Energy Studies Institute

Policy Brief 67

30 November 2023

Is Nuclear Fusion a Game-Changer in the Making for Nuclear Power?

Nur Azha Putra

SYNOPSIS

A series of breakthroughs in nuclear fusion experiments suggest nuclear fusion could potentially reach the level that would make it suitable as a low-carbon option for generating power in the next few decades. It appears that the focus of research and development in the public and private sectors has shifted from theoretical exploration to commercial feasibility. These breakthroughs strengthen the belief that it is no longer a question of whether nuclear fusion can be achieved but rather how much of it can be sustained to achieve a net energy gain. While these questions are being explored in the laboratories, outside it, there is growing momentum within the international community to strengthen global cooperation and work towards an international safety regime for nuclear power plants and early-stage facilities.

KEY POINTS

- Recent results in nuclear fusion experiments suggest that the technology might be feasible sooner than later.
- The private sectors in Europe and North America have made significant strides in nuclear fusion research and development (R&D).
- There is a growing momentum in multilateral cooperation in nuclear fusion R&D.
- Governments can do more to support nuclear fusion experiments by establishing legal and regulatory frameworks that facilitate R&D.

INTRODUCTION

Nuclear fusion occurs when two nuclei combine to form a single nucleus and, in the process, release an enormous amount of energy. It is the primary energy source for the sun and other stars. Nuclear fusion holds immense promise as a clean and virtually unlimited energy source. Still, its practical realisation has long been a challenging endeavour, even after nearly 80 years of research and development (R&D) and 6 billion dollars' worth of public and private sector investments across 30 countries. However, recent breakthroughs in nuclear fusion experiments appear to have resolved the theoretical argument of whether fusion can be achieved, repeated, and generate net energy gain in a controlled environment. It is no longer a matter of if. Rather, it is now a matter of when nuclear fusion can be safely scaled up for power generation.

The recent breakthroughs in nuclear fusion experiments suggest that nuclear fusion could be a potential low-carbon option for power generation. The timeline with which nuclear fusion may reach commercial feasibility appears to be between the next two to three decades. The recent successes have led to renewed enthusiasm from both the public and private sectors and strengthened the notion that further development can be achieved with more advanced engineering equipment and sophisticated facilities. It also raises the question of whether the international community is ready for the next wave of innovation in nuclear energy while ensuring

Energy Studies Institute
29 Heng Mui Keng Terrace,
Block A, #10-01, Singapore 119620
Tel: (65) 6516 2000 | Fax: (65) 6775 1831
esi.nus.edu.sg

that nuclear safety and security remain at the heart of future development.

ANALYSIS

General Approaches in Fusing Atoms

There are several approaches to nuclear fusion. Among them, two methods, namely laser-driven inertia confinement fusion and magnetic confinement fusion, stand out due to their effectiveness in creating the required conditions for nuclear fusion to occur.

The laser-driven inertia confinement fusion approach uses high-powered laser beams to heat a hydrogen pellet (fusion fuel), comprising deuterium and tritium isotopes, thereby forcing both to fuse, which would lead to the release of energy in the process. As for the magnetic confinement fusion approach, magnetic fields are used to induce fusion reactions within the plasma. Plasma is the matter where fusion reactions happen. The more stable the plasma is, the greater the likelihood that fusion reactions will occur and be sustained. To achieve this condition, nuclear scientists use devices such as tokamaks and stellarators to confine the plasma and sustain the required conditions for fusion to occur. Both approaches have been used for decades and have led to incremental success over the years. However, there have been a series of breakthrough developments in the last two years.

Recent Developments

In March 2022, a notable breakthrough was achieved at the privately funded Tokamak Energy laboratory based in Oxford, United Kingdom (UK). The ST40 tokamak device successfully generated a plasma temperature of 100 million degrees Celsius, which is the threshold needed for commercial fusion energy. It is the highest temperature ever generated by the device.

Another notable breakthrough happened in December 2022 when the team at Lawrence Livermore National Laboratory's National Ignition Facility in the United States achieved a net energy gain during a fusion ignition experiment. The fusion ignition experiment injected 2.05 megajoules of energy in the form of a laser and achieved a return of 3.15 megajoules, or a 50% net return. A net energy gain feat was reportedly achieved again in July this year, which yielded even higher energy return, although this has yet to be verified by the Laboratory. The experiment uses lasers to induce fusion reactions (laser-driven inertia confinement fusion method).

A similar ground-breaking achievement was recorded at the Culham Science Centre facility in February 2022. The facility undertakes fusion energy research and experiments with the support of the United Kingdom Atomic Energy Authority and as part of the European fusion (EUROfusion) research programme. EUROfusion is a conglomerate of nuclear fusion research institutes in Europe, the UK, Switzerland, and Ukraine. The experiment, which used the Joint European Torus (JET) tokamak device that uses the magnetic confinement fusion approach, managed to achieve fifty-nine megajoules of sustained fusion energy over a five-second period.

In April 2023, China's Experimental Advanced Superconducting Tokamak device at the Institute of Plasma Physics, which is run by the Chinese Academy of Sciences, managed to achieve a steady-state high-constraint mode plasma operation for slightly more than six minutes. In August, China National Nuclear Corporation's Huanliu-3, a large-scale research facility for controlled nuclear fusion at the Southwestern Institute of Physics, managed to achieve improved plasma performance and stability.

Closer to Singapore, a tokamak device named Thailand Tokamak-1 (TT-1) was activated in July at the Ongkharak site in Nakhon Nayok province, Central Thailand. The Chinese Academy of Sciences' Institute of Plasma Physics donated, refurbished, and installed the device. The device was used at the Institute's facility in Hefei, China, before being shipped to the Thailand Institute of Nuclear Technology's (TINT) facility. TT-1 is based on the Chinese HT-6M design, which was first developed in 1984. TT-1 will be jointly operated with the TINT, and it is believed to be the first nuclear fusion experimental device in the ASEAN region.

Multilateral Cooperation

According to the International Atomic Energy Agency (IAEA), there are about 130 experimental devices worldwide that are dedicated to nuclear fusion R&D. These facilities include the International Thermonuclear Experimental Reactor (ITER), Korea Superconducting Tokamak Advanced Research, Germany's Wendelstein 7-X and ASDEX Upgrade.

Among these facilities, the ITER project stands out on the basis that it is the first global collaboration to build an international tokamak device. This project involves members from 35 countries. It is being built at an estimated cost of USD 22 billion to USD 25 billion. The European Union finances nearly half of the project costs (45.6%) while China, India, Japan, Korea, Russia, and the USA account for the remainder of costs equally (9.1% each). ITER is currently being constructed in Cadarache, France and will be jointly operated by the ITER members. ITER was first initiated as an international collaborative project led by the leaders of the United States and the Soviet Union at the Geneva Superpower Summit in 1985. Both countries were already, at that point, the leading nuclear power states in the world. Although the ITER project was delayed by several years due to management issues and increasing costs, it now appears on track to be fully operational in 2025.

When fully operational, ITER will initially study the potential and dynamics of deuterium-tritium (nuclear fuel) plasmas before conducting fusion experiments by 2035. In the meantime, as part of the ITER project, the Fusion for Energy (F4E) organisation, which drives the European Union's contribution to ITER, convened two roundtable discussions in 2022 and 2023, specifically for contracting and procurement officials. These events were jointly organised with the International Nuclear Law Association and the ITER Organization. Both roundtables discussed the importance of an innovative legal framework that would promote and support the successful implementation of fusion projects and the future deployment of fusion energy. A potential outcome of both roundtables is the establishment of an informal independent panel of legal experts that could provide guidance on the legal framework for nuclear fusion. The name of the panel has not been formally decided yet, but it could potentially be referred to as the International Group of Legal Experts on Fusion Energy.

Another example of a collaborative international effort is the Agile Nations working group on fusion energy regulation. The Agile Nations working group is an intergovernmental initiative that was started by the UK government in 2020 in order to foster innovative regulatory practices among like-minded member states. The group comprises the UK, Canada, Denmark, Italy, Singapore, Japan, and the United Arab Emirates. Specifically, the working group on nuclear fusion regulation includes the UK, Japan, and Canada, while Singapore and Bahrain are observers. Since its inception, the group has analysed two case studies and published a set of five recommendations on how countries could regulate the nuclear fusion industry. In summary, the working group recommends that states acknowledge the role that nuclear fusion could play in climate change and energy security; develop a regulatory framework on nuclear fusion; collaborate and adopt a harmonised approach to nuclear fusion regulation; the regulatory framework should prioritise safety and environmental protection; and finally, raise public awareness through public education.

On a broader global level, the IAEA recently announced that it will convene the first meeting of the World Fusion Energy Group in 2024. IAEA's objective in assembling this group is to bring together various experts from the public and private sectors to share information and provide more clarity on the potential for nuclear fusion deployment in the future. More details on this group will be released in due time.

The IAEA's announcement was swiftly followed up with convening a technical meeting on fusion design safety and regulation at its headquarters in Vienna, Austria, in October 2023. More than 100 participants from 23 countries, including officials from the national regulatory bodies and domain experts from the private sector, attended this meeting. The technical meeting was in response to the recent breakthroughs in fusion experiments, growing investments from the private and public sectors, and the increasing global interest in fusion power plants (FPPs). The objective of the technical meeting is to lay the groundwork for the establishment of a set of principles for the safety assessments and regulations of FPPs and early-stage fusion facilities. The IAEA's current Safety Standards do not account for FPPs and fusion facilities.

CONCLUSION

If the recent breakthroughs can be sustained, replicated, and scaled up for power generation at an economically viable cost, then nuclear fusion is almost certainly a game-changer for the power generation industry. While nuclear fusion for power generation might still be decades away rather than years, the general sentiment among nuclear scientists is that nuclear fusion leading to a net energy gain is more than just a theoretical possibility. It has now been proven that given the right controlled environment and conditions, atoms can indeed be fused to release energy. How quickly nuclear fusion can be developed further is now a matter of engineering certainty, i.e., with more advanced engineering tools and facilities, scientists could use more sophisticated equipment and advanced facilities to create more efficient conditions for fusion to occur. To that end, the private sector would require more funding from investors and policy support from governments, such as legal and regulatory frameworks that facilitate R&D. At the same time, investors are likely to channel more support to private companies if the government could enact laws and regulations that protect their investments and liabilities.

Additionally, scientific organisations could at the national, regional, and international levels develop a peer-review mechanism to assess and verify claims of breakthroughs and success from within the public and private sectors. A scientific review mechanism would further strengthen investors' confidence and protect them and the financial institutions from fraudulent claims, by companies that are eager to manufacture progress and report breakthroughs in their experiments.

WHAT TO LOOK OUT FOR

- IEA's inaugural World Fusion Energy Group meeting in 2024
- Development of International Thermonuclear Experimental Reactor project
- Agile Nations Working Group on Fusion Energy Regulation
- Thailand's Takamak-1 nuclear fusion research

Nur Azha Putra, PhD is a Research Fellow at the Energy Studies Institute, National University of Singapore.

Keywords: Nuclear Fusion, Tokamak, Magnetic Confinement Fusion, Laser-Driven Inertia Confinement Fusion, Nuclear Energy

This policy brief builds on the ESI's "Nuclear Safety Governance: Best Practices, Lessons Learned and Future Prospects" research project.