

Fusion Energy Innovation Strategy

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The Integrated Innovation Strategy Promotion Council

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1. Introduction

✓ **Energy, environmental problems in Japan**

Countries around the world are accelerating their efforts to achieve carbon neutrality as a common target for humankind in response to the deepening impact of climate change such as extreme weather, Japan is also moving forward with various initiatives for realizing a carbon-neutral society by 2050.

In particular, the rapidly rising energy costs in the crude oil and natural gas markets caused by the Russia's aggression against Ukraine in February 2022 have changed the contours of the world's energy situation in a way unseen up to now, impacting Japan as well. For Japan, whose energy self-sufficiency rate is 13.4%¹-- quite low compared to that of other OECD countries²-- ensuring its energy security while transitioning from fossil fuels to clean energy sources from now is a pressing issue.

✓ **Fusion energy as a solution**

Fusion energy is energy produced when two light nuclei (deuterium, tritium) fuse to form a single heavier nucleus (helium), the same kind of energy that illuminates the Sun and stars.

Fusion energy has the following advantages:

1) Carbon neutrality

Carbon dioxide is not emitted during the process of power generation;

2) Abundant fuel (

On top of the fact that the fuel exists abundantly in seawater and can be generated nearly inexhaustibly, a huge amount of energy can be produced by a small amount of fuel;

3) Inherently safe

The nuclear reaction stops when the fuel supply or the power supply is cut off;

4) Environmental preservation

Only a low level of radioactive waste is generated and it can be processed with existing technology) ;

As such, fusion energy is expected to be the next-generation energy source that can solve both energy problems and global environmental problems at the same time.

Moreover, since seawater, the source of the fuel, covers two-thirds of the surface of the Earth and numerous countries, they can produce the fuel as long as they have the technology, and the problem of the unequal distribution of energy resources can be

¹ Comprehensive Energy Statistic Preliminary figures for 2021

² Energy self-sufficiency rates for other countries in 2020 (Japan's rate from *Japan's Energy. 10 questions about energy--FY2022 Edition*): Canada: 182.6%, USA: 106.0%, United Kingdom: 76.0%, France: 54.9%, Germany: 34.7%)

eliminated. Thus, providing great hope that fusion energy will contribute to world peace and stability. At the same time, as energy hegemony will shift from those countries possessing energy resources to those possessing the technology, it will become vital to ensure energy security through the acquisition of technology. In the ‘Sixth Basic Energy Plan’³, the policy for nuclear power is to reduce dependence on nuclear power as much as possible and to utilize the necessary scale of nuclear power on a sustainable basis. In addition, based on ‘the Basic Policy for the Realization of GX’⁴, a shift to decarbonized power sources such as renewable energy and nuclear power will be promoted to overcome the current energy crisis. The development of human resources by this promoting of nuclear power generation will also contribute to the development of fusion energy in the future. On the other hand, based on the fact that nuclear fusion possesses special characteristics (inherent safety, environmental preservation, etc.) arising from the differences in the physical principles underlying nuclear fission and that “nuclear fusion” as an academic term is called “fusion” in the energy field in the UK and the US in recent years, this strategy labels nuclear fusion energy as “fusion energy” to prevent misunderstanding arising from the confusion with nuclear fission.

✓ **Fusion energy as a new industry**

An international project, ITER has required the production of equipment and devices using advanced technology unseen up to now. However, through the development of manufacturing technology, the core assembly of ITER’s facilities began in 2020, and 77.5% of the construction activities that will lead to the First Plasma have been completed (as of December 2022). Moreover, as a result of improvements in confinement technology for the implosion method by high-power lasers, in December 2022, researchers at the Lawrence Livermore National Laboratory succeeded for the first time in history in generating more energy from a fusion reaction using the deuterium-tritium fuel than was necessary to produce it.⁵

With the trend toward global carbon neutrality, such government-led scientific and technological breakthroughs are being made, and private-sector investment in this area is also increasing in many countries.⁶ Spurred by this booming private-sector investment, fusion start-ups in the US, the UK, and elsewhere are accelerating fusion R&D competition with setting ambitious targets for fusion power generation⁷ ahead of

³ 22 October 2021 Cabinet decision

⁴ Basic Policy for the Realization of GX - Roadmap for the Next 10 Years (Cabinet Decision, 10 February 2023)

⁵ The fusion reaction was achieved on December 5, 2022, and the US Department of Energy announced the research results on December 13. The fusion ignition produced 3.15 MJ of energy, 1.5 times the 2.05 MJ of laser energy provided.

⁶ According to the Fusion Industry Association, private-sector investment has amounted to some \$2 billion up to 2021, and it predicts another \$2.7 billion in private-sector investment in the future.

⁷ Commonwealth Fusion Systems in the US: development of demonstration SPARC reactor in 2025, and commercial operation of ARC reactor in early 2030s; Tokamak Energy in UK: operation of ST-E1 pilot plant in early 2030s and operation of commercial reactor in mid-2030s; TAE Technologies in US:

the schedules of government plans up to now. Moreover, China is also making strong progress in its plans⁸ for the government-led construction of experimental equipment and a prototype reactor, which could make China a very strong competitor in fusion research and development.

To produce fusion energy, a cluster of various technologies (“fusion technologies”) such as those for producing strong magnetic fields from high voltage currents and vacuums produced by high pressure is necessary. The industry (“fusion industry”) serving as the foundation for fusion technologies is broad-based, and it is also expected that ripple effects of fusion technologies will spread to other fields.

The funds invested in fusion start-ups are invested in various type of companies in the form of investment for joint research and equipment procurement, and supply chains are being created overseas. The US and the UK governments formulated their national strategies (US: March 2022; UK: October 2021)⁹ targeting the commercialization of fusion energy, and have started confining relevant technologies to their own countries. The race to commercialization has already begun without waiting for the actual realization of fusion power generation.

Japan is a strong partner candidate for other countries, because Japan possesses technological advantages cultivated through its research and development, reliability in its manufacturing industries, and the basic research infrastructure and human resources development frameworks for supporting those industries. The synergistic effects from cooperation with other countries allow the utilization of partner countries’ technologies for domestic development and provide opportunities¹⁰ for the acquisition of overseas markets. At the same time, considering the accelerating pace in other countries, Japan is facing the risk of lagging behind in commercialization though it provides technology and losing market competitiveness as a result. In particular, fusion technologies, which produce ripple effects to other industries, are important for ensuring economic security based on technological security.

To take the shortest route to the commercialization of fusion energy in Japan, , Japan will strongly promote the approach of the ITER Project and BA Activity followed by development of a DEMO reactor, because the clarification of the cost and timing of a prototype reactor’s power generation demonstration period and the prompt

operation of commercial reactor in early 2030s; UK government-led UK Atomic Energy Authority (UKAEA): operation of prototype STEP reactor by 2040s.

⁸ Operation of CRAFT research facility complex to acquire core fusion technologies from 2025; operation of BEST demonstration reactor using actual fuel from 2027; construction of an engineering test reactor, which is on the same scale as ITER’s, by 2030s and modification to power generation reactor by 2050s.

⁹ The United States held a symposium titled “Developing a Bold Decadal Vision for Commercial Fusion Energy” at the White House. The United Kingdom formulated its “Towards fusion energy: the fusion strategy.”

¹⁰ In January 2023, the UK’s Tokamak Energy Ltd. and Furukawa Electric Co., Ltd. signed an agreement regarding the provision of high-temperature superconducting wire.

construction of a DEMO reactor are essential. In addition, to take advantage of this opportunity and keep pace with other countries' moves to commercialization, Japan regards fusion energy as a new industry and needs to adopt a multifaceted approach, including entering without delay the global supply chains that are being created.

By doing so, in addition to making more robust the DEMO development approach by utilizing the new technologies and innovation developed in the process of commercialization, Japan will be able to build from now the foundation for the future fusion industry ecosystem and take new measures for accelerating the realization of fusion energy.

2. Vision for a National Strategy

Based on the background described above, the government labeled its fusion strategy for the coming ten years as: “Towards the practical realization of fusion energy, the world's next-generation energy source — The commercialization of fusion energy: Seizing the winning market edge by leveraging Japan's technological advantage.”

It will be necessary to promote the further participation of Japan's private-sector companies and for industry, academia, and government to collaborate in the efforts for realizing this vision for fusion energy. The government has formulated a national strategy for this vision, which will incorporate concrete action for pump-priming private investment.

3. Basic concepts and specific measures for realizing the vision

The basic concept for realizing the vision is the integrated promotion of strategies for developing the fusion industry, developing fusion technologies, and framework for promoting the Fusion Energy Innovation strategy. The following are concrete tactical actions for realizing the fusion energy vision.

(The following acronyms and titles are used below: Cabinet Office; MOFA [Ministry of Foreign Affairs]; MEXT [Ministry of Education, Culture, Sports, Science and Technology]; METI [Ministry of Economy, Trade and Industry]; MOE [Ministry of the Environment].)

3-1 Developing the fusion industry

Considering the trends of private companies worldwide and large-scale investment these days, it is important for Japan not to lose opportunities in overseas markets. While supply and demand will shrink with the decrease in procurement as the ITER Project progresses, a blank period in supply and demand will arise until supply and demand expand with the necessary procurement for the building of the DEMO reactor. Because of that situation, it will be essential to build the foundation for the DEMO with the aim of establishing a future fusion energy ecosystem and promoting the acquisition

of necessary technology in anticipation of the participation of private companies in the development of Japan's DEMO.

In addition to the further participation of private companies already engaged in the development of fusion energy, the government will provide continuous support at each stage in the “visualize, connect, foster” process for promoting the fusion industry and involving interested private companies that have not participated in fusion energy up to now.

Visualization

By providing clearer visualization of the targets of the strategies, the government will be able to enhance the predictability of the fusion industry and increase the participation of private companies in it.

- Clarifying the position of fusion energy in society (Cabinet Office [relevant ministries, agencies])

To clarify the positioning of the fusion industry by backcasting from Japan's future energy mix rather than grasping the social implementation of fusion energy by extending forward from current research and development, the Cabinet Office will study and consider the social and economic utility and cost targets for fusion energy in cooperation with relevant ministries and agencies.

- Clarifying as early as possible the power generation demonstration period to enhance the predictability of the fusion industry (MEXT)

In addition to acquiring overseas markets, establishing domestic markets is also important. MEXT's “Roadmap toward Fusion DEMO Reactor (first report)”¹¹ sets the period for the achieving of power generation around 2050, and the results of study by MEXT's Task Force on a Comprehensive Strategy for DEMO Development has shown that it is possible technically to move that timeline forward.¹² Based on the progress of the ITER Project and the ambitious targets set by various other countries,^{7,8} the government will clarify as early as possible the timing for the power generation demonstration and realize the early completion of the DEMO reactor by accelerating research and development.

- Creation of technology and market opportunity maps regarding fusion energy showing technology readiness levels, initiatives based on economic security perspectives (Cabinet Office)

To organize supply chains and parties engaged in the fusion industry and promote the participation of private companies, the Cabinet Office will create technology and

¹¹ “Roadmap toward Fusion DEMO Reactor (first report)”, July 24, 2018.

¹² “Action Plan for development of DEMO based on study for moving forward the timeline for fusion energy power generation”, October 28, 2022.

market opportunity maps making clear the industrial needs and the technologies that are expected to produce ripple effects extending to other industries.

Although the various technologies for fusion energy can be covered by domestic companies, fusion energy requires a collection of technologies from a wide range of fields. Since resources (funds, human resources, time, etc.) are limited, it is essential to prioritize the investment of resources in required areas rather than trying to evenly distribute them over all areas. Moreover, since it is necessary to take into consideration the perspective of economic security that in turn takes into account the accelerating trends in other countries, strategic initiatives must be taken based on the ideas below when conducting research and development and developing the fusion industry. At those times, in terms of economic security, priority must be given to those vital areas requiring the highest priority from among those core areas in which Japan has strengths.

- Core areas of fusion energy systems

These are areas that must be addressed regardless of their market size or Japan's strengths or weaknesses in them and that are important in terms of economic security (autonomy, indispensability).

In particular, these are areas in which resources should be focused since the technologies that Japan is strong in provide opportunities for acquiring overseas markets. Moreover, areas that like-minded countries are also strong in should be addressed while strategically cooperating with those countries. Furthermore, those areas that could hinder the realization of fusion energy in Japan if dominated by other countries should be approached from the perspective of supply chain access regardless of whether Japan has strengths or weaknesses in them.

- Areas in which fusion technologies are expected to produce ripple effects in other areas

These are areas that should be addressed to meet market expectations such as technologies that can be commonly used in various types of fusion reactors regardless of their positioning in fusion energy systems or whether Japan has strengths or weaknesses in them. Particularly those areas expected to produce ripple effects (spinouts) to a wide range of industries such as fields related to resources and energy, medical care, and security are important because they produce expansive effects as fusion industries as well as promote the further participation of private companies.

- Areas that are expected to integrate existing or new technologies from other fields

These are areas where it is important to integrate technologies from other fields such as AI analysis and simulations, high-capacity data communication, and so on, in addition to academic research and development in the field of fusion energy for the social implementation of fusion energy systems.

Connections

The seeds for the new fusion industry will be sown through the matching between fusion technologies or matching fusion technologies with technologies of other fields.

- Setting of opportunities aiming at the fostering of the fusion industry (Cabinet Office [relevant ministries, agencies])

The Cabinet Office is reorganizing the Fusion Energy Forum of Japan, a forum for industry, academia, and government, to promote information exchange and business matching regarding fusion energy among private companies and to foster the fusion industry, with the aim of newly establishing the Fusion Industry Council of Japan (provisional name) in fiscal 2023. The Council will allow the participation of private companies as formal members and promote the new participation of interested private companies. The participation of academia and QST¹³ will further promote industry-academia-government cooperation.

Fostering

The government will seek to build an environment in which innovation can be created, enabling the social implementation of new products and services as outcomes of the development of fusion energy.

- Provision of support to close the gap between the technological seeds possessed by private companies, including start-ups, and the industrial needs (Cabinet Office, MEXT)

Even if private companies have the technological seeds, since further research and development will be needed until the needs are suitable for social implementation, the Cabinet Office and MEXT will support the R&D by private companies that will play a major role in developing the fusion industry. In particular, support to start-ups will be enhanced from fiscal 2023.

- Discussion with like-minded countries on safety regulations (MEXT, MOFA)

The United States, the United Kingdom, and other countries are taking the lead in holding discussions on safety regulations. Since the formulation and standardization of safety regulations through international collaboration is necessary for acquiring overseas markets, Japan has been participating in the Working Group holding discussions on “Approaches to International Fusion Energy Regulations” being conducted under the Agile Nations¹⁴ framework, and the government will summarize the Working Group discussions in fiscal 2023.

¹³ National Institutes for Quantum and Radiological Science and Technology

¹⁴ Agile Nations is an intergovernmental regulatory cooperation network aiming at the promotion of cooperation in the implementation of innovative regulatory practices among the participating governments.

- Formulation of basic ideas regarding ensuring safety (Cabinet Office [relevant ministries, agencies])

Since the performance and design required for equipment needed in the fusion industry will change in accordance with the contents of safety regulations, it will be necessary to consider these safety regulations as early as possible to promote the participation of private companies.

To do so, the Cabinet Office will establish a task force comprising engineers, regulatory specialists, and citizens to consider in cooperation with the relevant ministries and agencies the basic concepts for ensuring safety while keeping in mind the fostering of the fusion industry and the promoting of the development of the DEMO reactor so as not to fall behind in the commercialization of fusion energy. In this study, since fusion energy is different in principle from fission energy, discussions should also include the frameworks for considering the regulations.

3-2 Developing the fusion technology

In order to build up a fusion technology portfolio based on strategic autonomy and indispensability in preparation for future uncertainty, Japan will support challenging research that will open up future possibilities as well as promoting technological development that will be at the core of fusion energy through the ITER Project and BA Activity and related domestic R&D.

- Strengthening original emerging technology support measures such as potentially game-changing miniaturization and high-performance technologies (Cabinet Office, MEXT)

Other countries and private companies are developing advanced technologies and various reactor types, and these original and emerging technologies could have a game-changing impact. In fiscal 2023, Japan also will begin study of optimum types of support for challenging research leading to innovation that will open up future possibilities to widen the range of fusion technologies and hedge against future risks. When supporting the research, the government will encourage collaboration between research institutes and private companies in anticipation of commercialization and the fostering of common basic technologies.

- Acquiring key technologies through ITER Project/BA Activity (MEXT)

Since Japan is responsible for both key equipment in the ITER Project and making important efforts for the development of the DEMO through its BA Activity, Japan will continue to promote both areas of activities to acquire the necessary key technologies for realizing fusion energy.

- Accelerating R&D in anticipation of the future development of the DEMO (MEXT)
The government will promote research and development for the DEMO reactor and introducing mechanisms for promoting the greater participation of private companies to accelerate the design of the future DEMO.

- Continuous promoting of academic research on fusion energy (MEXT)
Fusion energy requires a collection of diverse technologies and may hold the possibility of an even wider range of technologies. Moreover, since innovation is uncertain due to the existence of many unresolved problems, the government will continue to promote academic research, which undertakes intellectual and creative activities in a wide range of fields.

- Advancing the Action Plan for the DEMO development with the incorporation of new technologies developed by private companies including start-ups (MEXT)
Because of the rational basis for the Action Plan created based on the research results of the ITER Project and other endeavors, Japan should flexibly incorporate emerging technologies and international cooperation that will contribute to the early realization of fusion energy and its cost reduction.

Moreover, since it is unclear what the technical needs for the DEMO development are for private companies, they would be venturing into participation without being able to measure any gaps in the technical levels of their own companies. In addition, because the project involves long-term and difficult technology development, the government will introduce the stage gate process for the creation of an appropriate technology road map for the DEMO development and appropriately manage its progress.

3-3 Framework for promoting the Fusion Energy Innovation strategy

The government will build a framework for promoting the strategy in order to drive the formulated national strategy forward through industry-academia-government collaboration.

- With the Cabinet Office as the “control tower,” advancing the strategy together with relevant ministries and agencies (Cabinet Office [relevant ministries, agencies])
Functioning as the government’s command center, the Cabinet Office (Council for Science, Technology and Innovation) will advance the strategy towards the realization of the innovation of the practical application of fusion energy. The strategy will be regularly revised, employing EBPM,¹⁵ to respond to changes in the market, the progress of research, etc.

¹⁵ EBPM: Evidence-Based Policy Making

- Building frameworks for the implementation of R&D by bringing together, centering on the QST, academia and private companies for the development of the DEMO and for fostering private companies (MEXT)

Since building a framework system after the decision to transition to work on the DEMO will create a lag in the progress toward commercialization, the government will begin in fiscal 2023 discussions for the building of such a framework. However, at present when there is no leading body for the DEMO development, a framework will at first be established centering on the QST for promoting the participation of private companies, and the framework will proceed according to the progress made. In this way, private companies that can become the key players in the development of commercial reactors will be fostered.

- Establishing hubs for fusion technology innovation at QST to develop, relay, commercialize technologies developed in the ITER/BA Activity at QST; and for foster human resources (MEXT)

To transfer technologies owned by QST to private companies as early as possible with the aim of acquiring markets, in fiscal 2023 the government will launch a study aiming at the early establishment of fusion technology hubs, which will be engaged in initiatives from research and development to social implementation. Technical coordinators will be assigned to these hubs to connect with private companies, and the joint use of facilities and equipment possessed by QST will be promoted for private companies.

- Clarifying future career paths and systematically fostering human resources engaged in fusion energy in industry, academia, and government (MEXT)

To strategically foster human resources engaged in fusion energy such as the development of the DEMO reactor, the government will promote the dispatch of young human resources from academia and industry, including the nuclear energy field, to the ITER Project, JT-60SA and other large-scale projects in Japan and abroad. Consideration will be given to ensuring the career paths of those dispatched, including seconding them to projects while allowing them to keep their positions at the organizations or companies they belong to, so as to promote the continued mobility of human resources active in posts related to fusion energy.

- Strengthening the fostering of human resources in Japanese universities and carrying out efforts for acquiring excellent human resources from other fields and other countries (MEXT)

To increase the number of human resources engaged in the fusion energy field in Japan, where the falling birthrate has created a shortage of human resources, the government will make efforts to secure human resources from other fields and other countries by promoting the interdisciplinaryization of fusion science and realizing the broad circulation of “brains.” The government will promote study of the provision of educational programs encouraging the participation of students and young

researchers from numerous universities and human resources from abroad and enabling the study of fusion energy from a broad holistic view.

- Implementing outreach activities to deepen the understanding of citizens (MEXT)
The government will strengthen the functions of the outreach headquarters¹⁶ and promote activities for deepening citizens' understanding of fusion energy to advance the practical application of fusion energy while enhancing its social acceptability.

4. Conclusion: Society realized by fusion energy

Fusion energy will not only solve the energy problems of Japan, which is poor in ready-to-use energy resources, as well as its environmental problems, and become the foundation for supporting Society 5.0, which is hailed as the model for the future society Japan should aim for, but it will also enable the sustainable development of humankind on a global scale. It is science and technology that Japan can harness to greatly contribute to the international society.

For example, if the uneven distribution of energy resources can be solved through the realization of fusion energy, wars fought in countries around the world over energy resources will be eliminated, thus truly contributing to peace and stability in the world. Moreover, by not only becoming a substitute for existing energy resources but also a source of power for space and deep-sea exploration since it can generate a huge amount of energy from a small amount of fuel, fusion energy is expected to open up unexplored frontiers for humankind. Beyond Japan's national strategy, such a future awaits.

Problems that still need to be solved for the realization of fusion energy remain, and since we must respond to changing markets, advances in research and so on, Japan will regularly update and revise its national Fusion Energy Innovation strategy.

¹⁶ The outreach headquarters (implementing bodies: MEXT, QST, National Institute for Fusion Science, universities, etc.) was established in February 2019 with the aim of centralizing the outreach activities conducted separately by universities and research institutions and conducting such activities in a strategic and integrated way.