Giant laser from 'Star Trek' to be tested in fusion breakthrough

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The breakthrough came in an impossibly small slice of time, less than it takes a beam of light to move an inch. In that tiny moment, nuclear fusion as an energy source went from far-away dream to reality. The world is now grappling with the implications of the historic milestone. For Arthur Pak and the countless other scientists who've spent decades getting to this point, the work is just beginning.

Pak and his colleagues at Lawrence Livermore National Laboratory are now faced with a daunting task: Do it again, but better—and bigger.

That means perfecting the use of the world's largest laser, housed in the lab's National Ignition Facility that science-fiction fans will recognize from the film "Star Trek: Into Darkness," when it was used as a set for the warp core of the starship Enterprise. Just after 1 a.m. on Dec. 5, the laser shot 192 beams in three carefully modulated pulses at a cylinder containing a tiny diamond capsule filled with hydrogen, in an attempt to spark the first fusion reaction that produced more energy than it took to create. It succeeded, starting the path toward what scientists hope will someday be a new, carbon-free power source that will allow humans to harness the same source of energy that lights the stars.

Pak, who joined the Lawrence Livermore lab outside San Francisco in 2010, woke at 3 a.m. that day, unable to resist checking the initial results from his San Jose home. He'd tried staying awake for the shot itself, finally giving up as the experiment's painstaking preparations dragged late into the night. "If you stayed up for every shot, every time for 10 years, you'd go insane," he said.

For the last several months, it was clear his team was getting close, and in the pre-dawn dark, he checked for a key number that could show whether they'd succeeded—a count of neutrons the blast produced.

"When I saw that number, I was blown away," he said.

"You can work your whole career and never see this moment. You're doing it because you believe in the destination, and you like the challenge," said Pak, leader for diagnostics on the experiment. "When humans come together and work collectively, we can do amazing things."

The team at Lawrence Livermore—a government-funded research lab—will likely run its next test in February, with several more experiments to come in the months after. The goal will be to keep increasing the amount of energy that's produced in the reaction. The means more tinkering: Use more laser energy. Fine-tune the laser blast. Generate more X-rays within the target—a key step of the process—using the same amount of energy. Maybe, eventually, upgrade the facility itself, a decision that would require buy-in from the Energy Department and a huge amount of funding.

All of that will take years, if not decades, starting with the Lawrence Livermore lab's bite-sized experiments that last just nanoseconds.

"We need to figure out: Can we make it simpler? Can we make this process easier and more repeatable? Can we begin to do it more than one time a day?" said Kim Budil, director of the Lawrence Livermore lab. "Each of these is an incredible scientific and engineering challenge for us."

Most experts forecast that the world is still at least 20 to 30 years away from fusion technology becoming viable on a scale that's large and affordable enough to produce commercial power. That timeline places fusion beyond the scope of significantly being used to reach the world's net-zero emissions goals by 2050. In that sense, fusion could be the carbon-free energy source of the future, but not of the current global energy transition that's faced continuous hurdles.

Fusion has captured the scientific imagination for decades. It's already used to give modern nuclear weapons their devastating power, but the dream is taming it for civilian energy demand. If it can be brought to scale, it would lead to power plants that supply abundant electricity day and night without emitting greenhouse gases. And unlike the nuclear power of today, sparked through a process called fission, it wouldn't create long-lived radioactive waste. Entire generations of scientists have pursued it. President Joe Biden's chief science advisor, Arati Prabhakar, spent a summer working on the lab's laser-fusion program as a 19-year-old college student in bell bottoms—in 1978.

"This is such a tremendous example of what perseverance can achieve," she said at a press conference last week. "This is how you do really big, hard things."

Merging atoms

The successful laser shot produced fusion reactions generating 3.15 megajoules of power, topping the 2.05 megajoules imparted by the laser. It was a major threshold, the first time more energy came out than went in from the laser. But the equation needs to tilt much more in the direction of how much comes out to become commercially viable.

While today's nuclear power plants employ fission, splitting atoms apart, fusion merges atoms together. Fusion researchers have followed two primary tracks. Lawrence Livermore, using a process called inertial confinement, blasts targets with laser beams, imploding a small amount of hydrogen until it fuses into helium. A commercial plant using this approach would need to repeat the process over and over again, extremely rapidly, to generate enough energy to power the electric grid.

Numerous companies are developing inertial confinement systems, though there are significant differences. Some are looking at different materials for the target, while others use particle accelerators instead of lasers, triggering the fusion reaction by slamming atoms together.

The main competing idea is called magnetic confinement, with systems that create a cloud of plasma, superheated to hundreds of millions of degrees, which can trigger a fusion reaction. Powerful magnets control the plasma and sustain the reaction. This approach has not yet achieved a net-energy gain, and the approach faces challenges including developing better magnets and creating materials that can withstand superhot temperatures and be used for the container to contain the plasma.

About $5 billion in funding has gone into fusion companies to date, with the vast majority aimed at magnetic confinement technologies, according to the Fusion Industry Association trade group.

Inertial confinement may be better suited to proving that fusion can work, said Adam Stein, director of nuclear energy innovation at The Breakthrough Institute, an Oakland, California-based research group. But in the longer run when it comes to commercialization, "plasma magnetic confinement is more likely to succeed," he said.

'Be an optimist'

Years were spent refining each part of the process at the Lawrence Livermore lab.

A lot of the success came down to precision. The fuel capsules all contain minute imperfections that can make a significant difference in how the reaction proceeds. So can the frozen hydrogen inside, a mix of the isotopes deuterium and tritium. The team would often produce the hydrogen ice, melt it back down and try again several times before a shot, hoping to get the best possible target and increase the chances of success.

Everyone working on fusion "has to be an optimist," said Denise Hinkel, a physicist who focuses on improving the predictive ability of the program's computer simulations and who has worked at Lawerence Livermore for 30 years. "Otherwise, you wouldn't stay in the field."

By this summer, the giant laser will be able to deliver about 8% more energy than it did during this month's shot, according to Jean-Michel Di Nicola, chief engineer for the National Ignition Facility's laser. Michael Stadermann, the target fabrication program manager, said that the lab is also developing a computer program that can examine the fuel-capsule shells for flaws much faster than humans can. They're also working with capsule maker on improving the fabrication process.

It's possible that the Lawrence Livermore breakthrough will remain just a moment of scientific history, and not mark the beginning of a new fusion industry powering the globe. Bridging the gap from experiment to commercialization could take decades, if it happens at all. And magnetic confinement could eventually be the fusion method that wins out, providing the world abundant clean energy. Pak, a soft-spoken man with a swoop of brown hair and a quick wit, said that outcome wouldn't disappoint him.

"They can learn from us—we can learn from them," Pak, 40, said. "When I'm an old man, I'm going to be really satisfied with my contributions."

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