SUSTAINABILITY

Nuclear fusion could change the world. How close are we?

Humans have been trying to master fusion since the 1950s. Global warming is raising the stakes.

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By Rodika Tollefson

Imagine a world where we would never run out of clean, affordable energy—where any industry could thrive with unlimited access to fuel or electricity, and energy could be generated anywhere it's needed. This is the promise of nuclear fusion energy. We just need to get there.

The long road ahead

Produced by combining two lighter atoms into one heavier atom, nuclear fusion releases a very large amount of energy. It's how the sun produces energy—nuclear fusion is, essentially, the source of life on Earth.

"What's most appealing about fusion is that it's an almost inexhaustible source of fuel," says Greg Piefer, founder and CEO of SHINE Technologies, a next-generation fusion technology company. "If we mastered it as a species, we would have access to energy at unprecedented levels."

Humans have been trying to master fusion since the 1950s. Theoretical understanding of the science is more than a hundred years old, but turning theory into practice has been described as "one the most significant scientific challenges ever tackled by humanity." One reason is that achieving fusion ignition in a controlled lab requires incredibly high temperatures and control and confinement of the plasma for a long enough time to "ignite" the fusion reaction.

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"The simplest fusion reaction happens at around a hundred million degrees, and obviously there's no material that will survive that, so you have to build these complex ways of confining them," Piefer explains.

One such complex way is called inertial confinement fusion, which uses lasers to induce fusion. In December 2022, the U.S. Department of Energy announced a breakthrough: scientists at the Lawrence Livermore National Laboratory's National Ignition Facility (NIF) achieved ignition.

"This was the first time, in any fusion experiment, that more energy was produced by fusion than was required to heat and confine the plasma," says Mike Campbell, who was instrumental in establishing the NIF during his tenure in the early 1990s as the associate director of the Lawrence Livermore National Laboratory. Campbell, who retired in March 2022 from the University of Rochester Laboratory for Laser Energetics, is an internationally recognized expert in inertial confinement fusion.

The size of a sports stadium, California-based NIF is the world's largest laser facility. Campbell acknowledges that the NIF feat, while a major achievement for physics, does not prove the practical applications for the commercialization of nuclear fusion. It simply wasn't intended to demonstrate practical applications—it was designed only to prove the science was sound, which it did in his view.

Piefer, however, is among those who believe fusion is still a long way off. A nuclear engineer with a doctorate decree, he does see the NIF achievement as significant. But, he says, it didn't necessarily prove that the physics works from a cost-economics perspective because the experiment cost several million dollars while generating a few cents worth of heat.

"It proved that you can start to trigger a burn, and I'm excited to see where this goes, but to me, fusion energy is not feasible yet," he says.

Campbell equates the NIF milestone to the first Wright Brothers' airplane experiment, where they showed that machines that are heavier than air could fly.

"And look where we are today—in less than a century, we had commercial airliners and people are traveling around," he says. "We're not going to turn the lights on tomorrow because of fusion, but this was a necessary step."

Does that mean that it would take a century to get there?

What fusion needs next

Governments have been heavily investing in nuclear fusion via inertial confinement for decades, especially the U.S. government, because, according to Campbell, the technology has national security implications. Several countries, including the U.S., are also investing in fusion directed solely to energy production, where strong magnetic fields are used to confine the plasma, he adds. One such system, tokamaks, has made significant progress in the science and supporting technology for this fusion approach. But things in the government move at a slow pace, and what nuclear fusion needs next is private sector investment.

"The science is rapidly developing, but we need more advances in science and engineering," Campbell says. "Engineers can perform miracles when they're given a compelling problem and the tools to solve it—and the money to do it."

Private investment into nuclear fusion was at least $2.8 billion in 2021 globally, for a total of at least $4.7 billion so far, based on a 2022 report by the Fusion Industry Association. The recent NIF milestone will further spark investor interest, says Verineia Codrean, head of sustainability and strategic partnerships at Startup Norway, which has built a startup ecosystem that connects founders with venture capitalists and corporate investors.

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"The news that nuclear fusion energy gained momentum gave startups enough of a runway for extra investments and extra time to develop their solutions," Codrean says. "Startups can innovate much better than established companies because they can take higher risks and are willing to lose it all."

Investing in nuclear fusion energy is a long game, and anyone looking for shorter-term returns would be deterred once they realize just how far commercialization is. But, Codrean says, many investors diversify with longer-term "bets" while some specifically seek out truly cutting-edge developments that border on science fiction.

"NIF showed the physics was possible with lasers that were decades-old," Codrean says. "Imagine what could happen with some investment."

Much has changed in the decades since those lasers were built. Technology, additive manufacturing and precision engineering have advanced tremendously, and laser technology itself is more efficient. Artificial intelligence and machine learning could reduce the time for designing experiments to hours and days from what in the past took years. All these innovations, among others, could shortcut the road to commercializing nuclear fusion energy to just two or three decades—a timeline that experts like Campbell believe is possible.

Some companies, like SHINE Technologies, are also incrementally improving various aspects of the technology by using nuclear fusion to solve other problems. Of the 33 companies surveyed by the Fusion Industry Association, most were working on producing some form of energy, but some were exploring applications ranging from space propulsion to medical.

Medical applications are where SHINE is currently focused. Founded in 2005, the Wisconsin-based company is developing fusion technology for producing medical isotopes, which could solve a variety of diagnostic imaging challenges, and potentially improve radiology cancer treatments.

Fusion power generation remains a future phase, but in the interim, Piefer says that everything SHINE does at its technology development facility and its production facility helps move nuclear fusion toward commercial feasibility.

"We're not just building fusion machines that create value and generate money now but we're getting practice with all the things you need for fusion power," he says. "We're practicing building cost-effective fusion systems and manufacturing our own equipment—we're being more pragmatic and more grounded in near-term applications while taking an iterative approach to continue pushing the envelope."

Taking the leap for the planet

Financial returns and technology advancements aside, there's another driver that could push nuclear fusion energy forward.

"Climate change is on everybody's minds, and everybody is interested in finding solutions to solving it, but without stopping the development of our society," Codrean says.

Then there's the energy crisis, ranked as the fourth-biggest global risk in 2023, according to a survey of more than 2,700 risk professionals by Allianz. Likewise, energy experts have declared a global energy crisis at the January 2023 World Economic Forum of global leaders. Generating abundant, clean energy from nuclear fusion would be one giant leap toward addressing the energy crisis and climate change at the same time.

"I think the investment industry has started to realize that the private sector needs to be part of the thought leadership on how we're going to overcome climate change," says Piefer. "It's great to see people investing in that and deciding it's not just up to the government to take care of this Earth."

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What the future may hold

Nuclear fusion energy has other advantages besides abundance. Unlike fission, used by nuclear power plants, it generates only a very small, controllable amount of nuclear waste. Additionally, an accident would be extremely unlikely because the temperatures required for fusion are so high that any problem would stop the reactions, Campbell says.

Regardless of those benefits, fusion is not likely to replace other sources completely, believes Dan Derr, a chemist with a doctorate degree in inorganic chemistry and an expert on renewable energies.

"We have renewables available today, like solar and wind, that are available and successful," says Derr, who works at Integrity BioChem. "While they require upfront costs, they have advantages because they don't need a lot of maintenance."

Fusion, nonetheless, is pivotal in his view. "It's such a different paradigm in terms of the amount of energy stored in a small bit of fuel," he says.

He believes this new paradigm could especially benefit energy-intensive industries like aluminum production, or industries that aren't as feasible with technologies available today, like interstellar travel.

"We're still a long way from making money selling fusion power, but because it's such a game-changer, we need to continue working on this problem as a society," Derr says.

When we do solve this problem, Codrean expects to see changes across every industry.

"This is not a small discovery within one little industry," she says. "When we shift from generating kilowatts to gigawatts of clean energy that doesn't create waste and carbon emissions and runs nonstop in any part of the world on and off the grid—it will affect how business is done."

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