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Nuclear Fusion and its National Security Considerations

Policy Primer

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Introduction

Breakthrough technologies are emerging at an unprecedented rate. While these technologies have the potential to revolutionize humanity and uplift millions from poverty, hunger, and illness, they can also lead to the development of dangerous or harmful consequential technologies if the risks are not thoroughly understood and safeguards are not put in place. One such technology is nuclear fusion energy. Countries are racing to be the first to commercialize nuclear fusion energy, as world energy consumption is forecast to grow by 50% between 2019 and 2050, according to the U.S. Energy Information Administration,[1] driven largely by economic development in Asia, especially China and India, the development of data centers in the United States, and expansive industrialization and electrification in various regions. With the promise of affordable, safe, and nearly limitless energy, nuclear fusion is regarded as a crucial technology to propel humanity into the future.

But how does fusion work, how much money is being spent on its research and development, and what does the United States stand to lose if they fall behind in the race to commercialize fusion? This policy primer will answer those questions. It will outline the scientific foundations of various fusion technologies, survey the global fusion research landscape, and examine the related challenges. Fusion energy development straddles multiple domains: engineering, great power politics, and energy security being a few. This primer will provide readers with a comprehensive understanding of why fusion is a timely and strategic issue for the United States today.

Fusion has recently transitioned from a distant aspiration to a very achievable goal for many countries, thanks to breakthrough achievements and a subsequent appetite for fusion energy investment by public and private entities. In December 2022, Lawrence Livermore National Laboratory's (LLNL's) National Ignition Facility (NIF) achieved fusion *ignition*—the first controlled experiment in human history to produce more energy than the laser energy used to start it, according to the U.S. Department of Energy (DOE).[2] This experiment delivered a fusion yield of 3.15 megajoules from 2.05 MJ of input laser energy, making history by accomplishing what was previously thought to be impossible. DOE called it a "historic, first-of-its-kind achievement" that would "provide unprecedented capability to support NNSA's Stockpile Stewardship Program," and "provide valuable insights into the prospects of clean fusion energy."[3]

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[1] U.S. Energy Information Administration, "EIA Projects Nearly 50% Increase in World Energy Usage by 2050, Led by Growth in Asia," *Today in Energy* (September 24, 2019). https://www.eia.gov/todayinenergy/detail.php?id=41433. Accessed January 13, 2026.
[2] U.S. Department of Energy, "DOE National Laboratory Makes History by Achieving Fusion Ignition" (December 13, 2022). https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition. Accessed January 13, 2026
[3] Ibid.

Since then, NIF has replicated its success and increased its yield; in April 2025 a NIF experiment had a yield of 8.6 MJ, according to LLNL,[4] demonstrating the rapid progress that NIF has made since its initial ignition in 2022. This breakthrough proved that a fusion reaction in a lab environment can achieve Q>1 (more energy output than input, otherwise known as ignition). Since then, there has been a significant shift in the prioritization of fusion research globally.

Fusion is timely not only because of its recent scientific breakthroughs and applications to U.S. stockpile stewardship, but also because of mounting global energy needs amid a world order and U.S. grand strategy seemingly in flux. The growing global demand for abundant energy, paired with the rapidly growing energy-consuming AI industry, and fusion's potential to supply reliable baseload power, makes the energy source enormously attractive. Baseload power refers to the consistent, around-the-clock electricity needed to meet minimum demand. Fusion's ability to provide this, unlike intermittent sources like solar and wind, positions it as an alternative to fossil fuels. Fusion's appeal as a long-term baseload energy source coincides with a period of geopolitical tension and techno-economic competition, especially between the United States and China. Both nations have prioritized global fusion leadership as a strategic goal tied to their national interests. As Chinese nuclear physicist Peng Xianjue put it, "Fusion ignition is the jewel in the crown of science and technology in today's world."[5] This statement, coupled with China's prioritization of state funding for fusion research, implies that there is an undeniable race for fusion energy, which China intends on winning. In recent years, China has poured resources into tokamak reactors (which use magnets rather than lasers to initiate a fusion reaction) and is reportedly constructing what will be the world's largest laser fusion facility, projected to be 50% larger than LLNL's NIF.[6]

Looking beyond the prospect of abundant energy, fusion energy also connects to national security and economic resilience, as well as technological dominance. Reliable domestic fusion power could strengthen domestic energy security, shield the economy from energy supply disruptions and price shocks, and reduce the strategic leverage of adversaries upon whom the United States is reliant for certain energy sources. Members of Congress have framed fusion in competitive terms, noting that China's fusion strategy is "rapidly building out" and even "mimicking" DOE's research infrastructure, and warning that the United States must not lose the advantage in this field.[7]

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[4] Lawrence Livermore National Laboratory, "Achieving Fusion Ignition." https://lasers.llnl.gov/science/achieving-fusion-ignition. Accessed January 14, 2026.
[5] Stephen Chen, "China's Top Weapons Scientist Says Nuclear Fusion Power 6 Years Away," *South China Morning Post* (September 14, 2022). https://www.scmp.com/news/china/science/article/3192435/chinas-top-weapons-scientist-says-nuclear-fusion-power-6-years. Accessed January 13, 2026.
[6] Gerry Doyle, "Images Show China Building Huge Fusion Research Facility, Analysts Say," Reuters (January 28, 2025). https://www.reuters.com/world/china/images-show-china-building-huge-fusion-research-facility-analysts-say-2025-01-28/. Accessed January 13, 2026.
[7] American Nuclear Society, "Senators Probe Global Competition in Fusion Energy Deployment," ANS Newswire (September 25, 2024). https://www.ans.org/news/article-6414/senators-probe-global-competition-in-fusion-energy-deployment/. Accessed January 13, 2026.

Fusion is at the nexus of science, policy, and national security strategy. The international race to harness fusion has accelerated, and there are significant implications for future energy production, national economies, and global political power dynamics. This primer will provide a background on the science of fusion and its potential applications, then analyze the global fusion landscape, and finally discuss national security concerns, including how the United States measures up in the fusion race and what challenges must be addressed to ensure fusion's benefits are realized while risks are mitigated and dual-use technologies are properly controlled.

I. Background: The Science of Fusion

How Fusion Creates Energy

Nuclear fusion is the process by which energy is created on all stars, like our Sun. In a fusion reaction, two light atomic nuclei "combine to form a single heavier one while releasing massive amounts of energy," as explained by the International Atomic Energy Agency (IAEA).[8] The reason energy is released in this reaction is because the mass of the single heavier nucleus is slightly less than the combined masses of the two original nuclei, and due to the mass-energy equivalence principle ($E=mc^2$), a loss in mass comes with a massive release of energy. According to this formula, even a small loss of mass results in the release of significant amounts of energy. It's important to note that, as described by the first law of thermodynamics, energy in the universe can be neither created nor destroyed. It can only be converted from one form to another. Therefore, when it is said that fusion "creates," "releases," or "generates" energy, it means that mass is being converted to energy.

While fusion naturally happens on the Sun due to conducive temperature, pressure, and density conditions, Earth exists under very different conditions. Therefore, here on Earth, scientists have been studying how to recreate the Sun's energy production mechanism with earthly materials and constraints.

Most Common Isotopes in Fusion Energy Research

The most common and practical materials that are used in fusion research are two isotopes of hydrogen: deuterium (D) and tritium (T). When a deuterium nucleus fuses with a tritium nucleus, the result is a helium nucleus and one free neutron, plus a release of kinetic energy, according to DOE.[9] While a fusion reaction can occur between elements other than deuterium and tritium, D-T is

[8] Matteo Barbarino, "What Is Nuclear Fusion?" International Atomic Energy Agency (August 3, 2023). https://www.iaea.org/newscenter/news/what-is-nuclear-fusion. Accessed January 13, 2026.
[9] U.S. Department of Energy, "DOE Explains…Fusion Reactions." https://www.energy.gov/science/doe-explainsfusion-reactions. Accessed April 3, 2025.

of particular interest due to the large amounts of energy produced from such a reaction as well as the lower temperature needed to fuse (which is still an incredibly hot 100 million degrees Celsius).[10]

> Fusion can involve many different elements in the periodic table. However, researchers working on fusion energy applications are especially interested in deuterium-tritium (DT) fusion. DT fusion produces a neutron and a helium nucleus. In the process, it also releases much more energy than most fusion. In a potential future fusion power plant such as a tokamak or stellarator, neutrons from DT reactions would generate power for our use. Researchers focus on DT reactions both because they produce large amounts of energy and they occur at lower temperatures than other elements.[11]

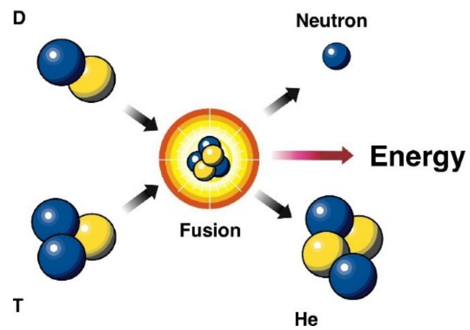

Figure 1: Fusion of deuterium (D) and tritium (T) produces a helium nucleus (He) and a neutron, releasing energy.

Why Temperatures Must Be So High for Fusion to Occur

At such high temperatures, matter exists in a plasma state—a state of matter in which electrons are freed from the atoms, according to the Princeton Plasma Physics Laboratory.[12] Plasma state is critical for fusion because it's how the atom separates into two categories, the nucleus and the electron, thus allowing the nuclei to fuse without the cushion of the electron.

Forms of Plasma Confinement and the Lawson Criterion

To create energy from a fusion reaction, plasma must be created and confined and the nuclei, free of electrons, must fuse.[13] Gravitational confinement is how our Sun, and all the stars in the universe, make energy. In stars, a combination of gravitational pressure and hot temperatures enable a fusion reaction. However, since gravity on Earth is far weaker than on stars like the Sun,

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[10] EUROfusion, "Fusion Conditions." https://euro-fusion.org/fusion/fusion-conditions/. Accessed April 3, 2025.
[11] U.S. Department of Energy, "DOE Explains…Fusion Reactions."
[12] Princeton Plasma Physics Laboratory, "About Plasmas and Fusion." https://www.pppl.gov/about/about-plasmas-and-fusion. Accessed April 3, 2025.
[13] Ibid.

this method of plasma confinement is unable to be replicated by humans at this time. There are several mechanisms that are being researched and developed to accomplish this on Earth; of particular interest are inertial confinement fusion (ICF) and magnetic confinement fusion (MCF).

In both MCF and ICF, the fundamental requirement is to reach what's called the "Lawson Criterion,"[14] which is a condition relating to the plasma temperature, density, and confinement time needed to achieve a net-positive energy output. In simple terms, the fuel must be hot enough and held together long enough at high density so that fusion reactions release more energy than was used to heat the fuel. This is a big challenge; for D-T fusion, temperatures above 100 million degrees Celsius are needed, which is several times higher than the temperature of the Sun's core. This is due to the lack of gravitational compression on Earth that sustains fusion on stars. In magnetic fusion, this temperature is achieved in a very low-density plasma, about one millionth of atmospheric density, confined for seconds or longer. In inertial fusion, much higher densities are achieved momentarily, but the confinement time is tiny—on the order of billionths of a second. Both pathways have now demonstrated the scientific feasibility of fusion burn; the task ahead is to improve and scale up these processes to a practical energy source, which will involve solving engineering challenges like continuous fuel supply and materials sourcing.

Initial Confinement Fusion (ICF)

Inertial Confinement Fusion (ICF) is a method of plasma confinement that utilizes lasers to rapidly compress and heat a tiny pellet (the size of a pencil eraser, as explained by LLNL)[15] of D-T fuel before it has time to disperse. This laser shot compresses the fuel pellet to extremely high density and temperature for a fleeting instant—just enough for fusion. LLNL's NIF is a research inertial confinement fusion facility that employs 192 lasers to accomplish the task of shooting a D-T pellet with such impressive and unlikely precision that fusion occurs, according to LLNL's website.[16] It is the world's most energetic laser, and in December 2022, achieved fusion ignition, where energy output was greater than the input.

Magnetic Confinement Fusion (MCF)

Magnetic Confinement Fusion (MCF), another method for plasma confinement, utilizes magnetic fields to shape and confine plasma to extremely hot and dense conditions, which enables the fusion of D and T. Two types of MCF devices are stellarators, which create magnetic fields with external coils and tokamaks (which is derived from a Russian acronym for Toroidal Chamber with

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[14] Phil Dooley, "Lawson's Magic Formula," ITER Organization (March 18, 2013). https://www.iter.org/node/20687/lawsons-magic-formula. Accessed January 13, 2026.
[15] Lawrence Livermore National Laboratory, "National Ignition Facility." https://www.llnl.gov/national-ignition-facility. Accessed December 23, 2025.
[16] Lawrence Livermore National Laboratory, "How NIF Works." https://lasers.llnl.gov/about/how-nif-works. Accessed December 23, 2025.

Magnetic Coils).[17] Tokamaks create magnetic fields with a combination of electric current in the plasma and external coils. Of these two, tokamaks are more widely utilized due to their ability to reach near-ignition conditions.

Fuel Cycles in Fusion Reactors, at a Glance

Understanding the fuel cycles of fusion energy is an essential foundational step in understanding its security implications, including proliferation concerns.

A fuel cycle for a fusion reactor can be described as "the process of obtaining, preparing, utilizing, and managing the fuel required for nuclear fusion reactions."[18] The "fuel" in a D-T fusion reaction are deuterium and tritium, both of which are isotopes of hydrogen. Deuterium is acquired from seawater and is extremely naturally abundant. Tritium is a greater challenge, as it is not naturally abundant and has a short half-life. Therefore, tritium is acquired by tritium breeding, which occurs in nuclear reactors. The tritium supply challenge is discussed in greater detail later in this paper.

The acquired raw deuterium and tritium must be "extracted, purified, and prepared into a form suitable for injection into the reactor,"[19] and after the fuel is "injected into the fusion reactor, where it's heated to incredibly high temperatures and confined using powerful magnetic fields (or lasers in some designs). Under these extreme conditions, fusion reactions occur, releasing energy."[20] This energy is then harnessed to generate electricity. This cycle must be repeated to generate sufficient energy to power a society.

Both ICF and MCF rely on D-T reactions, but the two types of plasma confinement have different fuel-cycle requirements due to differences in their operations and quantities of materials needed. For example, MCF requires hotter temperature conditions (100 million degrees as opposed to ICF's ~50 million degrees), and longer confinement time (minutes as opposed to ICF's seconds), but significantly less pressure (approximately 1 atmosphere as opposed to ICF's hundreds of billions of atmospheres).[21] Operationally, MCF is considered a "steady state" process, meaning it runs continuously, whereas ICF is a pulsed process, meaning it repeats discrete shots with specific starts and ends.[22] These distinctions raise important policy considerations surrounding materials management, tritium breeding, and proliferation risks, which are discussed later in this paper.

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[17] ITER Organization, "What Is a Tokamak?" https://www.iter.org/machine/what-tokamak. Accessed November 12, 2025.
[18] Sustainability Directory, "Fusion Fuel Cycle" (November 25, 2025). https://energy.sustainability-directory.com/term/fusion-fuel-cycle/. Accessed January 14, 2026.
[19] Ibid.
[20] Ibid.
[21] International Atomic Energy Agency, "Magnetic Confinement Fusion (MCF) and Inertial Confinement Fusion (ICF)." https://nucleus.iaea.org/sites/connect/FUSEpublic/SitePages/MCF-%26-ICF.aspx. Accessed March 26, 2026.
[22] Ibid.

Despite these differences, both fusion generating processes are reliant on tritium as a fuel source,[23] which is why both processes are aiming for sustainability by producing tritium internally. Put another way, a shared objective by both ICF and MCF processes is to establish a fuel cycle capable of sustaining fusion by breeding sufficient tritium internally rather than relying on external supplies, according to Oak Ridge National Laboratory.[24]

Fusion organizations across the world are attempting to solve the tritium supply issue by researching and developing internal tritium breeding capabilities. For example, ITER, which stands for International Thermonuclear Experimental Reactor and is an international collaboration to build the world's largest tokamak MCF generator,[25] is developing a comprehensive Test Blanket Module program to evaluate tritium production methods under real reactor conditions.[26] However, there is a delicate balance between breeding sufficient tritium for self-sustainment, and breeding excess to trigger or alarm regulators such as the International Atomic Energy Agency (IAEA). Thus, "the amount of tritium outside the plasma at any time must be minimized and losses eliminated wherever possible."[27] This is a prime example of potential proliferation concerns that can come out of a fusion fuel cycle.

The fusion cycle raises key nonproliferation and export control questions, including but not limited to the aforementioned tritium breeding question. Fusion fuel cycles require careful international monitoring, and regulatory consensus to support the advancement of peaceful fusion applications. These issues are explored in more detail in the proliferation and export control sections of this paper.

Key Applications of Fusion Science

Beyond its promise as an energy source, nuclear fusion has diverse applications across many domains. The pursuit of fusion technology has already driven innovation in many fields.

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[23] U.S. Department of Energy, "DOE Explains… Deuterium-Tritium Fusion Fuel." https://www.energy.gov/science/doe-explainsdeuterium-tritium-fusion-fuel. Accessed January 16, 2026.
[24] Sharon Robinson, K. Alicia Strange Fessler, and Bradley Patton, *DOE Challenges and Opportunities Associated with Accountable Nuclear Material Needs for Development and Commercialization of Fusion Nuclear Energy*, Oak Ridge National Laboratory (September 2025), p. 3. https://www.osti.gov/servlets/purl/3002214. Accessed March 11, 2026.
[25] ITER Organization, "ITER in a Few Lines." https://www.iter.org/few-lines. Accessed March 26, 2026.
[26] ITER Organization, "Tritium Breeding and Supporting Systems." https://www.iter.org/machine/supporting-systems/tritium-breeding. Accessed January 13, 2026.
[27] Chapman and Walkden, "An Overview of Shared Technical Challenges for Magnetic and Inertial Fusion Power Plant Development," p. 6.

Military and Security Applications

Fusion research is deeply intertwined with national security advancements. ICF facilities like NIF allow scientists to validate the physics of nuclear weapon behavior under extreme conditions without underground nuclear weapons testing, according to LLNL's website. [28] This stockpile stewardship role is a direct national security application; NIF's fusion experiments provide data to ensure the reliability of the U.S nuclear deterrent in the absence of testing.[29]

Fusion also holds potential to revolutionize space propulsion, which has civilian and military applications. If humanity aspires to propel heavy payloads into space, such as human beings, for the purpose of interplanetary travel, the power of the rocket's propulsion must be immensely powerful. Given the orders-of-magnitude higher energy density gain of fusion fuel compared with chemical combustion fuel, a fusion propellant shows promise for expanded space travel, according to NASA.[30]

Energy Applications

A well-known application of fusion energy is electrical power generation. Fusion offers the possibility of nearly limitless baseload electricity and zero "long-lived radioactive waste," according to the IAEA.[31] Because fusion reactions halt if the conditions are not perfectly maintained, fusion reactors have no risk of melting down.[32] Integrating fusion energy into the electric grid could greatly assist in achieving greater energy security. The steady output of a fusion reactor could complement intermittent renewables like solar and wind. Furthermore, fusion could enable energy-intensive processes like desalination at scale.

An emerging technology that is growing in popularity, as well as its demand for energy, is artificial intelligence. AI models require substantial amounts of electricity, primarily to power data centers that store, process, and transmit significant volumes of information. As AI applications spread, ensuring a steady supply of scalable, abundant energy to power the operation without overwhelming the grid will be critical.

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[28] Lawrence Livermore National Laboratory, "NIF & Stockpile Stewardship." https://lasers.llnl.gov/science/nif-stockpile-stewardship. Accessed January 12, 2025.
[29] Ibid.
[30] John Slough, "The Fusion Driven Rocket: Nuclear Propulsion through Direct Conversion of Fusion Energy" (March 25, 2019). https://www.nasa.gov/general/the-fusion-driven-rocket-nuclear-propulsion-through-direct-conversion-of-fusion-energy/. Accessed January 14, 2026.
[31] International Atomic Energy Agency, "Fusion – Frequently Asked Questions." https://www.iaea.org/topics/energy/fusion/faqs. Accessed January 14, 2026.
[32] Carley Willis and Joanne Liou, "Safety in Fusion," *IAEA Bulletin* 62, no. 2 (May 2021). https://www.iaea.org/bulletin/safety-in-fusion. Accessed January 14, 2026.

Medical Applications

The field of medicine and healthcare can benefit greatly from the development of fusion technologies. Medical radioisotopes, which are used in diagnostic and imaging devices, are currently produced in fission reactors which "face the problem of shutdown and maintenance, decommissioning, or dismantling, while the production capacity of domestic research reactors for medical radioisotopes is inadequate, and the supply capacity for medical radioisotopes faces major challenges in the future."[33] There are over 100 types of radioisotopes used in medicine, and more than 30 of them are used for diagnosing and treating diseases.[34] The radioisotope supply chain issue will need to be addressed in order to maintain and improve public health. Fusion generators could potentially yield radioisotopes as a byproduct of their operations by bombarding nuclei "of a stable isotope with particles (e.g., neutrons, protons), causing a nuclear reaction that transforms the stable nuclide into an unstable radioactive nuclide."[35] This application of fusion generators will not be evaluated in this policy primer, but the possibility of addressing the medical radioisotope supply chain crisis[36] with fusion technology is an important consideration when making decisions that will impact the fusion research and development landscape in the United States.

II. Global Fusion Landscape

Ever since the 1970s, when Soviet scientists had a breakthrough with a tokamak, fusion has been front of mind for scientists and leaders across the world. Today, many countries are working domestically, collaborating internationally, and even competing among each other to break records, achieve milestone breakthroughs, and ultimately move the world closer to self-sustaining fusion energy generation. This section of the paper first explores the historical and current international collaborative frameworks to advance fusion. Second, the section provides an overview of individual country efforts to further fusion. While not exhaustive, the paper will outline the efforts of those countries leading the push for fusion innovation.

International Cooperation

Fusion research has a strong tradition of international cooperation, driven by the enormous scientific and engineering scale of the challenge. Notably, after an initial period of Cold War secrecy due to the sensitive and adversarial nature of nuclear research for weapons development by the United States and Russia (then the USSR), fusion research was declassified in 1958 at the Atoms for Peace conference in Geneva, which broke down barriers of communication and collaboration

[33] Jia Li and Shanliang Zheng, "Feasibility Study to Byproduce Medical Radioisotopes in a Fusion Reactor," *Molecules* 28, no. 5 (February 21, 2023): 2040. https://doi.org/10.3390/molecules28052040. Accessed January 14, 2026.
[34] Ibid.
[35] Ibid.
[36] Ibid.

between the scientists of the East and West.[37] "Following a breakthrough at the Soviet tokamak, fusion research became 'big science' in the 1970s. But the cost and complexity of the devices involved increased to the point where international cooperation was the only way forward."[38]

ITER and DEMO

A prime example of exemplary international cooperation for fusion advancement is the International Thermonuclear Experimental Reactor, or ITER. This research reactor is a globally funded project, both through monetary contributions and in-kind contributions of equipment, materials, components, and peoplepower. The ITER tokamak is located in southern France but has contributors from all over the world. The primary objective of ITER is the investigation and demonstration of burning plasmas—plasmas in which the energy of the helium nuclei produced by the fusion reactions is enough to maintain the temperature of the plasma, thereby reducing or eliminating the need for external heating. ITER will also test the availability and integration of technologies essential for a fusion reactor (such as superconducting magnets, remote maintenance, and systems to exhaust power from the plasma) and the validity of tritium breeding module concepts that would lead in a future reactor to tritium self-sufficiency."[39]

ITER was born out of the 1985 Geneva Superpower Summit between U.S. President Ronald Reagan and Soviet leader Mikhail Gorbachev, where Gorbachev proposed the idea of a joint peaceful fusion project to Reagan.[40] One year later, the European Union, Japan, the USSR, and the United States became the original members of ITER. China and South Korea joined in 2003, then India in 2005. The seven signatories of the ITER agreement, which are China, the EU, India, Japan, South Korea, Russia, and the United States, "share in the cost of project construction, operation and decommissioning, and also share in the experimental results and any intellectual property generated by this project."[41] Beyond these seven signatory countries, there are a total of 27 member countries participating in ITER. There are also non-member nations that have signed cooperation agreements with ITER: Australia, Kazakhstan, and Canada.

Europe assumes most of the cost burden for ITER's construction at 45.6%. The other signatory nations assume 9.1% of the burden each, including the United States. Each member state contributes specialized hardware—for instance, superconducting magnet coils from Japan and Russia, cryogenics components from India, and advanced diagnostics from the United States and Europe.

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[37] World Nuclear Association, "Nuclear Fusion Power" (June 5, 2025). https://world-nuclear.org/information-library/current-and-future-generation/nuclear-fusion-power. Accessed January 15, 2026.
[38] Ibid.
[39] ITER Organization, "ITER in a Few Lines." https://www.iter.org/few-lines. Accessed January 15, 2026.
[40] ITER Organization, "The Road to ITER." https://www.iter.org/project/road-iter. Accessed January 15, 2026.
[41] ITER Organization, "ITER Members." https://www.iter.org/about/iter-members. Accessed January 15, 2026.

After the completion of ITER research, many countries will develop domestic DEMO plants to continue the research and application of tokamak technology. DEMO is short for DEMOnstration plant.[42] DEMO plants are intended to apply and build upon the research that comes out of ITER. They will be simpler with fewer diagnostics, and they will be focused on "the capture of energy" rather than "the exploration of plasma regimes."[43] Many ITER members are planning to build DEMO plants in coming decades, including China, Japan, India, South Korea, Russia, and the United States.

EUROfusion

EU countries as well as non-EU European countries support fusion R&D through a coordinated program among its member states and associated non-member countries, such as the UK and Switzerland. This coordinated program is called EUROfusion, or the European Consortium for the Development of Fusion Energy. EUROfusion consortium pools resources from "28 member institutes, 3 associated partners, and 162 affiliated entities from across Europe."[44] There are 29 participating countries in EUROfusion: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and the United Kingdom. This consortium came to fruition in October 2014, with the aim to fund fusion research and development activities "on behalf of the European Commission's Euratom programme within 26 EU member states, while Switzerland, Norway and the United Kingdom participate in the activities with their national fusion budgets."[45] EUROfusion's goal is to harness fusion energy for peaceful purposes and pave the way for abundant energy production by funding and supporting fusion activities in Europe.

Europe's Joint European Torus (JET), a magnetic confinement fusion research center located at the Culham Centre for Fusion Energy in Oxfordshire, UK, was a tokamak style machine that held fusion records and contributed heavily to fusion research. Over 31 laboratories across Europe supported JET, and it was attributed with laying the foundational groundwork for ITER. According to the ITER website, in February 2022 the JET tokamak "achieved a first-ever sustained, high-confinement plasma using the same wall materials and that ITER will use." This experiment "set a world record for the most energy produced in a single fusion shot, generating 59 megajoules of heat from fusion reactions in a sustained manner."[46] In 2023, it broke its own record by delivering 69 MJ of energy,

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[42] ITER Organization, "After ITER." https://www.iter.org/fusion-energy/after-iter. Accessed January 15, 2026.
[43] Ibid.
[44] EUROfusion, "Members." https://euro-fusion.org/eurofusion/members/. Accessed January 15, 2026.
[45] EUROfusion, "About EUROfusion." https://euro-fusion.org/eurofusion/. Accessed January 15, 2026.
[46] "JET Makes History, Again" (February 14, 2022). https://www.iter.org/node/20687/jet-makes-history-again. Accessed January 15, 2026.

“which is the amount of energy required to boil 26 litres of water from room temperature.”[47] This is a significant energy output, but still falls short of NIF’s net energy gain achievements.

> The JET result ought to be put into perspective by comparing to other fusion projects, of which NIF is the most advanced. The 2023 JET fusion energy output of 69 MJ was clearly higher than the NIF result of 3.1 MJ, so JET has the World Record of total energy produced in a fusion device. However, the NIF result represents the achievement of net energy gain in a fusion device for the first time. The JET press release does not talk of fusion energy gain in the plasma, but from other sources it can be gleaned that the ratio of energy out/energy in was about 0.3, hence a long way from a net gain. So, while the JET result was certainly an advance, the NIF result was a milestone.[48]

JET is no longer operational and has been in the decommissioning phase since December 2023, but it provided valuable experimental research and data for ITER. Looking ahead, the EU’s long-term strategy centers on building a DEMO fusion power plant after ITER to demonstrate commercial-state electricity generation; concept design and materials research for DEMO are underway via the EUROfusion consortium.

Broader Approach Agreement

Europe and Japan have a partnership called the Broader Approach Agreement, which supports the development of three fusion facilities in Japan “for the benefit of both parties.”[49] The three facilities include the JT-60SA in Naka, which is “the most advanced tokamak in the world, about half the size of ITER,”[50] and will “allow for an understanding of how plasmas can be confined under high pressure over long periods of time;”[51] the International Fusion Materials Irradiation Facility in Aomori, where “candidate materials for use in an energy producing fusion reactor can be fully qualified;”[52] and the International Fusion Energy Research Centre in Rokkasho, which “houses a number of projects to support ITER and DEMO… [including] the construction of a remote operation

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[47] John Carr, “New Fusion Record: A Reality Check,” *Global Warming Policy Foundation* (February 12, 2024). https://thegwpf.org/new-fusion-record-a-reality-check/. Accessed January 15, 2026.
[48] Ibid.
[49] European Commission, “The Broader Approach.” https://energy.ec.europa.eu/topics/research-and-technology/fusion-energy-and-iter/broader-approach_en. Accessed January 15, 2026.
[50] Ibid.
[51] Ibid.
[52] Ibid.

room from which ITER operational data can be analyzed in real-time, and… a state-of-the-art supercomputer."[53]

UK Agreements with Canada and the United States

There are also other cooperative programs, ranging from more to less formal in nature. For example, in 2024 it was announced that CNL (Canada Nuclear Laboratories) and UKAEA (United Kingdom Atomic Energy Authority) "signed a collaboration framework agreement to partner on the development of technologies in relation to the management of tritium, a fusion energy fuel,"[54] which directly followed the signing of a Memorandum of Understanding between the two countries to collaborate on, among other things, "research and development, regulatory harmonization, and skills and workforce development."[55] This is in addition to the strategic partnership formalized by the UK and United States in 2023, called the "Strategic Partnership on Fusion Energy…[to] support the UK's £650 million Fusion Futures programme, which is ensuring the UK remains at the cutting-edge of innovation—with training opportunities and dedicated funding for fusion companies."[56] This partnership aims to mutually benefit both signatories by establishing a pipeline of knowledge transfer and shared research and development.

IAEA

Beyond partnerships and agreements, international organizations also foster a sense of international cooperation. The International Atomic Energy Agency (IAEA) primarily ensures the safe and peaceful development and use of nuclear science and technology through on-site verification activities. The agency also hosts a biennial Fusion Energy Conference and coordinates research initiatives.

Individual Country Efforts and Milestones

United States

The United States has long been a leader in fusion science, with federal support for fusion research dating back to the 1950s. According to the Government Accountability Office, or GAO, "the United States began to fund magnetic confinement fusion research at national laboratories in 1951"[57] and in 1963 "the Atomic Energy Commission, a DOE predecessor agency, began funding laser fusion

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[53] Ibid.
[54] UK Atomic Energy Authority, "UKAEA and CNL Partner to Accelerate Fusion Energy Development," GOV.UK (February 14, 2024). https://www.gov.uk/government/news/ukaea-and-cnl-partner-to-accelerate-fusion-energy-development. Accessed January 15, 2026.
[55] Ibid.
[56] Ibid.
[57] Todd Kuiken, *Toward Commercial Fusion Energy: Considerations for Congress*, Congressional Research Service, R48866 (February 27, 2026). https://www.congress.gov/crs-product/R48866. Accessed March 11, 2026.

research."[58] In 2022, the United States achieved a breakthrough with LLNL's NIF achieving the first-ever controlled fusion experiment to reach ignition. In other words, for the first time in a controlled lab environment, a fusion reaction produced more energy than the energy that was consumed by the system to initiate the reaction. Since its initial breakthrough, NIF has repeated its success with higher yields several times.

U.S. fusion research and development spans both magnetic confinement fusion (MCF) and inertial confinement fusion (ICF) approaches. For example, private company Commonwealth Fusion Systems, which spun out of MIT, is constructing an MCF facility called the SPARC tokamak that aims to "become the world's first commercially relevant fusion energy machine to produce more energy from fusion that it needs to power the process—a threshold called net energy generation or Q>1."[59] They plan to meet this goal by 2027. Meanwhile, LLNL's NIF continues to advance an ICF approach through laser-driven fusion research.

U.S. government support in fusion has grown considerably. Commonwealth Fusion Systems has raised over $2 billion in capital thus far. In 2019, the Department of Energy announced the Innovation Network for Fusion Energy (INFUSE) to foster a network of fusion experts and an exchange of knowledge and capabilities across the national laboratory complex to advance fusion. In 2023, the DOE funded over $150 million of fusion research efforts.[60] In October of 2025, the Department of Energy announced its "Fusion Science and Technology (FS&T) Roadmap, a national strategy to accelerate the development and commercialization of fusion energy."[61] The goal of this roadmap is to "align public investment and private innovation to deliver commercial fusion power to the grid by the mid-2030s."[62] The roadmap establishes a strategy that ties together critical infrastructure development, the integration of supercomputers and artificial intelligence into fusion research, and bolstering public-private partnerships and workforce development.

There is plenty of private investment into fusion research as well; as of 2023, according to the Fusion Industry Association, there were over 40 private fusion companies globally "attracting $6.2 billion in investment,"[63] and 25 of those 40 companies on the 2023 roster were in the United States. This makes America the world's top hub for fusion innovation. The U.S. private sector's approach to

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[58] Ibid.

[59] Commonwealth Fusion Systems, "SPARC." https://cfs.energy/technology/sparc. Accessed January 15, 2026.

[60] Jane Nakano, "The United States Looks to Fusion to Re-Inject Energy into Global Climate Efforts," Center for Strategic and International Studies (December 8, 2023). https://www.csis.org/analysis/united-states-looks-fusion-re-inject-energy-global-climate-efforts. Accessed January 15, 2026.

[61] U.S. Department of Energy, "Energy Department Announces Fusion Science and Technology Roadmap to Accelerate Commercial Fusion Power" (October 16, 2025). https://www.energy.gov/articles/energy-department-announces-fusion-science-and-technology-roadmap-accelerate-commercial. Accessed January 15, 2026.

[62] Ibid.

[63] Jane Nakano, "The United States Looks to Fusion to Re-Inject Energy into Global Climate Efforts."

fusion research and development pairs with the U.S. government's complementary strategy; the government "aims to reduce the regulatory burden on U.S. companies, clearing the pathway to bring fusion energy to the grid faster."[64] This combination of research and development at the national laboratories, increased federal support, and private-sector growth positions the United States as a key player in the global fusion race.

China

China has rapidly expanded its fusion program with strong state support. In the field of magnetic fusion research, China's EAST tokamak set a world record in January 2025 by sustaining a high-temperature (100 million °C) plasma in steady-state for 1,066 seconds,[65] which is a landmark in long-duration confinement. This is a huge advancement for magnetic confinement fusion because it demonstrates that plasma can be kept at the incredibly high temperatures necessary for fusion for long durations without drastic fluctuations in plasma temperature. The longer that the plasma can be kept at a high temperature, the more time the atomic nuclei have to collide and fuse to produce energy. If the plasma becomes unstable or cools too quickly, the reaction stops, and the system fails to produce more energy than it consumes. Since MCF relies on continuous fusion of nuclei, long durations are critical for a fusion-friendly environment. China is also planning to construct a new China Fusion Engineering Test Reactor (CFETR) as well as Comprehensive Research Facilities for Fusion Technology (CRAFT) in Hefei as a bridge between ITER and DEMO, two other global-scale fusion research projects that are explained later in this paper. CFETR and CRAFT will further advance MCF fusion research and development for ITER, in China.

In parallel, China is investing in ICF capabilities: a large laser fusion research center, supposedly called the Laser Fusion Major Device Laboratory, according to construction documents shared with Reuters, appears to be being built in Mianyang, with an experimental chamber reportedly 50% larger[66] than LLNL's National Ignition Facility in the United States, indicating a capacity for enormous laser energies. While this does insinuate a push by China to invest in fusion energy research, it may also indicate a new capability for nuclear weapons research.

As of late 2023, China is "reportedly leading the world in fusion technology-related patent filing, followed by the United States, the United Kingdom, and Japan."[67] A prominent U.S. academic on

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[64] Asmeret Asghedom, Raymond Hughes, and Brandt Mabuni, "Energy Technology Competition: Is the United States Keeping Pace?" in Kimberly Peh and Michael Albertson, eds., *In Search of Strategic Advantage: Understanding the Landscape of Technology Competition* (Center for Global Security Research, Lawrence Livermore National Laboratory, November 2025), p. 129. https://cgsr.llnl.gov/sites/cgsr/files/2025-11/CGSR-Occasional-Paper-Technology-Competition_web_final.pdf. Accessed January 15, 2026.
[65] "Chinese 'Artificial Sun' Sets New Record in Milestone Step Toward Fusion Power Generation," Chinese Academy of Sciences (January 21, 2025). https://english.cas.cn/newsroom/cas_media/202501/t20250121_899052.shtml. Accessed January 15, 2026.
[66] Doyle, "Images Show China Building Huge Fusion Research Facility, Analysts Say."
[67] Jane Nakano, "The United States Looks to Fusion to Re-Inject Energy into Global Climate Efforts."

China has questioned whether China is utilizing fusion research to advance not only its energy initiatives, but military capabilities as well. Goodrich writes, “several of China’s most advanced fusion initiatives—particularly in laser and pulsed-power Z-pinch inertial confinement—are led by China’s nuclear weapons research lab, use technologies long associated with nuclear weapons simulation, and operate under a civil-military model that is rarely acknowledged publicly but visible in plain sight.”[68]

European Nations

Alongside cooperative research, EU nations are also conducting independent research. Germany has the Wendelstein 7-X stellarator, which is now the largest stellarator in the world,[69] and France has the WEST tokamak, focusing on plasma stability and materials. Several European governments have boosted fusion funding as well. For example, Germany announced in 2023 a €1 billion over five years for fusion research and development.[70] This program is aimed to bolster their domestic fusion efforts and remain competitive in the race as well.

The UK has a strong domestic fusion effort with both public and private components. The UK government is investing heavily in fusion commercialization efforts, from the STEPfusion tokamak to the UK Atomic Energy Authority, to reap the benefits of being among the first to commercialized fusion. In October of 2023, the enactment of the UK’s Energy Act 2023 made them the first nation to develop a regulatory framework for fusion development,[71] which uniquely positioned them to develop fusion technologies smoothly and safely.

The UK Atomic Energy Authority (UKAEA) operated JET alongside the partner countries in the EU, before its closure. It is now focused on developing the STEP (Spherical Tokamak for Energy Production) prototype, which will be a compact fusion pilot plant planned to deliver net electricity and prove commercial viability of the technology by 2040.[72] The UK government has demonstrated an interest in fusion research; the government has partnered with countries such as the United States to develop strategic partnerships to advance fusion technology. The UK-U.S. Strategic Partnership on Fusion Energy supports “the UK’s £650 million Fusion Futures programme, which is ensuring the UK remains at the cutting-edge of innovation with training opportunities and dedicated

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[68] Jimmy Goodrich, “Fusion and China’s Quest for Energy Independence,” University of California Institute on Global Conflict and Cooperation (May 27, 2025). https://ucigcc.org/blog/fusion-and-chinas-quest-for-energy-independence/. Accessed January 15, 2026.
[69] “New Records on Wendelstein 7-X” (June 10, 2025). https://www.iter.org/node/20687/new-records-wendelstein-7-x. Accessed January 15, 2026.
[70] Jane Nakano, “The United States Looks to Fusion to Re-Inject Energy into Global Climate Efforts.”
[71] “Biggest Piece of Energy Legislation in the UK’s History’ Will Support UK’s Fusion Development” (December 4, 2023). https://www.fusionindustryassociation.org/biggest-piece-of-energy-legislation-in-the-uks-history-will-support-uks-fusion-development/. Accessed January 15, 2026.
[72] Ibid.

funding for fusion companies."[73] Beyond the United States, the UK has also partnered with Canada to advance tritium fuel cycle technologies.[74] The UK hosts a handful of private fusion energy companies beyond STEP Fusion; Tokamak Energy is developing high-field spherical tokamaks with high-temperature superconducting magnets,[75] and First Light Fusion is pursuing an inertial approach with hyper-velocity projectiles.[76]

Japan

Japan has a robust fusion sector and is a major partner in international fusion projects. Domestically, Japan's flagship device was the JT-60 tokamak, built in the 1980s by the Japan Atomic Energy Research Institute in the city of Naka. The original objective of the JT-60 tokamak was to "investigate plasma confinement and heating in reactor-grade hydrogen plasmas and to conduct an integrated test of associated fusion technologies."[77] The JT-60 was recently upgraded to JT-60SA in collaboration with ITER. The SA stands for "super, advanced" according to jt60sa.org, and in September 2024, it was certified as the world's largest tokamak.[78] This is an important designation, because "creating conditions that are relevant for fusion such as high temperatures and high density and maintaining those conditions in the plasma core is more feasible with a bigger device."[79] Japan also operates the Large Helical Device (LHD), a stellarator that confines plasma using helical magnetic fields instead of the strong plasma currents used in tokamaks. It was the world's largest stellarator prior to Germany's W7-X. Additionally, Japan is deeply involved with ITER. For example, Japan has manufactured key components for ITER and is planning for the construction of its own DEMO reactor, called JA-DEMO, "in the 2040s-2050s to demonstrate steady and stable power generation beyond several hundreds of MW and fusion output of 1500 MW or higher. JA-DEMO will be designed to demonstrate tritium self-sufficiency, plant availability and a positive energy balance across the plant."[80]

South Korea

South Korea has emerged as another key player in fusion, primarily through its superconducting tokamak KSTAR, which stands for Korea Superconducting Tokamak Advanced Research. KSTAR has set records in recent years for high-temperature, long-duration plasma operation. In late 2020,

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[73] UK Atomic Energy Authority, "UKAEA and CNL Partner to Accelerate Fusion Energy Development."
[74] Ibid.
[75] Tokamak Energy, "Our Fusion Energy and HTS Technology." https://tokamakenergy.com/our-fusion-energy-and-hts-technology/. Accessed January 15, 2026.
[76] First Light Fusion, "Our Technologies." https://firstlightfusion.com/technologies/. Accessed January 15, 2026.
[77] M. Yoshikawa, "An Overview of the JT-60 Project," *Fusion Engineering and Design* 5, no. 1 (1987): 3–8. https://doi.org/10.1016/S0920-3796(87)90520-5. Accessed January 15, 2026.
[78] Samuel Davis, "JT-60SA Certified as World's Largest Tokamak," JT-60SA Official Website (October 18, 2024). https://www.jt60sa.org/wp/jt-60sa-certified-as-worlds-largest-tokamak/. Accessed January 15, 2026.
[79] Ibid.
[80] ITER Organization, "After ITER."

KSTAR sustained a 100 million °C plasma for 20 seconds continuously, which was the first device in the world at the time to maintain such a high temperature for longer than 10 seconds. This record was accomplished through joint research between Seoul National University in South Korea and Columbia University in the United States.[81] Alongside KSTAR, South Korea is actively planning a next step device after ITER called the K-DEMO reactor, with ambitions to reach net power generation by 2050. A prerequisite test facility named SUCCEX (Super Conducting Conductor Experiment) began construction in 2014 and was officially launched by the Korean government in 2021. "The SUCCEX magnet is being developed to evaluate superconducting Cable-in-Conduit Conductor (CICC) samples for future fusion magnets."[82]

Russia

Russia has played a foundational role in fusion research for many decades and continues to do so today. In the late 1950s, during the time of the Soviet Union, Soviet scientists pioneered the world's first tokamak fusion machine. They developed the T-1 tokamak in 1958, followed by other more advanced machines in later years.[83] In 1968, a Soviet tokamak achieved a breakthrough in reaching "temperature levels and plasma confinement times—two of the main criteria to achieving fusion—that had never been attained before."[84] This breakthrough catapulted the world into tokamak research, which continues to this day.

Today, Russia is a core partner of the ITER project,[85] providing a forum for fusion cooperation among Russia, the EU, and United States, despite their geopolitical tensions. Despite Russia's political challenges and fraying relationships with European countries and the United States due in large part to the conflict in Ukraine, there is no language in the ITER constitution permitting a country to be terminated from the project.[86] Furthermore, ITER is a project that relies on deep international cooperation and engagement. Rather than contributing money, most contributions are in the form

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[81] "The Korean Artificial Sun KSTAR Sets a New World Record of 20-Second-Long Operation at 100 Million Degrees," *KFE News*, vol. 27 (January 25, 2021), Korea Institute of Fusion Energy. https://www.kfe.re.kr/board.es?mid=a20402000000&bid=0026&act=view&list_no=7671. Accessed January 15, 2026.

[82] Hyun Wook Kim, Hyunjung Lee, Soo-Hyeon Park, Yong Chu, Mu-yong Kim, Seokho Nam, Young Min Park, Young-Ju Lee, Jinhwan Kim, Byung Su Lim, and Keeman Kim, "Design Updates of a Fusion Superconducting Conductor Test Facility Magnet, SUCCEX," *Fusion Engineering and Design* 215 (2025): 115040. https://doi.org/10.1016/j.fusengdes.2025.115040. Accessed January 15, 2026.

[83] V. P. Smirnov, "Tokamak Foundation in USSR/Russia 1950–1990," *Nuclear Fusion* 50, no. 1 (2010): 014003. https://doi.org/10.1088/0029-5515/50/1/014003. Accessed January 15, 2026.

[84] "60 Years of Progress in Fusion Energy." https://www.iter.org/fusion-energy/60-years-progress. Accessed January 15, 2026.

[85] "Recent Milestones: Russia" (September 9, 2024). https://www.iter.org/node/20687/recent-milestones-russia. Accessed January 15, 2026.

[86] Victor Jack, "Nuclear Fusion: The One Relationship Russia and the West Just Can't Break," *Politico* (December 21, 2022). https://www.politico.eu/article/the-one-relationship-russia-and-eu-just-cant-break-iter-fusion-ukraine-war/. Accessed January 15, 2026.

of equipment and materials. Therefore, Russia remains involved in ITER and continues to deliver equipment and participate in research for the greater good.[87]

Russia also runs an extensive domestic fusion program at the Kurchatov Institute in Moscow.[88] In 2021, the institute completed construction of the T-15MD tokamak, with intentions of supporting both global fusion research with ITER, as well as domestic research.[89] In 2023, the tokamak reached its first high-temperature plasma state.[90] This tokamak was the first fusion device built by the institute in 20 years, which demonstrates Russia's renewed prioritization of fusion testing.[91]

Russia has several additional fusion reactor projects planned for the near future. They are planning to build a demonstration reactor in 2033, called DEMO-FNS, to further expand upon ITER's research on tokamak reactors. After that, Russia plans to build another demonstration reactor called DEMO-RF by 2055 "to demonstrate gigawatt levels of electric power with deuterium-tritium fusion reactions."[92] Russia has a state nuclear organization called Rosatom, which is at the center of Russia's international cooperation and domestic development around fusion energy.

India

India joined fusion research and development efforts more recently but has made significant strides. According to ITER, India's first tokamak, Aditya (synonym of the word "sun" in Hindi), "is the first indigenously designed and fabricated tokamak in India."[93] It has been operational since 1989 and recently upgraded to Aditya-U.[94] It is a medium-sized tokamak that is used in research of high temperature plasma confinement. The now-upgraded Aditya-U is routinely involved with experiments that support the ITER project, contributing "to the international database of experimental results in the following areas: disruption mitigation, spontaneous and deliberately triggered disruptions and runaway electron generation and mitigation."[95] In other words, the tokamak is conducting research to better understand what causes "instabilities that may develop within the tokamak plasma and lead to the degradation or loss of the magnetic confinement of the

[87] Ibid.
[88] Nuclear Threat Initiative, "National Research Center Kurchatov Institute." https://www.nti.org/education-center/facilities/national-research-center-kurchatov-institute/. Accessed January 15, 2026.
[89] Tracey Honney, "Russia's T-15MD Tokamak Achieves First Stable Plasma," *Nuclear Engineering International* (April 18, 2023). https://www.neimagazine.com/news/russias-t-15md-tokamak-achieves-first-stable-plasma-10770011/. Accessed January 15, 2026.
[90] Ibid.
[91] Ibid.
[92] ITER Organization, "After ITER."
[93] ITER Organization, "International Tokamak Research." https://www.iter.org/fusion-energy/international-tokamak-research. Accessed January 15, 2026.
[94] Ibid.
[95] Ibid.

plasma"[96] (disruptions) by studying how they start (spontaneous/triggered) and managing runaway electrons that are generated during these events in an effort to better understand how to prevent them. It is also a training center for "students in tokamak operation and research."[97] India also has another larger superconducting tokamak, the Steady-State Superconducting Tokamak-1 (SST-1), at the Institute for Plasma Research (IPR) in Gujarat, which was commissioned in 2013. SST-1 "produces repeatable plasma discharges up to ~500 ms (milliseconds) with plasma currents in excess of 75000 A at a central field of 1.5 T," and the objectives of this facility are to "study feedback and control, divertor operation, and plasma-wall interactions in steady state plasmas."[98]

India's domestic private industry has contributed greatly to the development of the ITER reactor. Most notably, Indian manufacturing company Larsen and Toubro (L&T) completed the build of the ITER cryostat in 2022, which is a 3,800-ton vacuum chamber that encases the reactor core.[99] India's contribution to ITER by way of private industry doesn't stop there; other components include in-wall shielding for the vacuum vessel, cooling water and cryogenic systems, and the diagnostic neutral beam.[100] Not only do these scientific and technological components advance the mission of ITER, but they also help advance India's fusion sector and workforce through access to advanced technologies and training.

III. National Security Considerations

Nuclear fusion energy development promises enormous benefits, but we'd be remiss not to acknowledge the very real and unique set of national and global security considerations brought forth by the advancement of fusion. Among these national security considerations are great power competition, supply chain independence, international safeguards, and addressing the possible impact to the existing nonproliferation regime. While countries such as our closest competitor, China, are building "the infrastructure, supply chains, and industrial capacity required for deployment at scale—a proven strategy Beijing has already used to lead sectors like solar panels and advanced batteries,"[101] the United States must devise and execute a uniquely ambitious and well-organized strategy in order to win the race and ensure global and geopolitical energy superiority.

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[96] ITER Organization, "Disruption Mitigation." https://www.iter.org/machine/supporting-systems/disruption-mitigation. Accessed January 15, 2026.
[97] ITER Organization, "International Tokamak Research."
[98] Ibid.
[99] "An Exceptional, Yearslong Industrial Adventure" (March 28, 2022). https://www.iter.org/node/20687/exceptional-yearslong-industrial-adventure. Accessed January 16, 2026.
[100] "India's Contributions to ITER" (February 17, 2025). https://www.iter.org/node/20687/indias-contributions-iter. Accessed January 15, 2026.
[101] Commission on the Scaling of Fusion Energy, *Fusion Forward: Powering America's Future* (Special Competitive Studies Project, October 2025), p. 11. https://www.scsp.ai/wp-content/uploads/2025/10/Fusion-Commission-Fall-2025-Report-Draft.pdf. Accessed January 15, 2026.

Just as the space race took the world by storm from the 1950s-1970s, so, too, is the race to nuclear fusion energy. The space race was catalyzed by not only peaceful motivations, but military motivations as well, and the fusion race is no different. The stakes are high; fusion promises a low-cost and nearly limitless energy source for civilians to enjoy. This promise would lead to unprecedented quality-of-life advancements and economic advantages. Nuclear fusion also presents military advantages, from more efficient weapons with higher yield, according to DOE,[102] to advanced weapons research and simulation facilities, according to LLNL.[103] The race to fusion is highly consequential.

In this section, we examine the great power competition to develop fusion, the security of critical supply chains, such as deuterium, tritium, and lithium-6, and the challenges fusion presents for existing export control and nonproliferation regimes. Each of these dimensions carries implications for U.S. leadership, competitiveness, and long-term strategic stability.

Racing for Fusion Dominance Against China

While the United States is a frontrunner in this race, China is catching up quickly. China has made fusion a national priority and is investing heavily to edge the United States out of the race and establish supremacy in fusion technology, as China has done with other energy technologies such as solar panels and lithium-ion batteries. Within twenty years, China went from having a mere two electric vehicle battery producers to producing "more than three-quarters of all lithium-ion batteries worldwide and is home to six out of the 10 largest battery makers on the planet."[104] Their strategy for lithium-ion battery and solar panel market success was centered around three main variables: supply chain domination, scaled production, and cost controls.[105] While the United States has demonstrated unmatched leadership in research and breakthroughs, China has demonstrated their ability to implement and scale a supply chain.

The United States must consider these proven strengths in China's technology roll-out capabilities when evaluating the competitive landscape for fusion. Furthermore, China is investing heavily in research and development. Unlike batteries and solar panels, fusion technology has much to be understood, tested, and discovered. China recognizes this and is prioritizing their efforts accordingly.

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[102] U.S. Department of Defense and U.S. Department of Energy, *Nuclear Matters Handbook 2020 (Revised)*, chap. 13, p 165, "Basic Nuclear Physics and Weapons Effects." https://www.acq.osd.mil/ncbdp/nm/NMHB2020rev/docs/NMHB2020rev.pdf. Accessed January 13, 2026.
[103] Lawrence Livermore National Laboratory, "NIF and Stockpile Stewardship." https://lasers.llnl.gov/science/nif-stockpile-stewardship. Accessed January 13, 2026.
[104] Xiaoying You, "'They're Just So Much Further Ahead': How China Won the World's EV Battery Race," *BBC Future* (November 13, 2025). https://www.bbc.com/future/article/20251110-how-china-won-the-worlds-battery-race. Accessed January 15, 2026.
[105] Ibid.

> According to an analysis that the Special Competitive Studies Project published [in September 2025], the Chinese government's fusion program—a nationally coordinated effort funded at $6.5 billion since 2023—recognizes this reality. That Chinese funding is three times what the U.S. federal government spent on fusion over the same period.[106]

The Chinese investment strategy differs from the United States in that it provides significant state funding rather than relying mostly on private funders.[107] Therefore, larger state support for fusion research in China is not necessarily indicative of larger monetary support overall. While private fusion in China is less transparent, there are metrics to suggest that the United States' private funding landscape is aiding in maintaining its competitive edge against China. For example, the Fusion Industry Association (FIA) 2024 members lists consists of 40 member companies. Of those 40, 25 are U.S.-based companies and only 3 are China-based.[108]

In other metrics, the United States is losing to China. For example, according to Japanese law firm Nikkei-astamuse's 2023 nuclear fusion patent ranking, China holds the most nuclear fusion-related patents in the world, with the United States coming in second.[109] According to a report by the same firm, China graduates 10 times the number of nuclear fusion-related doctorates as the United States.[110] Patented technology and an educated workforce will be vital as the world gets closer to scaling and optimizing fusion. Workforce development has been identified by the Commission on the Scaling of Fusion Energy as a top priority for the United States to ensure a strong and well-resourced fusion sector in the future.[111] The Commission recommends supporting "graduate researchers and partnerships with universities, community colleges, and trade schools,"[112] something that China is already doing.

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[106] Bob Mumgaard, "How the US Must Respond to China's Moves to Win the Fusion Energy Race," Commonwealth Fusion Systems Blog (September 26, 2025). https://blog.cfs.energy/how-the-us-must-respond-to-chinas-moves-to-win-the-fusion-energy-race/. Accessed January 15, 2026.
[107] Asghedom, Hughes, and Mabuni, "Energy Technology Competition: Is the United States Keeping Pace?" pp. 115-116.
[108] "FIA Launches 2024 Global Fusion Industry Report" (July 16, 2024). https://www.fusionindustryassociation.org/fia-launches-2024-global-fusion-industry-report/. Accessed January 15, 2026.
[109] Michael K. Henry, "Nuclear Fusion: An Overview of the Patent Landscape," Henry Patent Law (December 20, 2023). https://henry.law/blog/nuclear-fusion-an-overview-of-the-patent-landscape/. Accessed January 16, 2026.
[110] Katie Tarasov, "How the U.S. Is Losing Ground to China in Nuclear Fusion, as AI Power Needs Surge," CNBC (March 16, 2025). https://www.cnbc.com/2025/03/16/the-us-is-falling-behind-china-in-nuclear-fusion-needed-to-power-ai.html. Accessed January 16, 2026.
[111] Commission on the Scaling of Fusion Energy, *Fusion Forward*.
[112] Katie Tarasov, "How the U.S. Is Losing Ground to China in Nuclear Fusion."

Fusion leadership is a priority for both nations for good reasons. Bob Mumgaard, founder and CEO of Commonwealth Fusion Systems in the United States, argues that fusion is a "foundational tool to build an advanced society"[113] and a "trillion-dollar market,"[114] which is why the United States must not allow China to surpass their fusion superiority.

This competitive drive has ultimately led to faster progress and fruitful partnerships and collaborations. In the Commission on the Scaling of Fusion Energy's October 2025 report, Chairman Eric Schmidt urged that the United States is slowly slipping from fusion leadership while China quickly accelerates, and that "U.S. leadership in fusion is not just a matter of scientific progress—it is a geopolitical necessity to maintain technological supremacy and ensure national security."[115] This report also states that "the nation that leads in fusion will secure significant economic advantages, ensure its energy independence, and maintain its technological edge in critical areas, including AI and national security."[116] The United States' ever-growing urgency around fusion dominance underscores the importance of wining the fusion race.

Supply Chain Security

Relying heavily on foreign sources for key fusion materials could leave the United States exposed to supply disruptions or strategic pressure, making supply chain independence an important foundation for secure, long-term leadership in fusion energy. While deuterium does not pose a supply challenge due to its natural abundance and ease of access, the same cannot be said for tritium or lithium-6. Tritium, which is a hydrogen isotope of interest, as well as lithium-6, an isotope of lithium, pose unique challenges and opportunities.

Deuterium

There are no supply chain concerns with Deuterium. Deuterium is stable and abundant—every cubic meter of seawater contains about 33 grams of easily-extractible deuterium.[117] This is about 1 in every 6,500 hydrogen atoms in the ocean, or about 4.6 x 10^13 metric tons of deuterium.[118] That is a clear abundance of the isotope, but it's an even more impactful number when we understand that the small amount of deuterium that is present in one liter of water can yield the equivalent amount of energy to 300 liters of combusted oil.[119] This means that there's more than enough

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[113] Mumgaard, "How the US Must Respond to China's Moves to Win the Fusion Energy Race."
[114] Ibid.
[115] Commission on the Scaling of Fusion Energy, *Fusion Forward*.
[116] Ibid.
[117] Puja Daya, "What Is Deuterium?" International Atomic Energy Agency (January 13, 2023). https://www.iaea.org/newscenter/news/what-is-deuterium. Accessed January 16, 2026.
[118] Robert Steinhaus, "Is There a Practical Form of Nuclear Fusion?" Planet Forward (October 11, 2012). https://planetforward.org/story/is-there-a-practical-form-of-nuclear-fusion/. Accessed January 16, 2026.
[119] International Atomic Energy Agency, "Nuclear Fusion Basics" (October 8, 2010). https://www.iaea.org/newscenter/news/nuclear-fusion-basics. Accessed January 16, 2026.

readily accessible deuterium in the Earth's seawater to generate millions of years' worth of power—more than enough for all of humanity until the end of time.

Tritium

Tritium, on the other hand, requires more effort to acquire, and presents supply chain risks. It's relatively unstable with a half-life of 12 years (meaning that it decays approximately 5% per year), according to the U.S. Environmental Protection Agency, [120] making it difficult to store and maintain and vital to habitually replenish. It is not naturally abundant—in fact, it exists only in low, trace concentrations in water and in the upper atmosphere. Therefore, solving the tritium supply challenge will be vital in advancing and scaling fusion energy.

It is estimated that the current stockpile of tritium is less than 30kg, decaying every moment, and each gram can cost up to $40,000 to purchase, according to the executive director of fusion technology at the UK Atomic Energy Authority.[121] To put that into context, "the annual tritium consumption of a fusion power plant operating at 1GW fusion power is ~55.6kg per full power year, or ~152 grams per full power day."[122] There's still much work to be done to increase the supply and drive down the cost of tritium to ensure its sustainability.

Currently, much of the world's civilian tritium (roughly 2 kilograms per year) is recovered as a byproduct from Canada's CANDU (Canada Deuterium Uranium) heavy-water nuclear reactors.[123] This tritium isn't necessarily available for purchase in the commercial fusion marketplace. Rather, Canada has entered into a formal agreement with ITER to commit the roughly 2kg per year of tritium byproduct to ITER research and development efforts.[124] Operational commercial fusion plants are expected to breed enough tritium in-house to meet their fuel cycle needs. However, there still needs to be sufficient tritium to complete the research and development phase and kickstart the

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[120] U.S. Environmental Protection Agency, *EPA Facts About Tritium* (Washington, DC: U.S. Environmental Protection Agency, July 2002). https://www.nrc.gov/docs/ML0609/ML060960589.pdf. Accessed January 16, 2026.

[121] David Matthews, "UK and Canada Team up to Solve Nuclear Fusion Fuel Shortage," Science|Business (February 27, 2024). https://sciencebusiness.net/news/uk-and-canada-team-solve-nuclear-fusion-fuel-shortage. Accessed January 16, 2026.

[122] S. Zheng, D. B. King, L. Garzotti, E. Surrey, and T. N. Todd, "Fusion Reactor Start-Up without an External Tritium Source," *Fusion Engineering and Design* 103 (2016), pp. 13–20. https://doi.org/10.1016/j.fusengdes.2015.11.034. Accessed January 16, 2026.

[123] Tobey Theiding, "Tritium: A Few Kilograms Can Make or Break Nuclear Fusion," Kleinman Center for Energy Policy (March 6, 2025). https://kleinmanenergy.upenn.edu/commentary/blog/tritium-a-few-kilograms-can-make-or-break-nuclear-fusion/. Accessed January 16, 2026.

[124] *Agreement between the Government of Canada and the ITER International Fusion Energy Organization for Cooperation in the Peaceful Uses of Fusion Energy*, E105606 – CTS 2021/2 (October 15, 2020). https://www.treaty-accord.gc.ca/text-texte.aspx?lcid=1036&id=105606&t=637587081129001642. Accessed January 16, 2026.

industry, and that is the tritium that governments and companies around the world are both collaborating and competing to produce.

The UK and Canada have joined forces for their agencies, the UK Atomic Energy Authority (UKAEA) and Canada Nuclear Laboratories (CNL), to "hone new ways of generating, recycling, and purifying tritium during the fusion process so future plants don't run out."[125] Italy and the UK are collaborating to build the UKAEA-Eni H3AT Tritium Loop Facility by 2028, which is on track to being the world's largest tritium fuel-cycle facility.[126] ITER is prioritizing research and experimentation of tritium breeding technologies,[127] in collaboration with Chinese scientists and engineers.[128]

In a fusion reaction, along with helium atoms and a bunch of energy, high-energy neutrons are also released.[129] ITER is experimenting with a Test Blanket Module (TBM) program that utilizes the high-energy neutrons to breed tritium. Essentially, the blanket, which contains lithium, would absorb the byproduct neutrons from the fusion reaction and react to form a tritium atom and a helium atom. That tritium "can then by removed from the blanket and recycled into the plasma as fuel".[130]

Lithium-6

Unlike tritium, which is radioactive and decays rather quickly, lithium-6 (Li-6) is a stable, nonradioactive isotope.[131] This means that the isotope doesn't emit any energy to stabilize and can therefore be stockpiled for future use. However, much like tritium, Li-6 is extremely scarce, according to DOE.[132] Most naturally occurring lithium isotope is lithium-7, with less than 10% being Li-6.[133] Therefore, obtaining enough Li-6 for fusion requires robust enrichment capabilities (which increases the portion of Li-6 isotope in a lithium pool) and isotopic separation capabilities (which isolates the Li-6 from the Li-7). In the 1950s and 1960s, the COLEX (column exchange) process was

[125] David Matthews, "UK and Canada Team up to Solve Nuclear Fusion Fuel Shortage."
[126] David Jen, "Largest Tritium Facility Underway to Advance Fusion Power," American Society of Civil Engineers (May 19, 2025). https://www.asce.org/publications-and-news/civil-engineering-source/article/2025/05/19/largest-tritium-facility-underway-to-advance-fusion-power. Accessed January 16, 2026.
[127] ITER Organization, "Tritium Breeding and Supporting Systems."
[128] "Chinese Test Blanket System Enters Preliminary Design Phase" (March 21, 2016). https://www.iter.org/node/20687/chinese-test-blanket-system-enters-preliminary-design-phase. Accessed January 16, 2026.
[129] ITER Organization, "Tritium Breeding and Supporting Systems."
[130] Ibid.
[131] ChemLin, "Lithium-6" (December 1, 2023). https://www.chemlin.org/isotope/lithium-6. Accessed January 13, 2026.
[132] U.S. Department of Energy, "DOE Explains... Deuterium-Tritium Fusion Fuel." https://www.energy.gov/science/doe-explainsdeuterium-tritium-fusion-fuel. Accessed January 13, 2026.
[133] Ibid.

used for lithium separation, requiring large amounts of mercury, according to DOE.[134] This process, though successful at yielding Li-6, had the negative consequence of discharging mercury, contaminating equipment and surrounding soils and posing health risks.[135] Due to these issues, Li-6 enrichment by COLEX ended in 1963 and the COLEX equipment was demolished in 2018. Since then, virtually no new Li-6 has been produced for civilian purposes, and fusion researchers have had to rely on dwindling Cold War stockpiles.[136] In fact, the remaining stockpile of Li-6 in the world today was almost zero, as of 2022.[137]

This poses serious supply chain challenges for the fusion industry. According to Stephen Wheeler, Executive Director of Fusion Technology at the UK Atomic Energy Authority (UKAEA), "all self-sustaining deuterium-tritium fusion power plants require...tonnage scales of highly enriched Li-6 (30-90%)."[138] For context, this means that power plants will require tonnage levels of lithium, 30% to 90% percent of which is Li-6, which is significantly more concentrated than the percentage of Li-6 found in nature, which is roughly 7%. There currently is not any commercial enrichment of lithium happening in the United States to meet that demand. According to the World Nuclear Association, the only two countries that are actively producing Li-6 are China and Russia.[139]

However, there are promising developments in the field of Li-6 production in the United States. For example, in early 2025 researchers at Texas A&M University and ETH Zürich published their Li-6 production breakthrough that was mercury-free. The method involves "an electrochemical process...which can selectively extract lithium-6 from natural lithium solutions without the use of toxic mercury—eliminating the need for the legacy COLEX process."[140] Additionally, fission nuclear fission reactor company Kairos Power is using isotopic separation to remove Li-6 from their lithium sources so that the remaining pure Li-7 can be used in their production of FLiBe,[141] a molten salt

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[134] "EM Deactivates Colex Equipment, Advances Mercury Cleanup at Y-12," U.S. Department of Energy (October 19, 2021). https://www.energy.gov/em/articles/em-deactivates-colex-equipment-advances-mercury-cleanup-y-12. Accessed January 16, 2026.
[135] Ibid.
[136] Karl Tischler, "A Mercury-Free Path to Fusion Fuel," Fusion Energy Insights Blog (April 3, 2025). https://fusionenergyinsights.com/blog/post/a-mercury-free-path-to-fusion-fuel. Accessed January 16, 2026.
[137] Richard J. Pearson, *The Availability and Supply of Critical Natural Resources for the Realization of a Fusion Pilot Plant: Fuels for Fusion,* Kyoto Fusioneering (June 2022), slide 4. https://science.osti.gov/-/media/fes/pdf/fes-presentations/2022/Pearson_resource-availability-and-supply_presentation.pdf. Accessed January 16, 2026.
[138] Karl Tischler, "A Mercury-Free Path to Fusion Fuel."
[139] World Nuclear Association, "Lithium" (August 23, 2024). https://world-nuclear.org/information-library/current-and-future-generation/lithium. Accessed January 16, 2026.
[140] Karl Tischler, "A Mercury-Free Path to Fusion Fuel."
[141] "Bringing Flibe Back: How Kairos Power Is Producing a 1960s Molten Salt Coolant for 21st Century Reactors," Kairos Power (October 20, 2025). https://kairospower.com/internal_updates/bringing-flibe-back/. Accessed January 16, 2026.

used as a coolant and fuel solvent in advanced nuclear reactors. This may present an additional stream of Li-6 supply from the civilian industry. However, it is important to note that Kairos acknowledges the dual-use nature of Li-6, and states that they must remove Li-6 from their natural lithium "before using the material in a reactor, where lithium-6 atoms would capture neutrons to make tritium."[142] Kairos has clearly stated that they are not in the business of tritium production; proper partnerships and cooperation will be vital in tapping into their Li-6 byproduct market to breed tritium for fusion facilities. Overall, a theme is that materials and fuel supply chains for fusion must be developed with security and scalability in mind.

Proliferation, Export Control, and Safeguard Challenges

Fusion technology raises new questions for the global nonproliferation regime. According to the IAEA, "nuclear material subject to safeguards includes special fissionable material from which nuclear weapons or other nuclear explosive devices could readily be made (e.g. plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233) and source material (e.g. natural uranium, depleted uranium or thorium) which cannot be directly used for nuclear weapons."[143] Fusion reactors do not use any of the aforementioned nuclear material. Therefore, current IAEA safeguards do not allow for verification where nuclear materials as they are currently defined aren't used. While fusion reactors do not use or produce nuclear material if operated normally, there are several proliferation concerns that must be acknowledged.

A fundamental understanding of the definitions and relations of proliferation, international export control, and the IAEA safeguards will make the rest of this section more comprehensible. Proliferation refers to the spread of weapons, or materials or technologies that could be used to build weapons. International export controls are regulations that restrict the transfer of sensitive materials, equipment, or knowledge among states to prevent misuse. International safeguards are technical measures overseen by the IAEA to verify that nuclear material and activities are being used for peaceful purposes and not being diverted for military uses.

Dual-Use Concerns

A dual-use innovation is one that has both civilian and military applications. In the context of nuclear science and engineering, this refers to technologies, materials, or knowledge developed for peaceful energy production for civilian use that can also be adapted for weapons-related purposes. Dual-use concerns in nuclear science are not new or unique to fusion; they have long been discussed, studied, and addressed with fission energy. In fact, the IAEA Safeguard regime was designed specifically to mitigate the risk of nuclear activities and materials diverting from peaceful to military applications. However, fusion introduces new complexities due to its reliance on

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[142] Ibid.

[143] International Atomic Energy Agency, *IAEA Safeguards: Serving Nuclear Non-Proliferation* (June 2015), p. 8. https://www.iaea.org/sites/default/files/safeguards2015.pdf. Accessed January 16, 2026.

processes and materials not currently regulated under existing nonproliferation frameworks. As fusion energy progresses towards commercialization, it is vital to identify and address any possible dual-use capabilities. The dual-use concerns that will be addressed in this section are tritium, high-energy neutrons, lithium, and knowledge transfer.

Tritium

Tritium is necessary for D-T fusion but can be diverted to the production of optimized, high-yield nuclear weapons. This underscores the risk of tritium diversion; a fusion energy reactor's plentiful tritium supply could, if not properly secured or regulated, be used in weapons programs. Since tritium is not currently regulated under the IAEA's safeguards regime, it is imperative to address the risk of tritium diversion to ensure a safe and globally accepted development of fusion energy.

In the decades before any substantial developments had been made in the fusion energy space, conversations were being had about the risks of tritium use for nuclear weapons development. Proposals such as limiting or eliminating tritium availability were discussed but lacked the political willpower to back them.[144] Today, tritium has more applications than just weapons development, but it is crucial that its dual-use applications be addressed. As global fusion research drives up demand for tritium, controlling its production and transfer will be essential.

Export Control and 123 Agreements (which is a legal framework authorized by Section 123 of the U.S. Atomic Energy Act of 1954 for peaceful nuclear cooperation between the United States and other countries, allowing transfer of nuclear materials, reactors, and other elements for nuclear energy research and development)[145] can be modified to safeguard against the weaponization of tritium. However, purely domestic tritium breeding and handling within a country's own fusion program falls outside of international safeguards. "The fusion community should be at the forefront of pushing for the development of a legal framework to support fusion safeguards, so fusion energy can have world-wide impact."[146]

High-Energy Neutrons and Fissile Materials (Plutonium-239 and Uranium-233)

A second dual-use material in the fusion process is high-energy neutrons, which are a byproduct of a fusion reaction, according to DOE.[147] D-T fusion generators in particular "produce abundant neutrons that can be used to breed fuel for nuclear weapons," according to the Princeton Plasma

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[144] Martin B. Kalinowski and Lars C. Colschen, "International Control of Tritium to Prevent Horizontal Proliferation and to Foster Nuclear Disarmament," *Science & Global Security* 5, no. 2 (1995), pp. 131–203. https://doi.org/10.1080/08929889508426422. Accessed January 16, 2026.
[145] U.S. Department of Energy. "123 Agreements for Peaceful Cooperation." *National Nuclear Security Administration*, last updated July 11, 2025. https://www.energy.gov/nnsa/123-agreements-peaceful-cooperation
[146] Goldston and Glaser, *Safeguards for Fusion Energy Systems*, slide 8.
[147] U.S. Department of Energy, "DOE Explains...Fusion Reactions."

Physics Laboratory, a DOE national laboratory.[148] IAEA safeguards would need to have a legal mandate to be able to acknowledge this risk and prevent plutonium production in fusion reactors.

Lithium

As mentioned in previous sections, Li-6 is used to bred tritium used to generate fusion energy. While Li-6 is vital for D-T reactors, they are another dual-use material, according to the Center for Arms Control and Non-Proliferation.[149]

The existing export control regime already accounts for Li-6. For example, the NSG guidelines and national laws such as U.S. export control regulations treat enriched lithium as a controlled material and therefore control its trade.[150] However, advances in lithium enrichment technology, which have been a focus for researchers in the quest for sustainable and optimized fusion energy, may trigger the need to update the existing export control regime to account for these new materials.
In short, the challenge posed by the advancement of fusion research and development is that the fusion cycle requires and produces materials, such as tritium and Li-6, that push the limits of existing export control norms and regulations. Additional legal authority may need to be developed to explicitly bring these materials into the fold to prevent a rogue State from exploiting the fusion fuel cycle.

Fusion Technology and Knowledge Transfer

Beyond materials, certain fusion technologies as well as knowledge can also be considered dual-use, necessitating export controls and security measures. For example, ICF research overlaps with nuclear weapon research and testing technologies, which presents proliferation risks, according to the Princeton Plasma Physics Laboratory.[151]

The overall goal is to ensure that state and non-state actors cannot acquire fusion-based capabilities and knowledge for weapons development. It is a delicate and difficult balance. On the one hand, excessive restrictions could stifle scientific collaboration and commercial growth. On the other hand, complacency could allow sensitive technology and information to spread to

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[148] Goldston and Glaser, *Safeguards for Fusion Energy Systems*, slide 8.
[149] Center for Arms Control and Non-Proliferation, *Fact Sheet: Thermonuclear Weapons* (November 18, 2022). https://armscontrolcenter.org/fact-sheet-thermonuclear-weapons/. Accessed January 16, 2026.
[150] Allyn Katherine Milojevich, *Applicability of the Export Control Regimes to Fusion*, Oak Ridge National Laboratory, p. 2.
https://resources.inmm.org/sites/default/files/2023-07/finalpaper_593_0518072806.pdf. Accessed January 16, 2026.
[151] Robert J. Goldston and Alexander Glaser, *Inertial Confinement Fusion R&D and Nuclear Proliferation*, Princeton Plasma Physics Laboratory Report PPPL-4618, Princeton University (April 2011), p. 1. https://www.pppl.gov/sites/default/files/PPPL-4618.pdf. Accessed March 11, 2026.

malicious actors. Policymakers thus face the challenge of crafting export controls that target genuine proliferation-sensitive items without unduly hampering fusion research and advancement.

Gaps in International Safeguards System and Proposed Solutions

In summary, the advent of practical and sustainable peaceful fusion energy will test the adaptability of the current nonproliferation and export control regimes. Existing IAEA safeguards were not designed to account for fusion energy and all its proliferation risks, such as the sheer amount of tritium and enriched lithium in the fuel cycle, as well as technology and knowledge transfer. Demonstration projects such as ITER could serve as a testbed for developing novel international safeguard approaches.

Additionally, a revision of export control lists could ensure peaceful advancement of fusion technology, by updating them to encompass fusion-related equipment and techniques. Strong international cooperation and preemptive policy development will be needed to prevent fusion energy from inadvertently opening doors to nuclear proliferation. By acknowledging the dual-use risks, the world can work to institute appropriate verification regime before fusion power plants come online and become commonplace.

Conclusion

As fusion transitions from a distant dream to a reality that involves private industry, venture capitalists, governments, scientists and researchers around the globe, it is vital that we explore its transformative technological potential and its complex array of security considerations. This primer has surveyed the landscape of fusion research and development globally and identified key findings regarding the global competition, resource challenges, and nonproliferation considerations.

Fusion potentially offers a source of baseload energy that is abundant and safe. Recent breakthroughs, such as NIF's ignition achievement and China's record sustained plasmas in their research tokamak facilities, have dispelled doubts about fusion's fundamental feasibility. Fusion energy, if realized at scale and becomes economically viable, could bolster energy security by reducing reliance on fuel sources from other nations, drive economic growth, and contribute to a country's security and technological advancement. These benefits underscore why fusion has moved to the forefront of national agendas—there is much to be discovered, innovated, and scaled with regards to fusion; the country or countries that reach these milestones first will be well-positioned.

Global competition is growing, as is international collaboration. Many countries are now in a race for fusion, investing heavily in research and development facilities, materials, equipment, and personnel. The United States, after decades of leadership in fusion R&D, faces a strong challenge from China, whose government has invested three times the amount into fusion research and development as the United States government between 2023 and 2025.[152] U.S. allies like the EU, UK, Japan, and South Korea are also pushing forward with ambitious regional fusion development projects, and a rare moment of collaboration among the U.S., China, Russia, EU members, and other nations as seen in ITER, the research tokamak project in France. While these glimpses of cooperation have been important in the fusion research space, the prospect of commercially viable fusion has introduced competitive dynamics. Bob Mumgaard, founder and CEO of Commonwealth Fusion Systems in the United States, argues that fusion is a "foundational tool to build an advanced society"[153] and a "trillion-dollar market."[154] It's in the best interest of U.S. national security and economic dominance to maintain leadership in the race.

Key technical and supply chain resources remain due to the scarcity of tritium and Li-6, which are needed to generate fusion energy. Nonproliferation considerations are relevant to this discussion as well, as fusion technology, materials, and knowledge have dual-use applications. The current global safeguards and export control regime were designed primary with fission technology in mind, not fusion technology. These risks can be addressed by modernizing the nonproliferation regime to extend IAEA safeguards to large fusion facilities and their tritium production, tracking and controlling tritium and Li-6 flows, and updating the Nuclear Suppliers Group and Code of Federal Regulations lists to cover emerging fusion technologies more comprehensively.

Nuclear fusion is at a pivotal juncture. What was thought to be an unattainable pipe dream is here now; ignition was achieved, other breakthrough milestones have occurred, and billions of dollars have been funneled into research, development, and scaling of fusion technology. This progress is occurring against the backdrop of great power competition and a changing global energy landscape. Fusion offers an opportunity for abundant power and brings with it economic prosperity and global technological leadership. At the same time, it introduces new challenges and responsibilities. Resource challenges must be addressed, and existing nonproliferation frameworks must be revisited and updated to account for the dual-use concerns accompanied by this emerging technology. For the United States, maintaining leadership in fusion aligns with its domestic and international best interests. U.S. national labs, universities, and companies can continue to blaze the trail with their research, development, and innovation. International cooperation and partnerships can bolster our progress and legitimize our global leadership.

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[152] Mumgaard, "How the US Must Respond to China's Moves to Win the Fusion Energy Race."
[153] Ibid.
[154] Ibid.