation while also being widely involved in development for purposes other than power generation
Furukawa Electric ↓ Tokamak Energy	■ Utilize knowledge related to materials, including metals, to supply and develop products, including super conducting wire, contributing to the realization of fusion energy, which is referred to as the ultimate energy for solving environmental and energy problems ■ Strengthen the framework for development of small fusion reactors while promoting joint marketing and research and development in the development and commercialization of high-field electromagnets that will be important in sectors, including medical, drug discovery, aerospace, and next generation transportation

Outline of fusion start-ups in which Sumitomo Corporation has invested or has a tie-up

	Fusion method	Major initiatives of each company
TAE Technologies (US)	FRC, p-B11	■ 2014: Partnered with Google not only financially, but to utilize the company's machine learning technology in the development of fusion reactors ■ Late 2020s: Target for the commercialization of fusion reactors
Tokamak Energy (UK)	Tokamak method, D-T	■ 2022: Attained plasma temperature of 100M℃ ■ 2027: Scheduled to complete construction of a demonstration reactor that utilizes high temperature super conducting magnets ■ 2030s: Aiming to realize a commercial plant with the spherical tokamak method

Aims for strengthening investments and tie-ups	■ To deepen the understanding of cutting-edge technologies and sector trends in fusion energy power generation ■ To be involved in the fusion supply chain ■ To consider the possible uses in industries other than power generation

Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on materials published by each company

[US] Aiming for operation of fusion pilot plant between 2035 and 2040

- In the US, the academic institution the National Academies of Sciences, Engineering, and Medicine (NASEM) published a report on fusion "Bringing Fusion to the U.S. Grid" in 2021
  - In addition to indicating a roadmap to the operation of fusion energy power generation, it reports that urgent investment is needed from the US Department of Energy (DOE) and the private-sector to succeed in operating a fusion pilot plant between 2035 and 2040
  - This report performs the role of a policy for formulating support from the US Government

Roadmap for operation of the fusion pilot plan up until 2050 (Published by NASEM, 2021)

2021 — 2025 — 2030 — 2035 — 2040 — 2045 — 2050

Decision to construct pilot plant

Decision on a commercial plant

Concept design and preliminary design	Final design and construction	Start of operations	First operating phase	Second operating phase	Third operating phase
■ Form national teams to develop conceptual design and technology roadmap ■ Demonstrate physics basics ■ Increase technology readiness levels (TRL) of critical technologies ■ Define regulatory framework ■ Identify possible site options ■ Perform preliminary design	■ Complete design and construction ■ Perform integrated system testing ■ Obtain construction and operating licenses	■ Start non-nuclear plasma operations ■ Commission tritium systems	■ Demonstrate sufficient fusion plasma energy gain (Qe) that net electricity is feasible (Phase 1a) ■ Target at least 50 MW for at least 3 continuous hours with Qe>1 (Phase 1b)	■ Target 50 MW-100MW and Qe>1, for a period of time that integrated fusion components (including maintenance and exchange of components inside the reactor) ■ Obtain sufficient technical and cost information for a first-of-a-kind power plant	■ Operate through several environmental cycles furthe qualifying material lifetime and possible advanced technology tests

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. Based on National Academies of Sciences, Engineering, and Medicine, *Bringing Fusion to the U.S. Grid*

[US] Aiming to benefit the economy and national security through the realization of fusion energy power generation

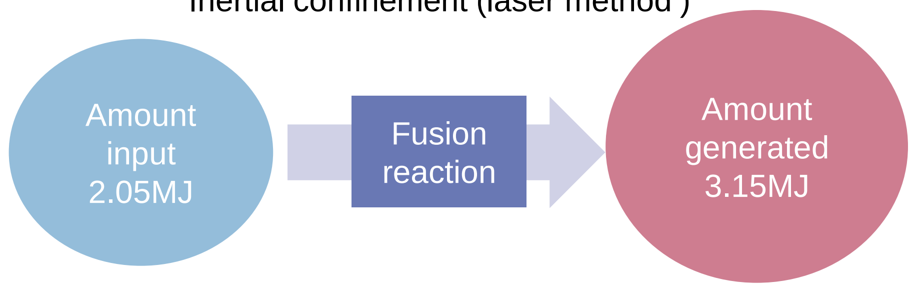
- The White House Office of Science and Technology Policy (OSTP) and DOE jointly convened a Fusion Summit on March 17, 2022 to accelerate the formulation of a bold decadal vision for commercialization of fusion. Aiming to ensure US technology leadership and benefit the US economy and national security
  - In addition to advancing the formulation of a bold decadal strategy, the DOE announced a total of USD 50 million in support for foundational research to support the design of a fusion pilot plant
- In December 2022, the DOE announced success in a fusion reaction that produced more energy than was input
  - Successful in a second fusion reaction test in July 2023

Net initiatives announced at the Fusion Summit

DOE's positioning of fusion	
■ Fusion promises to be a clean source of energy for the future ■ It will enable measures to address climate change, ensure US science and technology leadership, and benefit the US economy and national security	
Community engagement	■ Lead the development of a decadal strategy to accelerate the realization of commercial fusion energy that benefits all stakeholders
DOE Agency-wide initiative	■ The DOE launched an agency-wide initiative to accelerate the realization of commercial fusion energy in coordination with the private-sector
Support for fusion pilot plant	■ DOE will provide USD 500M that will support foundational science and technology research connected to high-priority issues for a future fusion pilot plant

[DOE] Successful fusion ignition (Lawrence Livermore National Laboratory)

Inertial confinement (laser method)



For the first time, success of "fusion ignition" in producing more energy than was input for the reaction

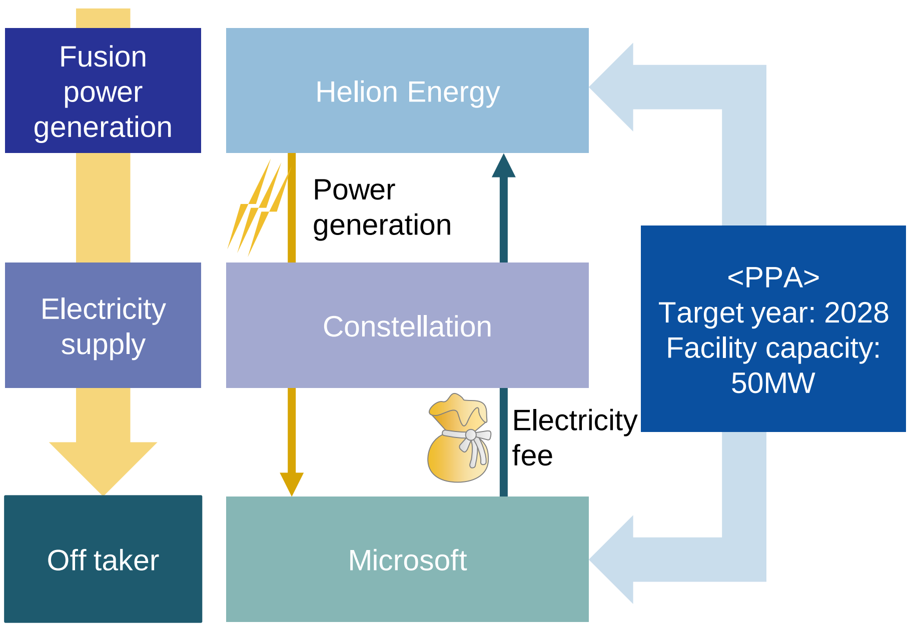
Extract of comments from DOE Secretary of Energy Granholm	■ The achievement of fusion ignition is a major scientific breakthrough decades in the making that will pave the way for advancements in national defense and the future of clean power ■ This is likely to be a game-changer for efforts to achieve President Biden's goal of a net-zero carbon economy ■ This will help us solve humanity's most complex and pressing problems, like providing clean power to combat climate change and maintaining a nuclear deterrent without nuclear testing

Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on White House and DOE materials

[US] Helion Energy plans to supply Microsoft with electricity in 2028

- Helion Energy, in which Open AI CEO Sam Altman invests, announced in May 2023 that it has entered into a Power Purchase Agreement (PPA) to supply electricity from fusion energy power generation to Microsoft by 2028
  - This is the world's first PPA contract from fusion energy power generation. The start of supply in 2028 is an ambitious goal considering the target timing for commercialization put forward by governments and major start-ups
- It is not only Microsoft, the company's founder, Bill Gates, is also investing in Commonwealth Fusion Systems, while Breakthrough Energy Ventures, which was established by Gates to invest in decarbonization, etc., has also invested in fusion start-ups

Outline of fusion PPA between Helion Energy and Microsoft



Microsoft related persons involvement in major fusion start-ups

	Tie-up/investee	Details of major initiatives
Microsoft	Helion Energy (FRC, D-He3)	■ 2020: Attain plasma temperature of 104M℃ ■ 2024: Power generation demonstration with Polaris ■ 2028: Supply electricity to Microsoft
Bill Gates + Breakthrough Energy Ventures	Commonwealth Fusion Systems (Tokamak method, D-T)	■ 2025: Power generation demonstration with the SPARC demonstration reactor that utilizes the world's highest high temperature super conducting magnet ■ Early 2030s: Aim for operation of commercial reactor ARC
Breakthrough Energy Ventures	Zap Energy (z-pinch , D-T)	■ Aim for around zero net energy with a current of about 650kA from Fuze-Q

Fusion promises to be a future clean power supply, with involvement in diverse fusion methods

Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on materials published by each company

[UK] Demonstrating three core pillars of international, scientific and technical, and commercial leadership

- The UK Government released Towards Fusion Energy – The UK Government's Fusion Strategy in October 2021
- The UK is aiming to construct a prototype reactor by 2040. The UK Government in cooperation with the UK Atomic Energy Authority (UKAEA), is planning to for the UK to demonstrate three core pillars of international, scientific and technical, and commercial leadership

Towards Fusion Energy – The UK Government's Fusion Strategy (October 2021)

Objectives of the fusion strategy	
1	For the UK to demonstrate the commercial viability of fusion by building a prototype fusion power plant in the UK that delivers net energy
2	For the UK to build a world-leading fusion industry that supports different fusion technologies and is capable of exporting fusion technology in subsequent decades.

To ensure UK leadership in the three core pillars of international collaboration, scientific and technical expertise and commercialisation in cooperation with the UKAEA

International leadership	Scientific leadership	Commercial leadership
■ To use international R&D collaborations to accelerate the commercialisation of fusion energy ■ To reduce the cost and risk of UK fusion programmes through collaboration, while protecting UK intellectual property and competitive advantage ■ To lead the development of international fusion standards and regulation, to ensure safety and maximise the global potential of fusion whilst creating important market opportunities for the UK	■ Maintain global leadership in fusion science, technologies and facilities. ■ Attract, grow and retain leading fusion talent, including supporting engineering disciplines	■ Create a vibrant fusion technology cluster (or clusters) in the UK ■ Attract inward investment into fusion and related technologies ■ Develop the supply chain and skills base to support fusion delivery and equip UK firms to compete successfully in a future global fusion market

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on UK Government materials

[UK] The UK Government is providing support for the Tokamak method

- The UK Government has been supplying funding for fusion research
  - A GBP 484M support package for the UK R&D sector was announced in November 2022. This included an allocation of GBP 126.1M to support fusion
- In February 2023, the UK Government established UK Industrial Fusion Solutions Ltd (UKIFS), which is schedule to construct a prototype STEP (Spherical Tokamak for Energy Production) program fusion energy plant at West Burton by 2040

The UK Government's financial support for fusion

The Ten Point Plan for a Green Industrial Revolution (October 2020)	■ Already provided GBP 222M to STEP (Spherical Tokamak for Energy Production) ■ Providing GBP 184M for new fusion facilities, infrastructure and apprenticeships to lay the foundations of a global hub for fusion innovation in the UK
Investment Package to Support UK Science Research (November 2022)	**Fusion industry program: GBP 42.1M** ■ To galvanise the UK fusion sector through a challenge fund, designed to engage and support UK businesses in important technical challenges of fusion, helping to build capabilities and spur commercial innovation **JET Operations: GBP 84M** ■ To support JET (Joint European Torus), as the world's largest and most powerful fusion experimentation, to continue operations, which will provide valuable new insights and support other UK fusion programmes such as STEP (Spherical Tokamak for Energy Production)

Outline of fusion programs (JET, STEP)

JET (Tokamak method)	
Started operations	1983
Location	Culham, UK
Purpose	Demonstration for ITER

- JET is designed for research of fusion energy in close to the required conditions for power plants. It is the only testing facility able to operate with Deuterium and Tritium used in commercial fusion energy power generation
- Conducts fusion energy research for testing ITER plasma physics, systems, and materials

STEP (Tokamak method)	
Timeline	2024 Concept design 2040 Operations commence
Location	West Burton, UK
Purpose	To demonstrate the commercial viability of fusion energy
Features	Smaller than ITER Spherical No commercial operations

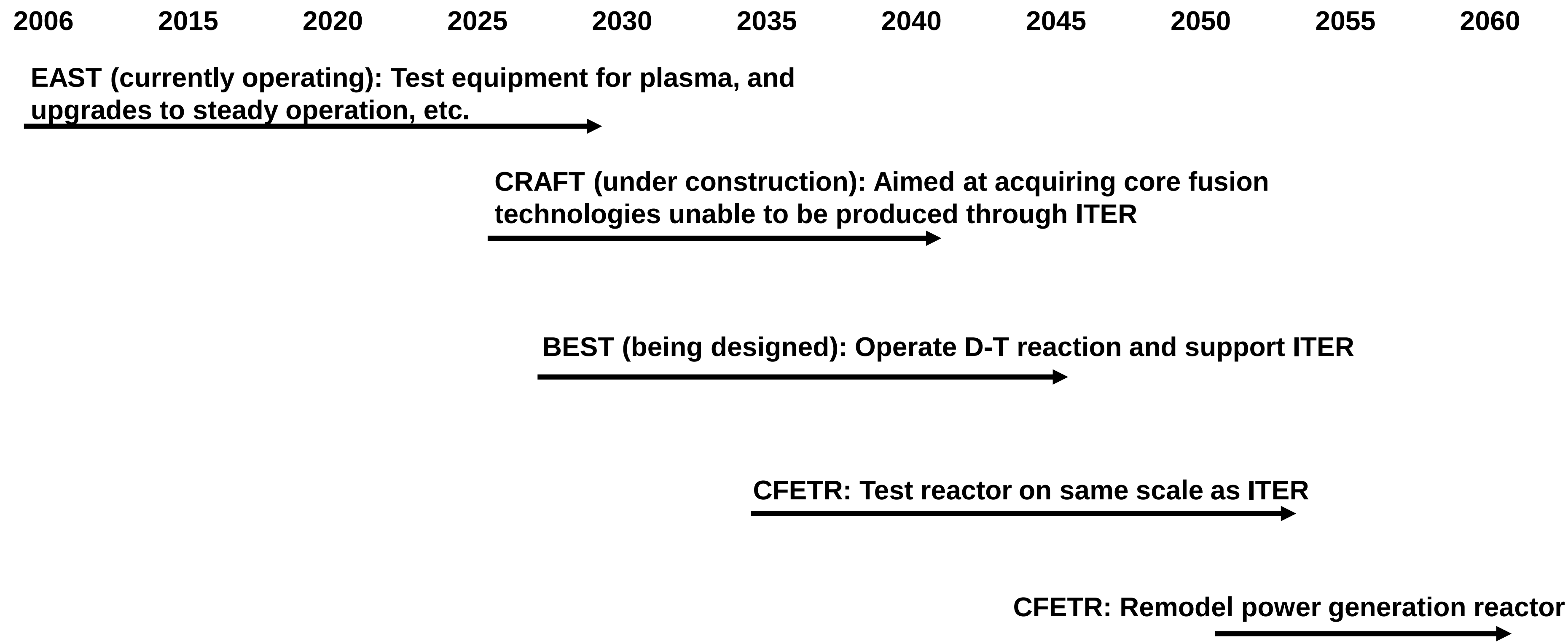
- STEP is a UKAEA program to demonstrate the net electricity generation capabilities from fusion
- The goal of phase 1 is to generate a conceptual design by 2024
- The goal of phase 2 is to obtain all approvals and licenses for plant construction following detailed engineering design
- The goal is completion by about 2040, with construction of a prototype reactor to commence in phase 3

Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. Based on materials from the UK Government and the IAEA

[China] Government led initiatives from test reactor to power generation reactor

- Following construction of a test reactor (CFETR), which is a similar scale to ITER, by the 2030s, China plans to remodel to a power generation reactor in the 2050s
  - The currently operating test device "EAST" has technical superiority attaining the world's longest plasma operations of 403 seconds in April 2023
  - USD 900M was required for the construction and operation of "EAST" up until 2019, and the Government has provided an additional USD 900M as project funding

China's roadmap for fusion development



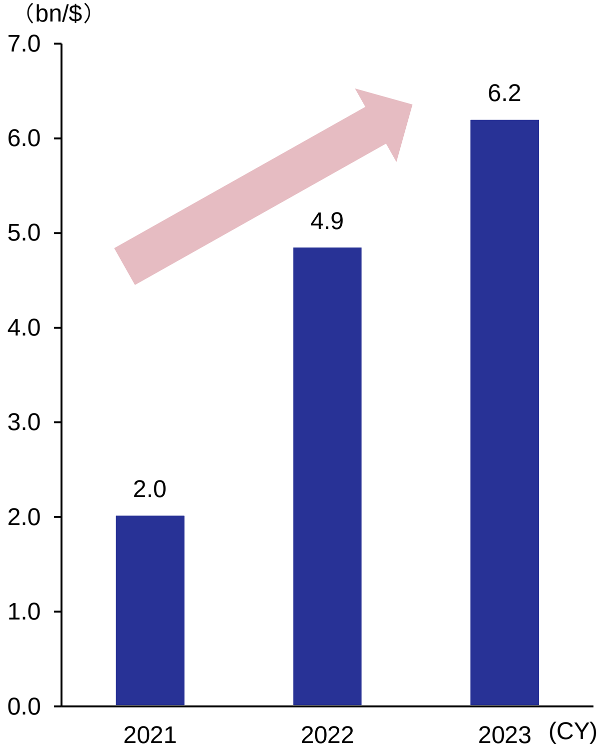
Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

3. Current status of fusion energy power generation and the path to commercialization of power generation

Acceleration of investment in fusion start-ups

- The cumulative investment in fusion start-ups as of July 2023 was about USD 6.2B, an increase of USD 1.3B from the USD 4.9B in the previous year
- Major fusion start-ups are concentrated in the US and Europe, with the top 5 companies raising more than USD 400M
  - Private-sector investment in fusion is accelerating. This includes investment by Microsoft founder Bill Gates in Commonwealth Fusion Systems (US) and Amazon founder Jeff Bezos in General Fusion (Canada), as well as Google's investment in TAE Technologies (US)

Cumulative investment in fusion start-ups



Top 10 companies in fundraising

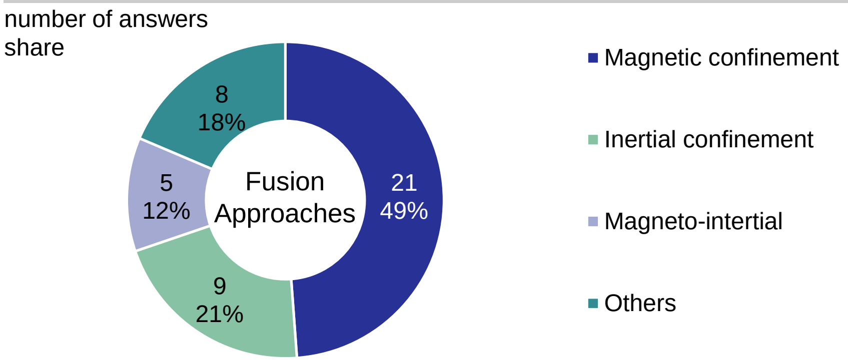
Name	Country	Found year	Fund volume	Approach
Commonwealth Fusion Systems	USA	2018	More than 2.0bn $	Tokamak
TAE Technologies	USA	1998	More than 1.2bn $	FRC
SHINE Technologies	USA	2005	0.7bn $	Magnet electrostatic
Helion Energy	USA	2013	0.6bn $	FRC
ENN	China	2006	0.4bn $	Tokamak
General Fusion	Canada	2002	More than 0.3bn $	Magnetized target
Tokamak Energy	UK	2009	0.25bn $	Tokamak
Zap Energy	USA	2017	0.2bn $	Z-pinch
General Atomics	USA	1955 (Note)	0.1bn $	Tokamak
Energy Singularity	China	2021	0.1bn $	Tokamak

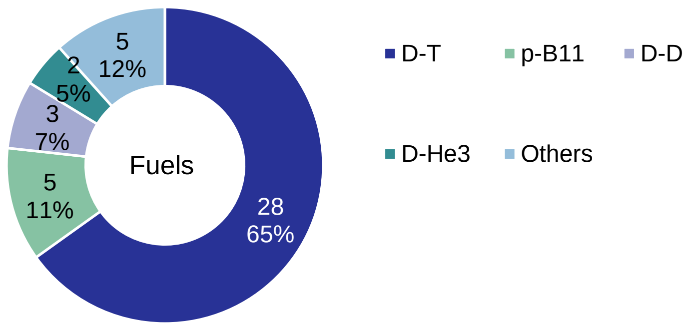
Note: Initiatives for the commercialization of fusion commenced in 2022
Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Fusion Industry Association, *The global fusion industry in 2023*

Major start-ups forecast electricity supply from fusion energy power generation in the 2030s

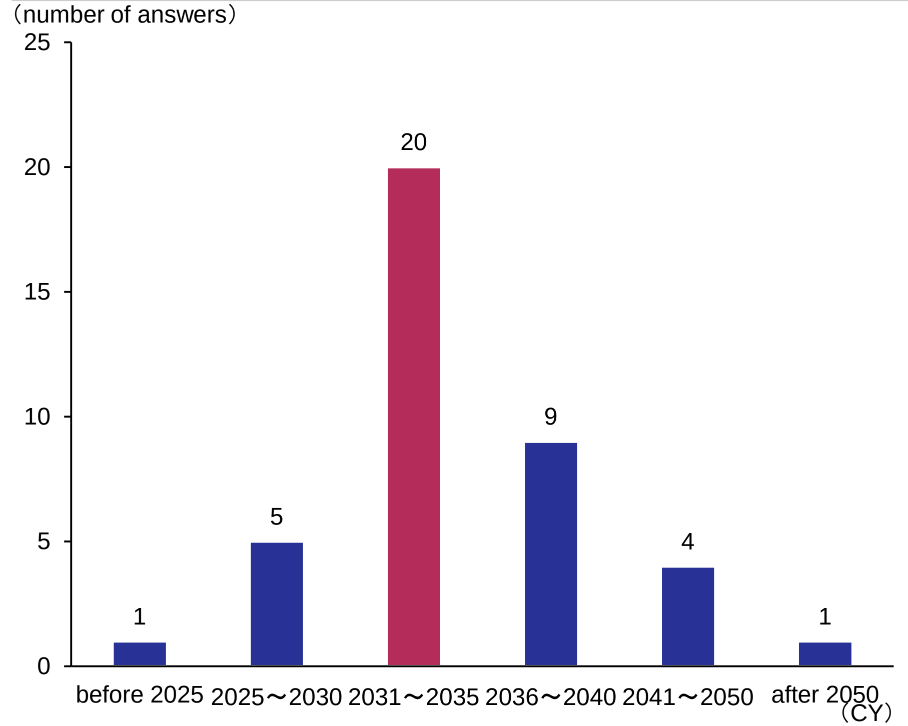
- Magnetic confinement, inertial confinement, and compound methods (magnetic and inertial) account for most of the fusion energy power generation methods adopted by major start-ups, with more than 60% of start-ups also using D-T (Deuterium-Tritium) reaction as fuel
  - Broadly speaking, even if the method is the same, the actual fusion method differs for each company. Each company conducts research and development for their respective technologies and are advancing initiatives towards commercialization
- According to the 2023 Survey Report from the Fusion Industry Association, the forecast timing for the first electricity supply from fusion energy power generation with the highest response was 2031-2035

Types of fusion energy power generation methods for major start-ups





Forecast timing to connect the first reactor to the power grid

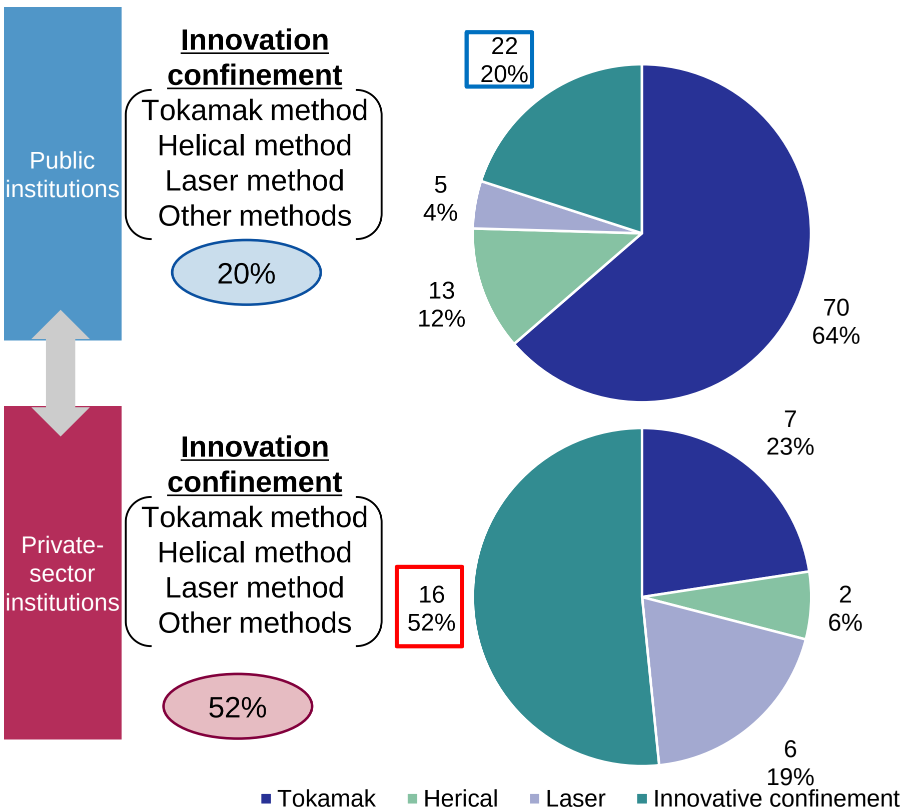


Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Fusion Industry Association, *The global fusion industry in 2023*

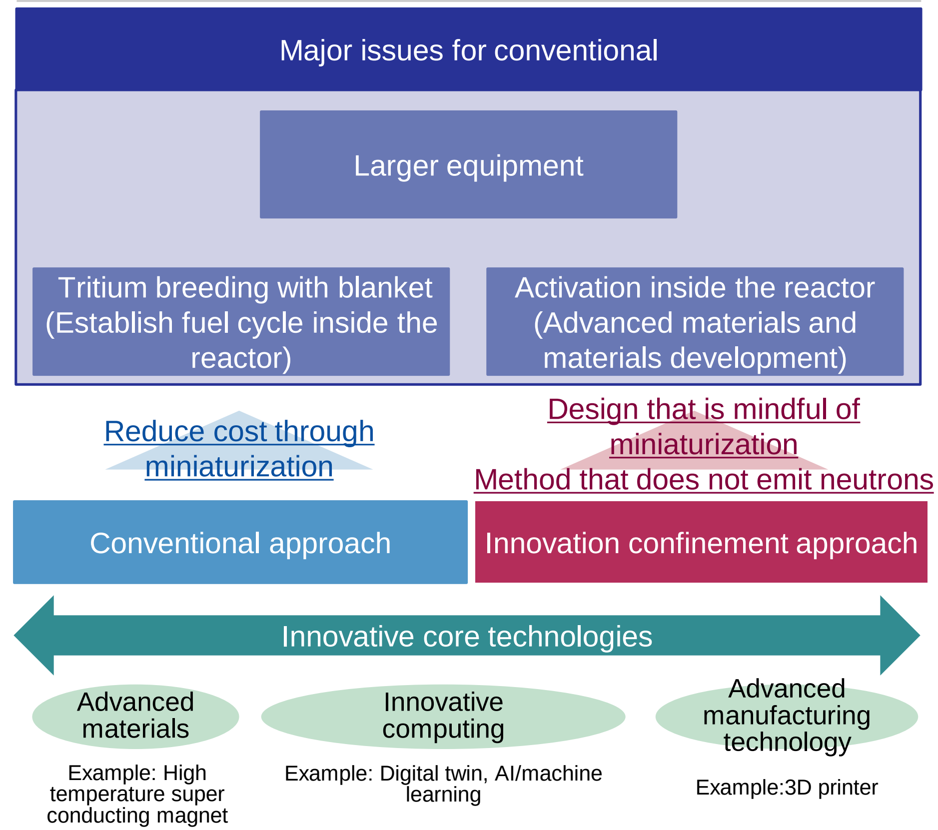
Private-sector are engaged in innovative core technologies and problem solving through innovation confinement method

- 80% of the methods of fusion energy power generation involving public institutions are the conventional Tokamak method, Helical method, and Laser method, while innovation confinement method accounts for the majority of the methods involving private-sector institutions
- Fusion start-ups involved in conventional methods are engaged in initiatives for problem solving through measures, including miniaturization using innovative core technologies. On the other hand, start-ups adopting innovation confinement are engaged in initiatives to solve issues for conventional methods through measures, including miniaturization of the design of innovation confinement itself and fuels that do not emit neutrons

Difference in the methods of fusion energy power generation involving the public and private sectors



Fusion start-ups' approach to problem solving

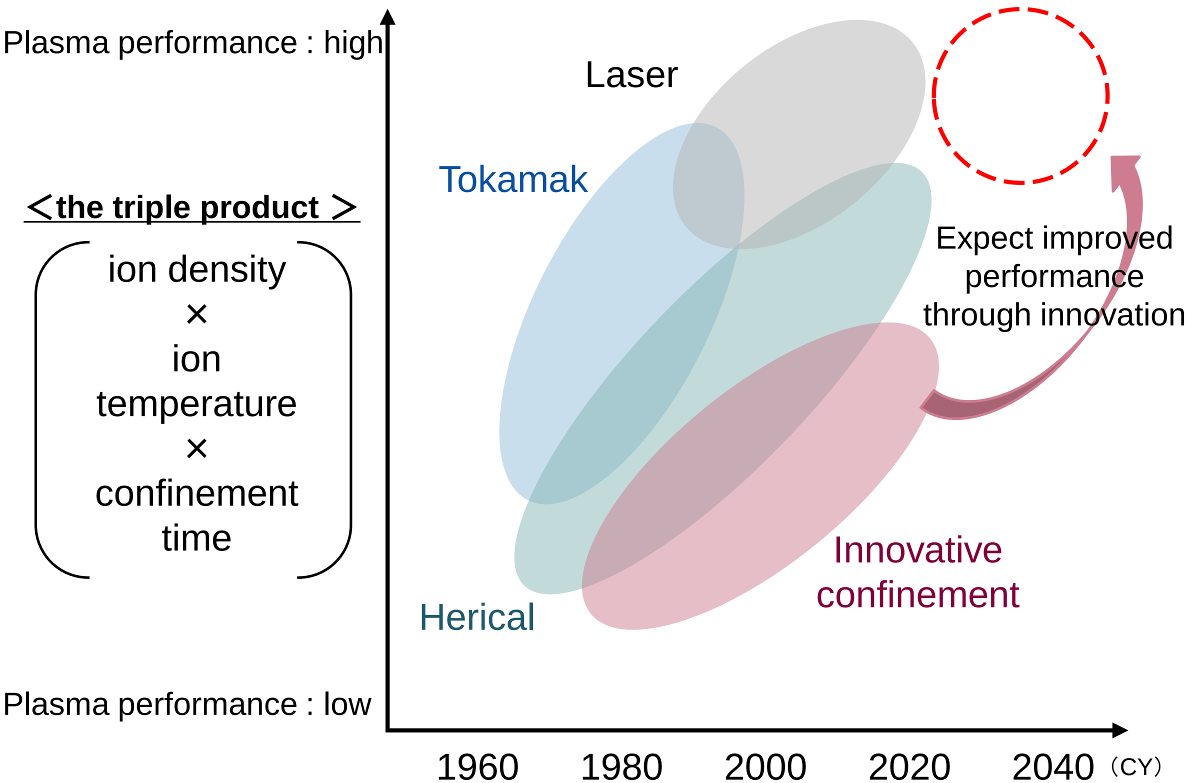


Source: Both charts are compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Conventional leads in plasma performance while innovation confinement follows

- The cumulative status of "ion density x ion temperature x confinement time" is an important indicator when evaluating the performance of each fusion method
- In the current circumstances, three types of conventional methods lead: Tokamak method, Helical method, and Laser method
  - Fusion start-ups deploying the innovation confinement method are taking initiatives in research and development aiming for dramatic improvement in plasma performance through innovation

Image of the change in performance for each fusion energy power generation method (Lawson diagram)



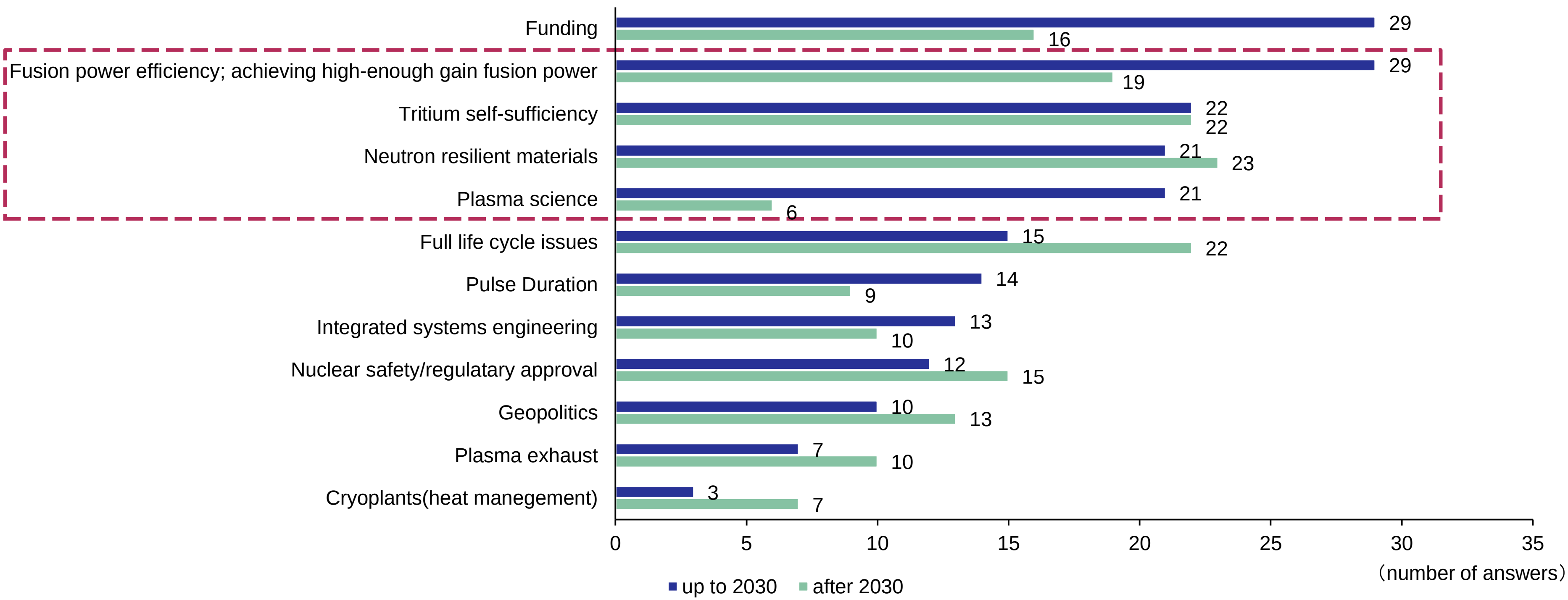
Conventional	■ Currently, the conventional Tokamak method, Helical method, and Laser method have high plasma performance ■ Among these, Commonwealth Fusion Systems, which is currently using the Tokamak method, is construction a demonstration reactor and in the lead
Innovation confinement	■ Research and development to improve performance is being carried out on innovation confinement methods, including FRC, used by Helion Energy and TAE Technologies, compound methods used by General Fusion, and Z-pinch used by Zap Energy

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

(P11 reposted) Challenges for fusion energy power generation vary from funding to the types of technology development

- In addition to funding, major challenges for fusion energy up to 2030 raised by fusion start-ups are fundamentals of fusion technology, including improving the efficiency of fusion energy and Tritium self-sufficiency
- Even after 2030, start-ups anticipate ongoing need for initiatives involving technology development and life-cycle issues, and also anticipate problem solving requirements on the software side, including regulations

Challenges for the commercialization of fusion energy power generation raised by major start-ups



Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on Fusion Industry Association, *The global fusion industry in 2023*

Apart from establishing the fuel cycle, it is import to reduce cost through miniaturization

- It is vital to establish a fuel cycle of tritium production inside the reactor with long-term maintenance of high temperature plasma. In addition to the research and development being carried out by each company, the aim is to reduce costs through miniaturization using innovative technologies and the innovative confinement method

Approach to major problem solving for the commercialization of fusion energy power generation (1/2)

Type of challenge	Major challenges	Counter-measures	Major players
Tritium self-sufficiency	Lithium extraction and Tritium production	■ Research and development by major fusion start-ups and others	■ All companies — Initiatives by businesses and research institutions undertaking fusion through D-T reaction
Plasma science	Long term maintenance of high temperature plasma	■ Research and development on diverters by major fusion start-ups	■ Helion Energy (US) — Attained plasma temperature of 104MºC in 2020 ■ Tokamak Energy (UK) — Attained plasma temperature of 100MºC in 2022 ■ General Fusion (Canada) — Attained plasma temperature of 100MºC in 2022, and maintained plasma for 10 milliseconds
Fusion energy efficiency and high levels of energy generation	Cost reduction through miniaturization	■ Miniaturization of magnets through development of high temperature super conducting magnet	■ Commonwealth Fusion Systems (US) — Successfully developed the world's most powerful 20 tesla magnet (indicating the magnetic flux density in the SI international system of units), making it possible to manufacture Tokamak devices with 1/40 the ITER size ■ Tokamak Energy (UK) — Currently constructing a demonstration reactor using high temperature super conducting magnets, with completion due 2026
		■ Adopt magnetic field-reversed configuration type	■ TAE Technologies (US), Helion Energy (US) — Able to confine high pressure plasma in lower magnetic field than in the Tokamak method, contributing to device miniaturization
		■ Adopting sheared flow stabilizing z-pinch	■ Zap Energy (US) — A method that does not use super conducting magnets, that enables the targeting of simpler manufacture, lower costs and miniaturization

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Development of peripheral technologies and reactor activation countermeasures are also required

- In addition to the need for the development of peripheral technologies for heat recovery with blankets in the lead up to the commercialization of power generation, there are also businesses engaged in the establishment of fusion energy power generation methods that do not emit neutrons themselves to address the degradation of materials caused by the activation of reactors

Approach to major problem solving for the commercialization of fusion energy power generation (2/2)

Type of challenge	Major challenges	Counter-measures	Major players
Fusion energy efficiency and high levels of energy generation	Efficient heat recovery and fuel generation through development of blanket technology	■ Use magnetic field-reversed configuration type	■ TAE Technologies(US), Helion Energy(US) — Power generation from electromagnetic induction by passing plasma through the coil without using a steam turbine
		■ Use liquid metal	■ General Fusion(Canada), Zap Energy(US) — Ability for more efficient heat recovery by using liquid metal inside the reactor
Neutron-resistant materials	Reactor activation countermeasures	■ Use non-D-T reaction (Deuterium･Tritium) so that no neutrons are emitted ■ Stable fuel procurement could be an issue	■ TAE Technologies(US) — Fusion through reaction of light hydrogen and boron 11. High temperature plasma of 1 billionºC and above is required. However, joint research with the National Institute for Fusion Sciences (NIFS) has demonstrated the possibility of fusion reaction by using high energy beams without the aformentioned temperatures ■ Helion Energy(US) — Fusion through reaction of Deuterium and Helimum3. Helium3 is obtained from a D-D reaction
		■ Use liquid metal	■ General Fusion(Canada), Zap Energy(US) — It not only protects the outer walls inside the reactor from the damage caused by neutron beams, but there is no need for periodic change of liquid metals

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Commercialization of power generation in the 2030s will be challenging, but it could be achieved through technical innovation

Overall image of fusion energy power generation	
Current location of fusion energy power generation technologies	■ Fusion energy research has been undertaken for some time, but in recent years, there has been **a certain degree of success** in areas, including the generation and maintenance of high temperature plasma required for fusion energy and reduced costs through technological progress. This is one reason for the increase in development by the private sector and the funding from the private sector
Behind the statements of bringing forward the commercialization of power generation	■ Behind the statements about commercialization of power generation in the 2030s, is the indication of more ambitious goals than before, with **the intent to attract investment from investors and companies that place importance on social demands,** including 2050 Carbon Neutrality and energy security
Current status evaluation	■ Research and development in areas not just for fusion energybut also in fuel extraction, breeding, and efficient heat recovery needed for fusion energy power generation is now in a state that can be finally be incorporated for further steps. However, **there are numerous technical challenges for all methods, and while the commercialization of power generation in the 2030s will be challenging, technical innovation could make this feasible**

Trends in major countries surrounding fusion energy power generation	
The US and Europe	■ The US Government and the UK Government have announced strategies for construction and operation of fusion reactors in 2035 and 2040 respectively ■ Fusion start-ups in the US and Europe that have raised enormous funds in the order of 100s of billions of yen have **issued targets for commercialization that are earlier than the government targets. At the current point, demonstration reactors are being constructed, and depending on their success, power generation commercialization could be closer**
Japan	■ The Japanese Government is responding **based on the progress of the ITER project, an international project for the Tokamak.** The aim is to commence construction of a prototype reactor immediately following the 2035 combustion experiment, and to demonstrate power generation from the prototype reactor in 2045 ■ On the other hand, in the private-sector, **Helical Fusion and EX-Fusion, which use the Helical method aimed for commercial reactor construction, are looking ahead to power generation, and there are also plans for monetization in other industries using laser technology. Kyoto Fusioneering not only designs components, but is also engaged in initiatives to assist with the design of fusion reactors**

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

Stronger involvement in fusion reactors and commercialization that includes peripheries is required for the commercialization of fusion energy power generation

- There are initiatives for R&D of fusion reactors with start-ups from both in and outside Japan at the core, but Japanese fusion related suppliers have high technical capabilities in relation to manufacturing as well as the design of materials and components needed for fusion energy power generation cultivated in ITER and elsewhere
- Given the uncertainty about which fusion energy power generation method will be successfully commercialized, it is important to promote not only fusion reactors but the fusion industry, including periphery areas that are Japan's strength
- In addition, looking ahead to the commercialization of power generation, Japan's industrial sector needs to strengthen its involvement through means, including investment and alliances with start-ups engaged in fusion reactors, which will also accelerate research and development in fusion reactors

The path to commercialization of fusion energy power generation

Japan's fusion-related businesses

Start-ups involved in fusion reactors	Helical method: Helical Fusion Laser method: EX-Fusion, Blue Laser Fusion FRC: LINEA Innovations
Fusion related technology	Kyoto Fusioneering, ITER related suppliers

R&D Competition ⟷ Product & materials supply

US and European start-ups

Major start-ups involved in fusion reactors	US Tokamak method: Commonwealth Fusion Systems FRC: TAE Technologies, Helion Energy Z-pinch: Zap Energy UK Tokamak method: Tokamak Energy

General trading companies, energy sector, communications sector, etc.

Promoting fusion industry, including periphery areas
＋
Involvement in fusion reactors through investment

Involvement in fusion reactors through investment

Accelerate investment and R&D to realize fusion energy power generation

Source: Compiled by the Industry Research Division, Mizuho Bank, Ltd. based on various official materials

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