

NUCLEAR FUSION: A POLICY BRIEF



**Western Interstate
Energy Board**

Aaron Beard, Policy Analyst – Energy and Nuclear Programs

Melanie K Snyder, Nuclear Energy Policy Senior Program Manager

Date: 2.19.25

INTRODUCTION

Fusion, the process that powers the sun and all stars in which two light atomic nuclei combine to form a single heavier one, releases vast amounts of energy, and it has long dangled the promise of being able to tap into a virtually limitless energy source.¹ A fusion reaction is about four million times more energetic than a chemical reaction such as the burning of coal, oil, or gas, and because a fusion reaction does not require that carbon-based fuels be burned to produce energy, the reaction does not emit any greenhouse gases.² Additionally, although fusion power devices can be quite large, they would not require the same kind of expansive land-use buildout or favorable weather conditions that renewables such as wind and solar require; nor be geographically dependent like geothermal or hydropower to generate energy. Fusion energy systems also are not expected to produce any high-level nuclear wastes like those that burden the fission energy sector, although some fusion devices will generate lower-level radioactive wastes. This all sounds promising; however, what is the actual state of the industry, what hazards does the technology pose, and what kind of regulatory framework exists to mitigate risks? This brief sketches answers to these questions to aid Western state energy policymakers and regulators in understanding what could be a viable electricity generating source in the not-to-distant future.

STATE OF THE TECHNOLOGY

The oft-repeated joke about fusion energy is that it is always 10 to 20 years away, no matter what year it is. However, recent rapid growth in the industry and headline-grabbing technological breakthroughs are making fusion finally look like science non-fiction. For example, in its annual survey, the Fusion Industry Association (FIA) reported that there are at least 45 fusion companies around the world; more than half of these companies started only in the last five years. In addition, reported fusion investment has gone from just under \$2 billion total in 2021 to over \$7 billion in 2024, with a notable 50% increase in public funding for these companies occurring between 2023 and 2024.³ As for those tricky timelines: 70% of respondents to the FIA survey assert that a fusion plant will deliver power to the grid by 2035 or earlier.⁴ However, not all are so optimistic: noted astrophysicist and former Argonne National Laboratory Director Robert Rosner, for example, who recently asserted that commercial-scale fusion is unlikely to be a reality in his lifetime—“and I think not in my children’s lifetime, or my grandchildren’s lifetime.”⁵

Although a full analysis of the state of fusion’s technological development is beyond the scope of this brief, a few worthwhile notes can be made. In 2022, the National Ignition Facility (NIF) at

Lawrence Livermore National Laboratory made history by achieving the first ever controlled fusion ignition—the moment when a controlled fusion reaction generates more energy than is needed to spark the reaction, or more energy “out” than “in.”⁶ Significantly, following the 2022 breakthrough, identical outcomes were repeated on three separate occasions in 2023, affirming that the initial success was reproducible.⁷ Another very recent noteworthy achievement was the WEST tokamak, run by the French Alternative Energies and Atomic Energy Commission, maintaining a plasma for more than twenty-two minutes at 50 million degrees Celsius, beating the last record of the Chinese EAST tokamak by five minutes.⁸ However, many technological challenges remain, including: lack of sufficient knowledge about the physics of plasmas; developing materials that can withstand the extreme heat and neutron damage of fusion conditions for the decades of expected operations; and, many system engineering problems associated with extracting energy from fusion reactions for electricity production.⁹

As of 2024, the United States maintains its spot as the global leader in this field. With the highest number of private companies focusing on fusion energy systems, the U.S. is at the forefront of research and development.¹⁰ However, some scientists familiar with China’s fusion facilities say that it could surpass the U.S.’s magnetic fusion capabilities in three or four years if it continues its current pace of development and spending – around \$1.5 billion a year, nearly twice the U.S. government’s fusion budget.¹¹

FUSION IN THE WESTERN STATES

Significantly, 13 of the 25 U.S.-based fusion companies have a base in the western United States, establishing the region as a leader, both nationally and internationally, in the development of fusion energy systems.¹² Looking at the Western Interconnection, companies in Colorado, Washington, and California are emerging as significant contributors to the development of fusion energy.

Table 1: Fusion companies based in, or with a significant presence in, Western states¹³

Name of company	Location of company	Fusion approach	Primary target market	Fuel source
Avalanche Energy	Tukwila, WA	Magnetic-electrostatic confinement	Space propulsion, marine propulsion	Deuterium-tritium
Blue Laser Fusion Inc.	Goleta, CA (HQ), Tokyo, Japan	Laser-driven inertial confinement	Electricity generation	Combination
Electric Fusion Systems, Inc.	Broomfield, CO	Pulsed magneto-plasma pressurized confinement	Electricity generation, off-grid energy	Lithium

Name of company	Location of company	Fusion approach	Primary target market	Fuel source
EX-Fusion	Osaka, Japan (HQ), Shizuoka, Japan (R&D), Adelaide, Australia, San Francisco, CA	Laser-driven inertial confinement	Electricity generation; hydrogen and/or clean fuels	Deuterium-tritium
Fuse	Palo Alto, CA; Napierville, Quebec, Canada	Magnetized liner inertial fusion	Electricity generation, off-grid energy	Deuterium-tritium
Helicity Space Corporation	Pasadena, CA	Magneto-inertial/plectoneme	Space propulsion	Deuterium-deuterium
Helion	Everett, WA	Magneto-inertial/field reversed configuration	Electricity generation	Deuterium-helium-3
Horne Technologies, Inc.	Longmont, CO	Hybrid magnetic/electrostatic confinement	Electricity generation, space propulsion, marine propulsion, medical, hydrogen and/or clean fuels, industrial heat	Deuterium-deuterium, deuterium-tritium, proton-boron (p-B11)
Longview Fusion Energy Systems	Livermore, CA	Laser-driven inertial confinement	Electricity generation and industrial heat	Deuterium-tritium
Magneto Inertial Fusion Technologies, Inc.	Tustin, CA	Magneto-inertial/Z-pinch	Electricity generation, hydrogen and/or clean fuels	Deuterium-tritium
TAE Technologies	Foothill Ranch and Irvine, CA	Magnetic confinement/field-reversed configuration	Electricity generation	Proton-boron (p-B11)

Name of company	Location of company	Fusion approach	Primary target market	Fuel source
Xcimer Energy Inc.	Denver, CO	Inertial confinement/laser-driven inertial confinement	Electricity generation, defense	Deuterium-tritium
Zap Energy	Everett, WA	Magnetic confinement/Z-pinch	Electricity generation	Deuterium-tritium

In addition, some recent legislative changes in CA and WA may help pave the way for the states' many fusion companies. In October 2023, California enacted Assembly Bill 1172, which distinguishes fusion energy from nuclear fission—the first time a state has done so in the U.S.¹⁴ The bill directs California's State Energy Resources Conservation and Development Commission to “include an assessment of the potential for fusion energy to contribute to California's power supply” in its 2027 integrated energy policy report, acknowledging that fusion energy systems could help the state's progress towards its renewable energy and climate mandates while also meeting its need for increased electrical grid capacity.¹⁵ In Washington, SHB 1942, “An Act relating to promoting the integration of fusion technology within state clean energy policies,” was signed into law in March 2024.¹⁶ Not only does the measure define fusion energy as clean energy, it also directs the state Energy Facility Site Evaluation Council and the Department of Health to form a state agency working group to explore pathways for permitting, siting, and licensing fusion energy plants.¹⁷

POTENTIAL RISKS, INCLUDING FUSION FUELS AND THEIR HAZARDS

Currently proposed fusion energy systems present reduced safety and environmental risks when compared to fission energy. For example, fusion energy systems pose no criticality or meltdown concerns because the reactions are difficult to sustain; any disruption results in the fusion reaction shutting down (indeed, keeping the fusion reaction sustained is one of the primary challenges associated with the technology). This contrasts sharply with fission energy, where the nuclear reactions must be carefully managed to keep them controlled. Further, fusion energy systems will not produce or use any special nuclear material such as enriched uranium or plutonium, which pose security, safety, and proliferation risks that necessitate tight regulatory control.¹⁸ Lastly, it is anticipated that fusion energy systems will not produce any highly radioactive wastes such as spent nuclear fuel, which needs to be isolated for hundreds of years and for which there is no current functional disposal program in the U.S (although many fusion systems will produce some radioactive wastes; more details on that below).

If fusion systems won't be using special nuclear materials as fuel, however, then what will they be using? While there are numerous fusion technologies under development with varying proposed fuel sources, the most prominent of these fuel sources are two isotopes of hydrogen: deuterium and tritium.¹⁹

ISOTOPES OF HYDROGEN

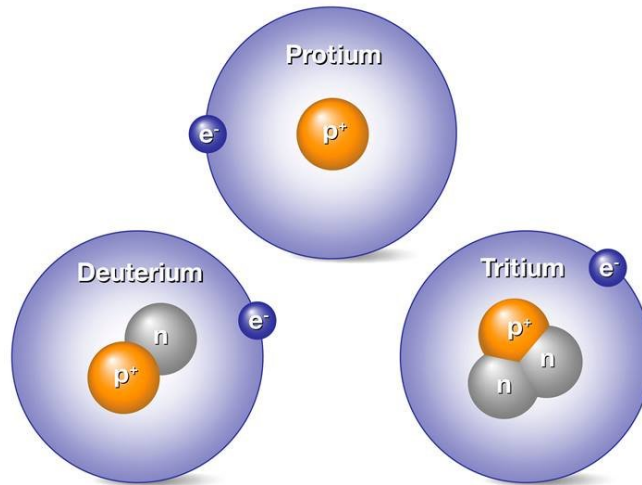


Figure 1: While all isotopes of hydrogen have one proton, deuterium also has one neutron, and tritium has two.²⁰

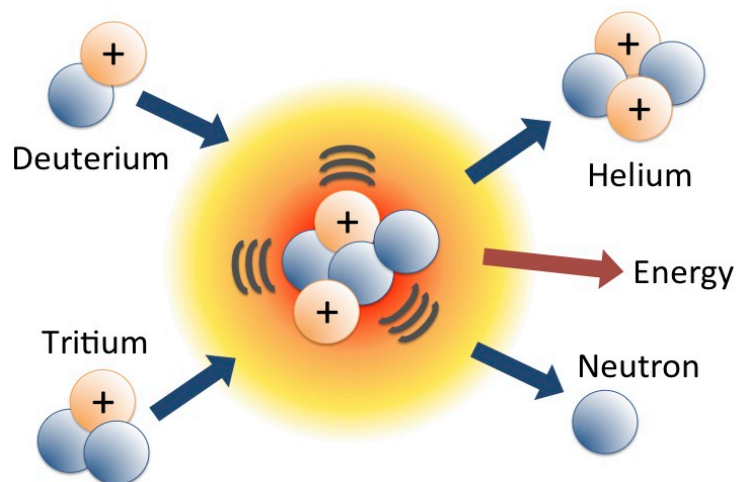


Figure 2: When deuterium and tritium fuse, they create a helium atom and an energetic neutron.²¹

Using deuterium-tritium fuel for fusion is appealing both because it reaches fusion conditions at lower temperatures than other elements, and because it releases more energy than other fusion reactions.²²

Deuterium is moderately plentiful in the Earth's oceans, and extracting it from seawater is a "simple and well-proven industrial process."²³ Tritium, on the other hand, is a radioactive isotope with a relatively brief half-life of twelve years which is found rarely in nature, and thus must be produced.²⁴ One way to produce tritium is to expose lithium to energetic neutrons, which as described above in Figure 2 are generated from the deuterium-tritium fusion reaction. Thus, there is the potential for fusion systems to breed their own tritium fuel during normal plant operations—a useful step if

developers wish to have self-sustaining power plants. This also means that lithium can be thought of as an essential fusion fuel for developers using tritium fuel. Although lithium is considered an abundant mineral on Earth, it must be either extracted from the ground or from briny water, both of which carry environmental and social costs.²⁵ Fusion energy's possible reliance on lithium for fuel may also put it in resource conflict with the lithium-ion battery industry.²⁶

WASTE MANAGEMENT

One of the enduring challenges of nuclear fission power is how to deal with the wide array of radioactive wastes that it produces. It's worth asking whether nuclear fusion energy will also create such wastes when considering a possible future buildout of this technology.

As we've already explored, the likely most common fusion reaction of deuterium and tritium produces helium and energetic neutrons. Helium is an inert gas that is not harmful to the environment or to humans.²⁷ However, the neutrons that are produced can affect the structural materials of the reactor, "activating" them – i.e., inducing radioactivity.²⁸ (To avoid this issue, some fusion developers are pursuing aneutronic fusion using fuels such as proton-boron. These fusion reactions release energy that's carried by charged particles instead of neutrons.²⁹) Similarly, if tritium fuel is present then it will contaminate the reactor components with its radioactivity.³⁰ Eventually, these irradiated materials will have to be dealt with, either via disposal, recycling, or "clearance," which in essence means that the materials have been deemed no longer radioactive enough to necessitate regulatory control.³¹

The choice of reactor materials will naturally have a strong effect on how they can later be handled once they are no longer being used in the fusion reactor. However, it is expected that if these materials are eventually handled as wastes, then they will meet the U.S. definitions of low-level wastes (LLW) or the International Atomic Energy Agency (IAEA) definition of intermediate-level waste (ILW).³² LLW can be safely disposed of in a licensed near-surface repository, which are created at or below the ground's surface with thick protective liners and coverings;³³ ILW, with higher levels of radioactivity, requires some shielding to preserve safety.³⁴ Since fusion energy systems are still in the developmental stages, the amounts of waste they will produce is not precisely known. However, some projections have suggested that the accumulation of LLW and ILW could fill existing nuclear waste disposal sites in a "short time."³⁵ Specifically, one recent study calculated that the volume of waste generated from just the power cores of several fusion reactor concepts (including the International Thermonuclear Experimental Reactor) could be up to four times as much as that generated by a typical fission reactor.³⁶ A further complication is that current nuclear waste repositories are not designed for large amounts of tritium; these wastes will either need to be de-tritiated, or disposal facilities will have to be modified to reduce potential environmental releases.³⁷

From an environmental perspective, recycling and clearance are more attractive options than disposal for fusion-produced radioactive materials. However, maximization of these two options will depend on the fusion system's design, industrial experience, more research and development, regulatory agencies' involvement, and appropriate market signals.³⁸

Although fusion energy systems are still primarily in the research and development phases, the question of what to do with the systems' byproducts is one that cannot go unanswered. Even now, the fusion scientific community is calling for waste strategies to be "developed to mitigate the impact

that the large waste volumes could have on the public perception of fusion as a viable and clean alternative source of energy.”³⁹

REGULATION

In 2019, the Nuclear Energy Innovation and Modernization Act (NEIMA) became law. This bill directed the U.S. Nuclear Regulatory Commission (NRC) to develop regulatory processes aimed at promoting advanced nuclear reactor technology – and included fusion in its definition of “advanced reactors.”⁴⁰ Following NEIMA, in January 2023 NRC staff put forward SECY-23-0001, a Policy Issue paper on “Options for Licensing and Regulating Fusion Energy Systems,” which detailed three options for the NRC Commissioners to consider:

- Option 1: Regulate fusion energy systems as utilization facilities under 10 C.F.R Parts 50-53. (The current framework for nuclear fission systems)
- Option 2: Regulate fusion energy systems under the byproduct materials framework in 10 C.F.R Parts 30-37.
- Option 3: Regulate fusion energy systems under a hybrid framework using either a byproduct or utilization approach based on potential hazards.

Figure 3: Nuclear Regulatory Commission Licensing Options.⁴¹

The main difference between the utilization facility (Option 1) vs. the byproduct materials (Option 2) framework is that the former focuses on the operation of the device – the entire interconnected nuclear power system – whereas the latter focuses merely on the control, confinement, and shielding of the radioactive material at the site. Naturally, proving that a complex nuclear power system will meet regulatory standards as designed and as sited is much more challenging than only having to prove that the radioactive material on site will be properly managed. Another notable difference between these two approaches is that “Agreement States” – states that the NRC has agreed to allow to assume some regulatory authority over nuclear materials – can regulate byproduct materials, but not utilization facilities. Some fusion developers have already been performing research and development activities under the jurisdiction of Agreement States such as California and Washington.⁴²

In the Policy Issue paper, the NRC staff’s analysis of near-term fusion energy systems led staff to recommend that these systems be regulated under Option 3. The NRC staff concluded that the fusion devices currently under development were unlikely to meet the Atomic Energy Act definition of a utilization facility, primarily because they do not use or produce special nuclear material (as noted above). However, the staff also acknowledged that yet-to-be-conceived fusion energy systems might have enhanced hazards that would need a stricter regulatory regime. In order to properly regulate these possible future fusion systems, under Option 3 the NRC staff would create a regulatory framework for fusion based on the existing byproduct material structure, and also develop decision

criteria to determine when any future fusion energy systems should be licensed under a utilization facility approach instead. In contrast, Option 2, favored by the FIA and by most Agreement State representatives, would have the NRC staff only create the fusion-specific byproduct materials framework, with no decision criteria.

On April 13, 2023, the NRC Commissioners voted unanimously to regulate fusion energy systems under Option 2.⁴³ Then-NRC Chair Christopher T. Hanson said that this choice would “protect public health and safety with a technology-neutral, scalable regulatory approach.” With this decision, the NRC staff was directed to conduct a limited-scope rulemaking to establish a regulatory framework for fusion energy systems based on the existing byproduct material framework. Staff sent the proposed rule for Commission review and approval on December 12, 2024; the anticipated publication date is May 28, 2025.⁴⁴

CONCLUSION

While improved regulatory certainty and significant technological achievements light the way for fusion power, many uncertainties still remain. Will the technology ever mature into commercial viability, and if so, when and at what cost; how will the necessary fuels be produced or obtained; and what will become of the irradiated fusion system’s components once the reactor is no longer operational? Western state energy policymakers and regulators are encouraged to keep these questions in mind as they continue to track the advancements of this technology, which could prove transformative to the energy sector.

REFERENCES

- ¹ Barbarino, M. (2023, August 3). *What is Nuclear Fusion?* International Atomic Energy Agency. Accessed February 19, 2025. <https://www.iaea.org/newscenter/news/what-is-nuclear-fusion>.
- ² *Tokamak Supporting Systems: Fuelling*. (n.d.). Retrieved February 19, 2025, from International Thermonuclear Experimental Reactor: <https://www.iter.org/machine/supporting-systems/fuelling>.
- ³ Fusion Industry Association. (2024). *The Global Fusion Industry in 2024*. Washington, DC: Fusion Industry Association. <https://www.fusionindustryassociation.org/wp-content/uploads/2024/07/2024-global-fusion-industry-report-FIA.pdf>
- ⁴ Ibid.
- ⁵ Drollette Jr, D. (2024, November 12). Introduction--Fusion, forever the energy of tomorrow? *Bulletin of the Atomic Scientists*.
- ⁶ Brady, P. (2023, November 16). *LLNL's National Ignition Facility delivers record laser energy*. Retrieved February 19, 2025, from Lawrence Livermore National Laboratory: <https://www.llnl.gov/article/50616/llnls-national-ignition-facility-delivers-record-laser-energy>.
- ⁷ Ibid.
- ⁸ Princeton Plasma Physics Laboratory. (2025, February 19). *Nuclear Fusion: WEST machine beats the world record for plasma duration*. Retrieved February 19, 2025, from Phys.org: <https://phys.org/news/2025-02-nuclear-fusion-west-machine-world.html>.
- ⁹ United States Government Accountability Office. (2023). *Technology Assessment: Fusion Energy: Potentially Transformative Technology Still Faces Fundamental Challenges*. GAO. <https://www.gao.gov/assets/gao-23-105813.pdf>.
- ¹⁰ Fusion Industry Association. "The Global Fusion Industry in 2024."
- ¹¹ Hiller, J., & Hua, S. (2024, July 8). China Outspends the U.S. on Fusion in the Race for Energy's Holy Grail. *The Wall Street Journal*. <https://www.wsj.com/world/china/china-us-fusion-race-4452d3be>.
- ¹² Fusion Industry Association. "The Global Fusion Industry in 2024."
- ¹³ Ibid.
- ¹⁴ Honney, T. (2023, October 18). California recognises fusion energy as distinct from nuclear fission. *Nuclear Engineering International*. <https://www.neimagazine.com/news/california-recognises-fusion-energy-as-distinct-from-nuclear-fission-11228490/>.
- ¹⁵ A.B. 1172, 2023-2024, (Calif. 2023) "An Act to Add and Repeal Section 25302.4 of the Public Resources Code Relating to Energy." <https://legiscan.com/CA/text/AB1172/id/2831255>.
- ¹⁶ H.B. 1924, 68th Legislature, 2024 (Wash. 2024), "AN ACT Relating to promoting the integration of fusion technology 2 within state clean energy policies; amending RCW 43.158.020; adding a 3 new section to chapter 43.21F RCW; and creating a new section." <https://lawfilesexternal.wa.gov/biennium/2023-24/Pdf/Bills/House%20Passed%20Legislature/1924-S.PL.pdf?q=20250122150007>.
- ¹⁷ Ibid.
- ¹⁸ *Advantages of Fusion*. (n.d.) Retrieved February 19, 2025, from International Thermonuclear Experimental Reactor: <https://www.iter.org/sci/Fusion>
- ¹⁹ Some other fuel sources being explored include deuterium-deuterium, proton-boron, and deuterium-helium3. Almost 70% of surveyed companies are using deuterium-tritium fuel, however. Fusion Industry Association. "The Global Fusion Industry in 2024." An exploration of all the possible fusion byproducts from any possible fuel sources is beyond the scope of this policy brief.
- ²⁰ "DOE Explains...Deuterium-Tritium Fusion Fuel." (n.d.) Retrieved February 19, 2025, from U.S. Department of Energy: <https://www.energy.gov/science/doe-explainsdeuterium-tritium-fusion-reactor-fuel>; *Tokamak Supporting Systems: Fuelling*. International Thermonuclear Experimental Reactor.
- ²¹ Schuster, E. (2022). *What is Nuclear Fusion?* Retrieved February 19, 2025, from Plasma Control Laboratory. https://www6.lehigh.edu/~eus204/lab/PCL_fusion.php
- ²² Ibid.
- ²³ Arnoux, R. (2011, March 11). *Deuterium: a precious gift from the Big Bang*. Retrieved February 19, 2025, from International Thermonuclear Experimental Reactor. <https://www.iter.org/newsline/167/631>.
- ²⁴ *DOE Explains...Deuterium-Tritium Fusion Fuel*. U.S. Department of Energy.

-
- ²⁵ MIT Climate Portal Writing Team. (2024, February 12). *How is Lithium Mined?* Retrieved February 19, 2025, from Massachusetts Institute of Technology Climate: <https://climate.mit.edu/ask-mit/how-lithium-mined>. A full analysis of lithium extraction's environmental, social, and actual costs is beyond the scope of this policy brief.
- ²⁶ Brunelli, K., Lee, L. Y., & Moerenhout, T. (2023, December 20). *Fact Sheet: Lithium Supply in the Energy Transition*. Retrieved February 19, 2025, from Center on Global Energy Policy at Columbia University School of International and Public Affairs: <https://www.energypolicy.columbia.edu/publications/fact-sheet-lithium-supply-in-the-energy-transition/>.
- ²⁷ *Fusion: Frequently Asked Questions*. (n.d.). Retrieved February 19, 2025, from International Atomic Energy Agency: <https://www.iaea.org/topics/energy/fusion/faqs>.
- ²⁸ Tan, H. Y., Yeong, C. H., Wong, Y. H., McKenzie, M., Kasbollah, A., Shah, M. N., & Perkins, A. C. (2020). Neutron-activated theranostic radionuclides for nuclear medicine. *Nuclear Medicine and Biology*, 55-68. <https://www.sciencedirect.com/topics/medicine-and-dentistry/neutron-activation-analysis>.
- ²⁹ Clynes, T. (2023, October 15). Five New Fusion Prospects, Minus the Neutrons. *IEEE Spectrum*. Retrieved February 19, 2025, from Institute of Electrical and Electronics Engineers: <https://spectrum.ieee.org/aneutronic-fusion>.
- ³⁰ Vicente, G. d., M., S., Smith, N. A., El-Guebaly, L., Ciattaglia, S., Di Pace, L., . . . Mandoki, R., et al. (2022). Overview on the Management of Radioactive Waste from Fusion Facilities: ITER, Demonstration Machines and Power Plants. *Nuclear Fusion*. <https://doi.org/10.1088/1741-4326/ac62f7>
- ³¹ *Clearance during nuclear power plant decommissioning*. (n.d.). Retrieved February 19, 2025, from Nuclear safety: an information portal of the Federal government and the Länder (German): <https://www.nuklearesicherheit.de/en/science/decommissioning-of-nuclear-facilities/residue-and-waste-management/clearance-during-nuclear-power-plant-decommissioning/>
- ³² Vicente et al. 2022. The IAEA regulatory classification of ILW generally matches the U.S. classification of Greater-Than-Class C (GTCC) LLW. Since the U.S. does not yet have a specific definition and thus no disposal pathway for GTCC LLW, this brief only discusses ILW. See Arlt, H., Brimfield, T., & Grossman, C. (2016, November 21-25). Greater-Than-Class-C Low-Level Radioactive Waste Characteristics and Disposal Aspects. Vienna.
- ³³ Vicente et al. 2022.
- ³⁴ *Radioactive Waste Management*. (2022, January 25). Retrieved February 19, 2025, from World Nuclear Association: <https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/radioactive-waste-management>.
- ³⁵ Vicente et al. 2022.
- ³⁶ Ibid.
- ³⁷ Ibid.
- ³⁸ Ibid.; El-Guebaly, L., Massaut, V., Tobita, K., & Cadwallader, L. (2008). Goals, challenges, and successes of managing fusion activated materials. *Fusion Engineering and Design*.
- ³⁹ Vicente et al. 2022.
- ⁴⁰ Nuclear Energy Innovation and Modernization Act, Public Law 115-439, 132 Stat. 5565 (2019).
- ⁴¹ *Fusion Machine*. Accessed February 19, 2025, from U.S. Nuclear Regulatory Commission: <https://www.nrc.gov/materials/fusion-energy-systems.html>.
- ⁴² Options for Licensing and Regulating Fusion Energy Systems, SECY-23-0001, U.S. Nuclear Regulatory Commission (2023, January 3): <https://www.nrc.gov/docs/ML2227/ML22273A163.pdf>. It's worth noting that the bulk of research and development activities related to fusion energy technology and plasma physics performed in the U.S. to date has been done either by or for the U.S. Department of Energy, which is not regulated by the NRC.
- ⁴³ Memorandum to Daniel H. Dorman - <https://www.nrc.gov/docs/ML2310/ML23103A449.pdf>
- ⁴⁴ *Fusion Machine*, U.S. Nuclear Regulatory Commission.