ENERGY RESOURCE & TECHNOLOGY REVIEWS

Rapid advancements in technology have responded to and pioneered changes in our state and across the world.

Often these resources and technologies are critical to the function of our society while also helping us work better and faster. This year, we focused on two topics that represent emerging and innovative technologies that could generate clean energy in support of Oregon's energy transition.

Enhanced geothermal electricity generation could address some of the high costs and risks associated with conventional geothermal energy development. Fusion power is still in earliest stages of research, but holds the promise of nearly unlimited energy that could easily meet anticipated future energy needs.

Innovation is a cornerstone of fundamental change, and new and improved technologies are certain to play an important role in Oregon's energy future. This purpose of this section is to provide information on energy technologies that people might be hearing about in the news, talking to their family and friends, or in energy-related discussions.

Previous Biennial Energy Reports have also included resource and technology reviews that cover a range of technologies from traditional to innovative, demonstrating the breadth of resources integral to meeting our state's energy needs. You can find information on other resources and technologies — such as hydropower generation, carbon capture and sequestration, electricity storage, zero emission vehicles, and more — in our 2020 and 2022 reports.

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Enhanced Geothermal Electricity Generation

Geothermal energy comes from heat generated continuously within the earth. The heat can be used as a renewable resource for electricity generation, space and water heating, or industrial processes.

Oregon has two geothermal power plants. The first, completed in 2010, is a 1.75-megawatt facility in Klamath Falls, which provides onsite electricity generation and space heating for the Oregon Institute of Technology. The second, completed in 2012, is the Neal Hot Springs geothermal power plant near Vale. This facility has a capacity of 22 MW and provides electricity to Idaho Power.[1] The City of Klamath Falls has had a downtown geothermal district heating system since 1981, and nearby Oregon Institute of Technology has used geothermal heating since 1964.[2] [3] The town of Lakeview also uses geothermal energy for a downtown heating district, and received a Community Renewable Energy Development Grant from the Oregon Department of Energy in 2023 to evaluate the feasibility of a system expansion.[4] Nearby, the Warner Creek Correctional Facility uses a geothermal well to provide space heating and domestic hot water.[5] These facilities, located in Malheur, Lake, and Klamath counties, demonstrate how Oregon's geothermal resources benefit some of the state's most rural communities.

Community Renewable Energy Grant Program

The Oregon Department of Energy's Community Renewable Energy Grant Program provides grants for planning and developing community renewable energy and energy resilience projects. To date, more than 90 projects have been selected for awards in communities across Oregon. Learn more on ODOE's website.

Geothermal power plants are not widely used because project development carries higher financial risks than many other electricity generation resources. While Oregon has abundant geothermal resources in some parts of the state, it is difficult to find hydrothermal reservoirs with high enough temperatures and sufficient flow to generate electricity. Development usually requires drilling multiple test wells to find an adequate hot water reservoir, which adds to the up-front costs for development. In some cases, test drilling does not lead to the identification of a viable resource. The financial risks associated with drilling unproductive, low-temperature, or dry wells has limited the commercial viability of geothermal power plant development.

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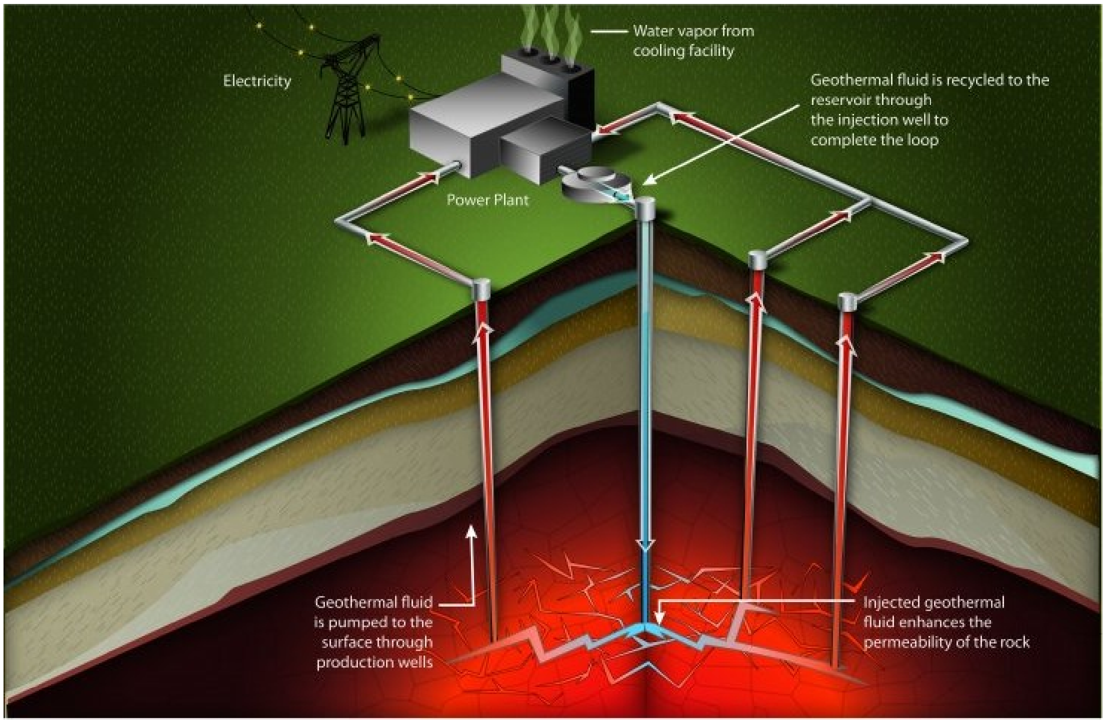
For a deeper dive on geothermal energy, see ODOE's *2020 Biennial Energy Report.*

How Does EGS Work?

Enhanced geothermal systems, also referred to as EGS, eliminate the risk associated with unproductive wells by harnessing energy from hot, *dry* rock deep underground. EGS uses injection wells to circulate fluid from the surface, where it is heated by passing through fractures within the hot rock.

Nearby extraction or production wells collect the heated fluid to generate electricity using a turbine. When the cooled water exits the power plant, it can be reinjected back into the hot rock, resulting in nearly continuous electricity production. Figure 1 shows the primary components of enhanced geothermal energy systems.[6]

Figure 1: Enhanced Geothermal System Diagram[8]



The heated water from enhanced geothermal wells can be used to drive steam turbines that generate electricity.[7] Another option is to use the hot water in a binary-cycle power plant. These plants transfer the heat from the hot water to another liquid – usually pentane, isobutane, or ammonia – that have a lower boiling point than water. The steam from that liquid is then used to drive the turbine.[8]

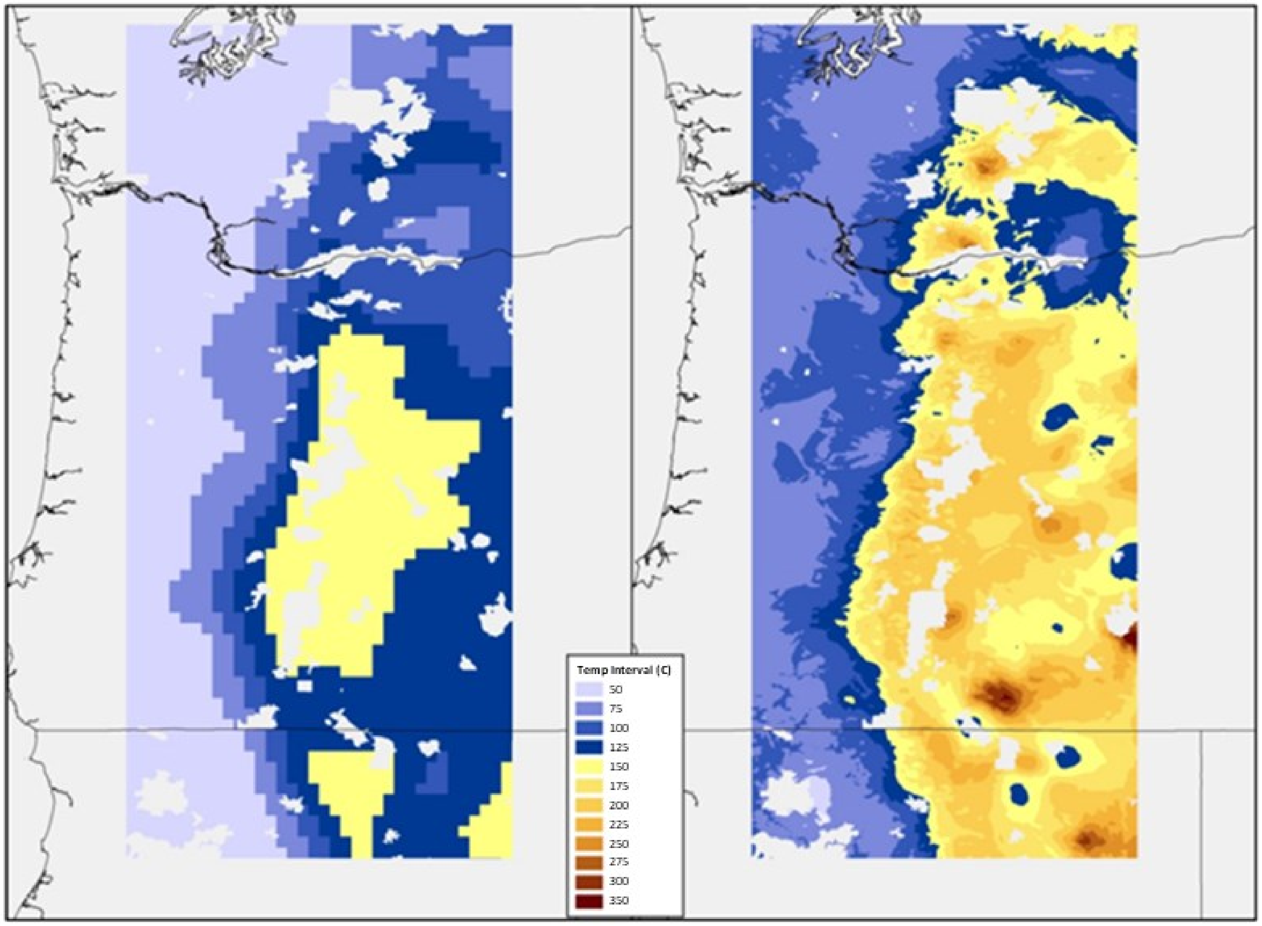
EGS Potential

Decades of research and several projects in many countries have demonstrated the viability of EGS for electricity generation. Early developments date to the 1970s when researchers successfully demonstrated the concept at the Hot Dry Rock project at the Fenton Hill site in New Mexico.[9] The first commercial sites were developed in France and Germany in the early 2000s, followed by projects in the UK, Australia, Japan, and Italy.[9] In the U.S. there are EGS research and production sites in Utah, Nevada, California, and Oregon.[10] In 2009, AltaRock Energy Inc. began development of a test site on the west flank of the Newberry Volcano in Central Oregon for EGS assessment around 10,000 feet underground.[11] Continued research is focusing on reducing the costs of drilling and developing techniques to improve water permeability through the hot rock.

In 2021, the U.S. Department of Energy launched the Enhanced Geothermal Shot initiative to advance innovations in EGS technologies, and reduce the cost of EGS by 90 percent by 2035, from $450 to $45 per megawatt hour.[12] For comparison, a new combined cycle natural gas power plant produces electricity at range of $45 to $108 per MWh.[13]

In 2022, the U.S. DOE, working with the National Renewable Energy Laboratory, completed the Enhanced Geothermal Shot Analysis, which uses the latest cost and performance assumptions to model potential EGS development in 16 states, including Oregon.[14] The analysis used updated EGS resource data that revealed a much greater geothermal resource in Oregon than was originally assumed. The left side of Figure 2 shows assumed geothermal resources taken from a national resource map generated in 2006. The right side of the figure demonstrates the results of an updated geothermal resource model that was used in a detailed regional study published in 2015.[15] The study utilized more granular regional data to better identify EGS development potential in central Oregon.

Figure 2: Maps Demonstrating Improved Identification of Potential Geothermal Resources Highlighted in the NREL Enhanced Geothermal Shot Analysis[14]



Oregon has excellent geothermal resources for EGS development. The Enhanced Geothermal Shot analysis shows that Oregon is also expected to have some of the lowest EGS development costs in the country. Figure 3 below shows levelized cost of energy[i] projections from the study for EGS development across 16 states in 2035. The vertical bars for states shows the range of potential LCOE from high to low. Oregon's 2035 LCOE range is about $32-$48/MWh.

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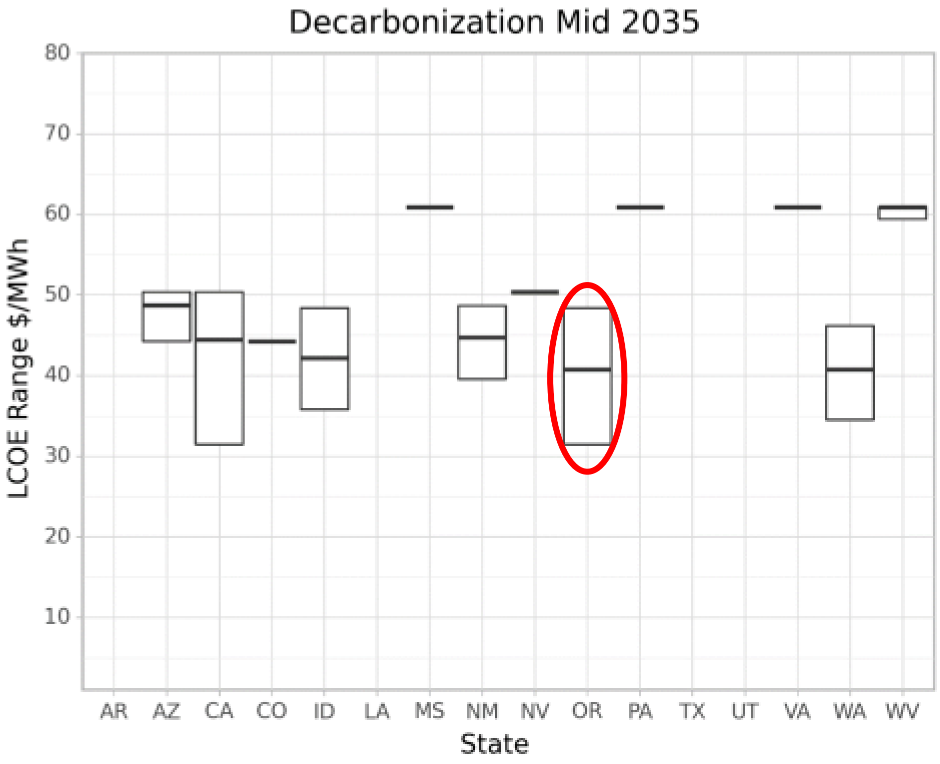
[i] Levelized Cost of Energy, or LCOE, is a measure of the total lifetime costs of an energy generation facility divided by the total lifetime energy production. LCOE helps compare the capital and operating and maintenance costs for providing a MWh of power from different types of energy resources.

Figure 3: Range of 2035 Costs for Enhance Geothermal System Electricity Generation by State[14]



The Enhanced Geothermal Shot analysis showed that Oregon could be one of the top states for future EGS electricity generation. Table 1 shows that Oregon is projected to rank third in geothermal electricity resource development by 2035 with 3.4 gigawatts of capacity, and fourth by 2050 with 8.4 GW of capacity.

Table 1: Total Projected Enhanced Geothermal Capacity by State in 2035 and 2050[14]

Year	Installed Enhanced Geothermal Capacity (GW)															
	AR	AZ	CA	CO	ID	LA	MS	NM	NV	OR	PA	TX	UT	VA	WA	WV
2035	-	2.1	18.2	0.3	5.1	-	0.0	1.1	0.1	3.4	0.0	-	-	0.0	0.3	3.1
2050	0.0	9.7	27.9	4.1	8.6	10.5	0.0	2.5	2.4	8.4	0.0	3.1	3.4	1.0	0.5	3.1

Future of EGS in Oregon

Before Enhanced Geothermal System resources can become commercially viable, some technological challenges will need to be overcome. The U.S. DOE's Office of Energy Efficiency and Renewable Energy has identified some specific challenges including:[6]

- High costs associated with deep drilling and operating drills in hot rock.
- The capability to create and sustain flow through rock fissures.
- Lack of subsurface data to inform potential developers and lower project development risk.

Once projects are developed, long-term operational performance will need to be monitored, which will be useful information for future project developments.

Federal and private research and development partnerships are helping to address the financial and technical challenges associated with EGS. The Frontier Observatory for Research in Geothermal Energy, or FORGE, located in Milford, Utah, is a federally funded, dedicated field laboratory where scientists and engineers develop and test new EGS technologies and techniques.[16] In February 2024, U.S. DOE announced funding for three additional EGS research sites, including projects in California, Utah, and Oregon.[17] The Oregon project, a first-of-its-kind superhot rock geothermal project, developed by Mazama Energy, Inc., is located on the Newberry Volcano in central Oregon. Together, the Mazama Energy project, FORGE laboratory, and other research sites may usher in a new source of clean, renewable, and reliable energy to help meet Oregon's clean energy goals.

Oregon Mazama Project

Mazama Energy is developing a first-of-its-kind superhot rock geothermal project at the Newberry caldera volcano in Oregon. Mazama's vision is to harvest heat from superhot rock — subsurface structures that are greater than 374°C (+705°F) — to generate utility-scale, carbon-free, baseload energy. The initial phase of the Newberry project begins in the fall of 2024, where Mazama will prove new technologies and gather data in one of the existing wells on site. In summer of 2025, Mazama will drill a new superhot rock well using additional drilling technologies. The new well will be set up for a connection and initial production test in 2026 in conjunction with the U.S. Department of Energy's Enhanced Geothermal Systems Pilot Demonstrations.

Newberry Volcano.

Beyond technological challenges, effects of EGS developments on local communities will also need to be considered. Oregon's geothermal resources are in rural parts of central and eastern Oregon, including some Tribal lands. Coordination with Tribes and environmental advocacy and local communities is critical for responsible and successful project development. Geothermal sites have benefits such as helping achieve Oregon's clean electricity goals and requiring less land compared to other clean energy resources, but they may create other local issues. For instance, establishing permeability in hot rock requires fluids be pumped deep underground, and injecting fluid into rocks has been shown to increase localized seismic activity.[18] Facilities may also require development of roads to access the sites, generate noise pollution, and require building transmission lines. Understanding the effects of development on local communities and the environment are important to informing EGS policy and development choices.

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Fusion Power

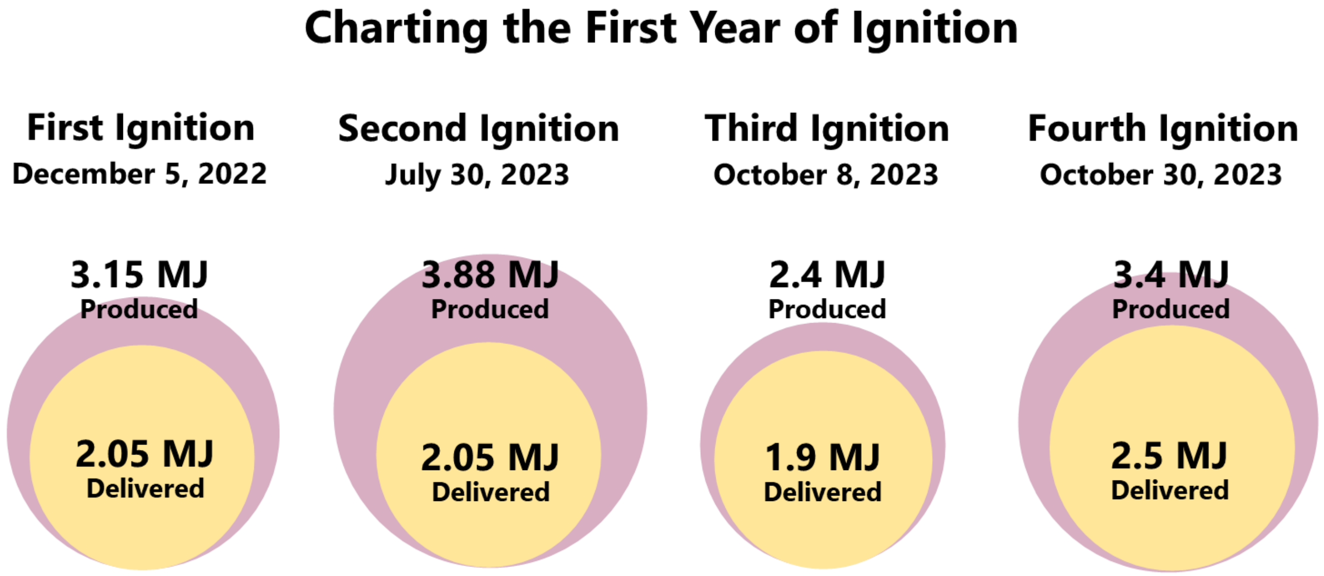
Fusion energy is what powers the sun, and if harnessed could provide nearly limitless clean energy.[1] New scientific advancements hold promise that one day fusion might also power the electricity grid, but significant research and development challenges must first be overcome.

On December 5, 2022, scientists at the U.S. Department of Energy's Lawrence Livermore National Laboratory achieved a major fusion milestone called ignition.[2] Ignition is the point at which a fusion reaction creates more energy than was delivered to start the reaction.[3] That December experiment at LLNL's National Ignition Facility produced 3.15 Megajoules using 2.05 MJ of laser energy – a net gain of 1.1 MJ.[4] While this is only enough energy to run an average refrigerator for an hour or two, it was the first successful real-world demonstration of nuclear fusion producing a net amount of energy. Since that date, the NIF team has recreated ignition multiple times.

Lawrence Livermore National Laboratory's National Ignition Facility reaction chamber, where fusion ignition was achieved on December 5, 2022.

A Megajoule is a unit of energy.[5]
One MJ = 0.28 kilowatt-hours.[6]

Figure 1: National Ignition Facility Experiments Demonstrate Successful Fusion Ignition[4]



LLNL has achieved fusion ignition at the NIF four times to date. Credit: Brian Chavez

How Does Fusion Work?

Nuclear fusion releases energy through the fusing of two light or very small atoms.[7] This differs from existing nuclear power plants, which use fission — the splitting of heavy or very large atoms — to produce energy. While fusion can involve different types of atoms, the fusion process most studied involves combining two isotopes[i] of hydrogen — deuterium and tritium — to form helium.[8] Also known as D-T fusion, this process releases several times more energy than fission reactions.[9]

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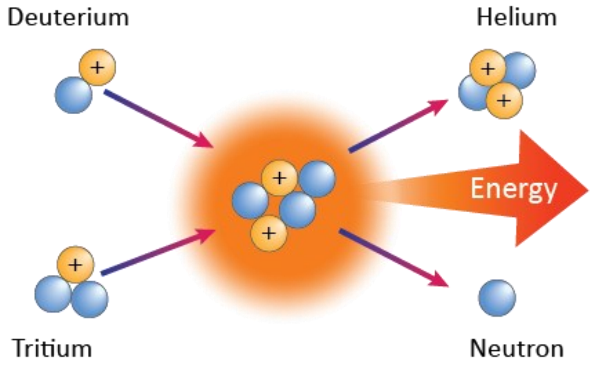
Learn more about nuclear fission power in ODOE's *2020 Biennial Energy Report.*

Figure 2: Diagram of a Deuterium-Tritium Fusion Reaction[7]



A useful **byproduct of nuclear fusion is helium** — a non-renewable resource that is available in only a few locations around the world.[11] [12] Helium is used in many applications, including for scientific research and high-tech manufacturing.

Why does nuclear fusion produce so much energy?

Energy is directly related to mass, as described by Einstein's famous equation **$E=mc^2$**, or "energy (E) = mass (m) times the speed of light (c) squared." In the fusion process shown in Figure 2, the fusion of the two hydrogen isotopes produces helium and a neutron — and in the process, a small amount of mass is lost and converted into energy as described in the Einstein equation.[8] While the mass (m) is very small, the speed of light squared (c^2) is very large, which is why so much energy can be generated from such a small amount of matter.[10]

Fusion reactors must be able to heat the deuterium and tritium to about 100 million degrees centigrade — nearly seven times hotter than the sun's core — to form an extreme state of matter called plasma, where atoms are ionized into positively charged ions and negatively charged electrons.[1] [13] [14] It is in this state that the deuterium and tritium can fuse and release energy. Plasma is highly volatile and difficult to control. Nuclear fusion research focuses on methods to control the plasma state so that the reaction can persist and continue to release energy.

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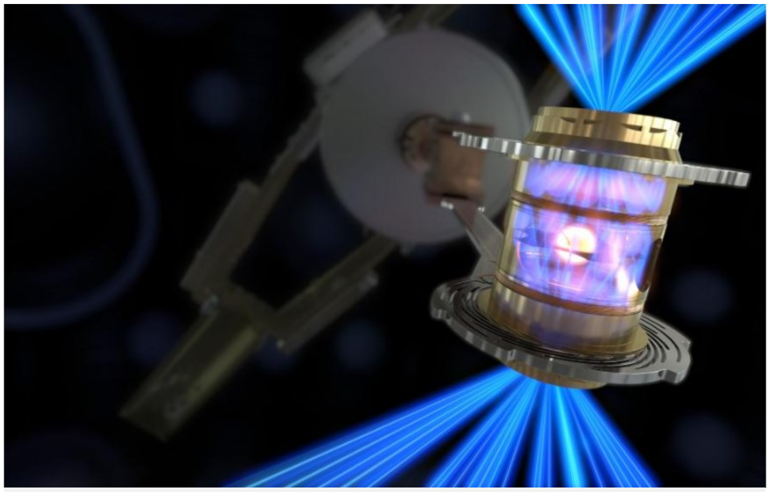
[i] Isotopes are different forms of the same element, which contain the same number of protons but different numbers of neutrons. For example, deuterium has one proton with two neutrons, and tritium has one proton with three neutrons.

There are two main types of fusion reactors currently being studied — inertial confinement fusion systems and magnetic confinement fusion systems.[15] The National Ignition Facility is an ICF machine, where lasers compress the deuterium-tritium fuel until the high pressure induces an extreme plasma state and ignition. MCS facilities use electromagnets to contain and control the plasma to achieve a burning plasma state. In either case, to produce electricity, the energy from the fusion reactions is ultimately used to heat water into steam that can spin electricity generating turbines. To date, only the ICF reactor at the NIF has achieved ignition.



National Ignition Facility lasers heating the deuterium and tritium fuel to create a super-heated state of matter called plasma.

The December 5 experiment at the National Ignition Facility lasted only a few trillionths of a second, and was initiated by a laser that is 1,000 times more powerful than the U.S. electric grid.[16]

ITER – International Thermonuclear Experimental Reactor

The ITER is an international project to demonstrate technical capability of a Magnetic Confinement System fusion system to produce enough energy to maintain a plasma state without the need for additional energy.[17] One of its goals is to produce 500 MW of power from only 50 MW of input power.

Interest in Nuclear Fusion Power Electricity Generation

Fusion reactions require a significant amount of energy to operate, so in the event of a power outage or other disruption, the reaction would simply stop.[1]

Fusion could provide tremendous amounts of energy with very small amounts of fuel, and it would not emit any greenhouse gases or other air pollutants.[1] If the technology can be commercialized, the fuel for the reaction is highly sustainable. While it creates a small amount of radioactive material, it would be continually consumed within the isolated reaction chamber of the reactor, so fusion would not create the amount and type of large-scale nuclear waste being generated by today's fission reactors. Fusion also does not have the potential for a runaway reaction, like nuclear fission. As the United States and other countries work to meet decarbonization targets and goals, a large source of consistent and clean power like nuclear fusion could be revolutionary.

However, fusion energy research in this area is still in the initial stages of demonstration, and the challenges to bring it to fruition are immense. Ignition is only the first step toward generating electricity from nuclear fusion power. Creating a sustained fusion reaction will require more technological advancements, and beyond this, building and maintaining a fusion electricity generator will need to be cost-effective.

Scientists have been interested in **fusion as an energy source** since the advent of the atomic age because if it could be developed at commercial scale, it would provide nearly limitless energy. For example, just a few grams of fuel could produce a terajoule of energy — approximately enough energy to support the energy needs of one Oregonian for over sixty years.[1]

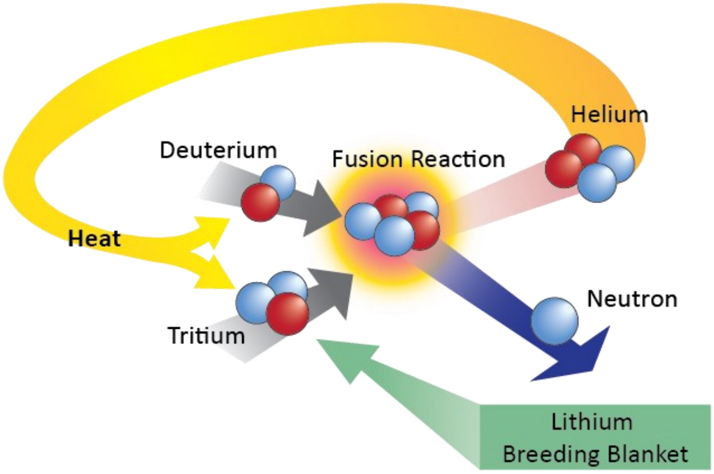
A particular challenge is the limited availability of tritium, one of the two hydrogen isotopes used in D-T fusion. There are only about 25 kilograms of tritium available in the world, making it incredibly rare and expensive.[18] Tritium is also radioactive, meaning any reactor components it comes in contact with will need to be handled and disposed of safely.[19] Because tritium is generally consumed during the fusion reaction, and because the reaction occurs in a chamber with shielding, it is unlikely to create a health hazard.[16] The NIF experiment used only 1 milligram of tritium. The radiation produced does not travel far in the air and cannot penetrate the skin.[19] Although it is generally consumed during the fusion reaction, unused tritium is a potential form of nuclear waste that could be released from a nuclear fusion reactor.

Tritium Exit Signs

Tritium is used in many emergency exit signs, making signs glow without a power source. During a power outage the sign will continue to glow, directing people inside toward the exit.[19] The tritium is enclosed within a tube. The radioactive particles emitted interact with a substance lining the tube, creating the glow. For this reason, these types of exit signs must be disposed of in accordance with Nuclear Regulatory Commission standards. The National Ignition Facility experiments used only about half the amount of tritium in an exit sign.

The primary source of tritium is from the operation of heavy water nuclear fission reactors equipped with a Tritium Removal Facility. Only two such facilities operate globally, and combined could produce about 260 grams of tritium in a year.[20] [21] [22] Fusion reactor operations are estimated to require 100 to 200 grams of tritium annually, so at current production levels, the global tritium supply could at most fuel a single reactor. Some of the global supply is already used for luminous material in exit signs and watches, in nuclear weapons, and as a radioactive tracer for scientific experiments.[23] Without new reactor development and/or additional Tritium Removal Facilities, there will be a dwindling supply of tritium production as existing reactors are decommissioned.

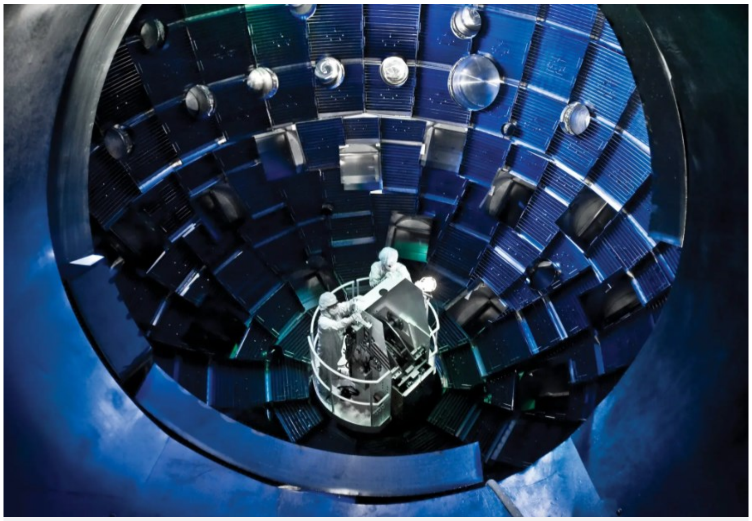
Figure 3: Diagram of a Deuterium-Tritium Fusion Reaction with Lithium Breeding Blanket[7]



One technology being researched in conjunction with D-T fusion, called a lithium breeding blanket, regenerates tritium after the fusion reaction.[28] The lithium captures the free neutrons created during the reaction to produce tritium and helium. This is a critical technological breakthrough for nuclear fusion to become commercially viable. Unless tritium is being bred faster than it is burned, there will be insufficient supply to fuel reactors of the future.

Unlike tritium, the other hydrogen isotope used to fuel nuclear fusion, deuterium, is significantly more abundant.[29] There are tens of trillions of tons of deuterium available in the earth's oceans. Deuterium is found in all water sources and is separated from normal water using distillation, electrolysis, or through chemical reactions known as isotopic exchange.[30] It is a relatively expensive commodity because the processes for extracting deuterium are energy intensive and complex.[31]

Another type of fusion reaction called D-D fusion occurs when two deuterium atoms are fused together, instead of deuterium and tritium.[32] The advantage of D-D fusion is that it does not require tritium, nor does it have radioactive byproducts.[33] However, most research is in D-T fusion, because it requires less initial energy input and produces more energy. A D-D reaction requires two to three times the amount of energy to ignite than a D-T reaction.[34]



Technicians working in the target bay at the [National Ignition Facility](#).

The radioactive waste resulting from current nuclear fusion experiments is much safer than nuclear fission. In 2018, Congress passed the Nuclear Energy Innovation and Modernization Act, which requires the Nuclear Regulatory Commission to develop and implement regulatory frameworks for advanced reactor designs, like nuclear fusion power, by 2027.[24] To implement this, NRC staff conducted an assessment of the types of fusion energy facilities currently being planned.[25] Their 2023 report found that these types of near-term facilities do not have the potential to create large accidental radiation exposures, present no risks of runaway reactions, and that the waste material cannot readily be used to develop nuclear weapons.[26] For this reason staff recommended regulating these facilities similarly to today's particle accelerators, which have much less stringent regulatory requirements compared with today's nuclear fission generation plants. On July 10, 2024, Congress passed the Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act, codifying near-term fusion reactor electricity generation facilities like energy particle accelerators.[27] This provision provides additional guidance to the NRC as they work to publish a proposed rule for licensing and regulating fusion energy systems in 2025.[24]

The federal Nuclear Regulatory Commission determined that regulations for byproducts of existing nuclear fusion systems should be addressed differently from nuclear fission reactors, largely because the radiologic waste products are sufficiently different.[46] The new NRC rules for disposal of waste from fusion reaction systems will be based on regulations governing other products containing tritium, including luminous exit signs, smoke detectors, and certain medical or industrial radiography instruments.

Supporting Nuclear Fusion Power Generation Research

The U.S. Department of Energy is seeking to accelerate commercialization of fusion power by facilitating the development of Fusion Innovation Research Engine collaboratives.[35] FIRE collaboratives support the US DOE strategy to achieve commercialized nuclear fusion within a decade by bringing together research scientists and technology innovators to bridge the gap between scientific studies and real-world applications.

Fusion Powered by Artificial Intelligence

AI has the capacity to look at results from solving one problem to predict how to solve related problems. The team at Lawrence Livermore National Laboratory used a combination of sophisticated modeling tools in conjunction with AI to more quickly learn from experimental results and develop new parameters that were more successful.[36] AI can also learn to maintain complex systems faster than human reactions or programming currently allow. An AI platform designed at Princeton University helps manage instabilities within the fusion reactor in real-time to better maintain the conditions needed for ignition to occur.[37]

There are more than 40 private companies working on fusion power or related technologies, providing over $6.2 billion of funding, with the goal of completing a fusion power plant in the 2030s.[38] Breakthroughs in material science technology and artificial intelligence will likely accelerate the potential for fusion-powered electricity.

Fusion in the Pacific Northwest

The Pacific Northwest is a central location for fusion technology research. Several prominent companies in Washington state and British Columbia are conducting reactor research, looking into efficient and affordable ways to produce nuclear fusion-generated power.[39] [40] [41] [42] [43] Helion, a Seattle-based company, is researching a fusion reactor that would directly generate electricity from the fusion reaction, rather than using the reaction's heat energy to generate steam. Helion recently signed a power purchase agreement to provide power from its nuclear fusion plant for Microsoft by 2029.[44] If successful, the 50 MW plant would start up in 2028 and begin providing power a year later.

Is Nuclear Fusion Part of Oregon's Energy Future?

It is uncertain if or when fusion power generation could be built in Oregon. In 1980, voters passed Measure 7, requiring voter approval and the existence of a federally licensed permanent nuclear waste facility in order to approve a nuclear plant site certificate.[45] The ballot initiative passed at a time when nuclear fission resources were the only form of nuclear power plant being considered, and fusion plants have significantly different waste profiles, with very little nuclear waste byproducts. Oregon rules and regulations have not yet been interpreted to include or preclude nuclear fusion development in the state. However, addressing public concerns about safety, environmental impact, effects on environmental justice communities, and any public safety risks associated with fusion energy will play an important role in any possible future development of this resource in Oregon.

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Learn more about the history of nuclear facilities and radioactive waste in ODOE's *2022 Biennial Energy Report*.

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