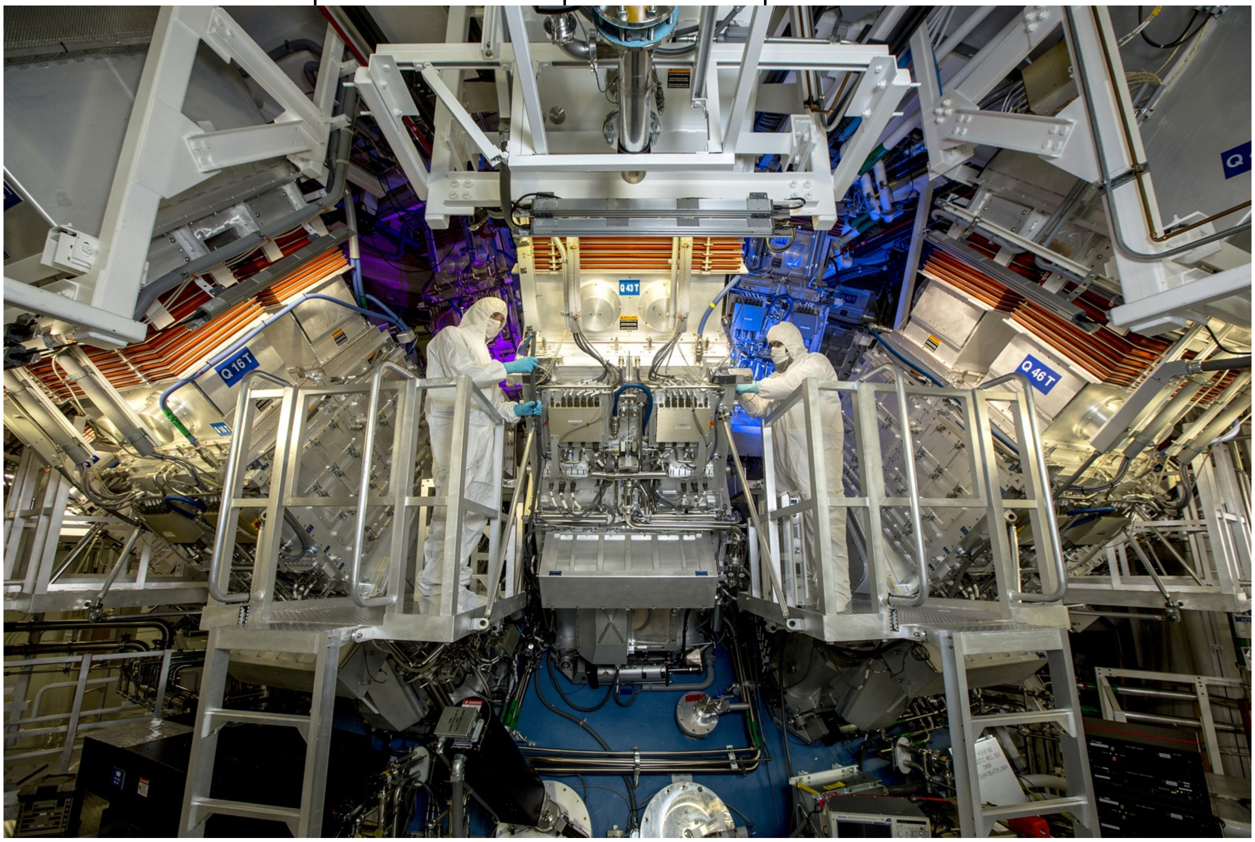
‘AN ENGINEERING MARVEL BEYOND BELIEF’

Scientific history made in Livermore

Lab scientists’ fusion experiment boosts hopes for a clean power future



At Lawrence Livermore National Lab’s National Ignition Facility, target area operators inspect a final optics assembly during a routine maintenance period. The facility’s breakthrough in nuclear fusion is a major step toward clean energy production. PHOTO BY JASON LAUREA

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Livermore looks nothing like the center of the sun, but this East Bay city, surrounded by pastoral vineyards and ranches, is where scientists have re-created the production of energy the way the sun does: through nuclear fusion.

On Tuesday, federal officials announced that Lawrence Livermore National Lab had achieved a historic breakthrough in its fusion research — creating a brief reaction that generated more energy than it consumed.

The long-elusive achievement, called “ignition,” brings the world one step closer to the goal of harnessing the same process that powers the sun to create safe, cheap, carbon-free electricity on Earth — although that reality is likely decades away.

Since World War II, scientists have dreamed that fusion might one day be exploited to create dependable electric power, with no carbon emissions or radioactive meltdowns or waste. Tuesday’s announcement comes at a time when the world is faced with soaring energy prices and a crisis of rising global temperatures caused by the use of fossil fuels.

“This is such a tremendous example of what perseverance really can achieve,” said Arati Prabhakar, White House Office of Science and Technology policy director, in a Tuesday morning news conference in Washington, D.C. “It’s a scientific milestone. But it’s also an engineering marvel beyond belief.”

Addressing a global audience, Lawrence Livermore National Lab director Kim Budil praised her team and lab partners “who ensured that we could reach this moment, even when the going was tough. ... Over the past 60 years, thousands of people have contributed to this endeavor, and it took real vision to get us here.”

At the lab’s $3.5 billion National Ignition Facility, the size of three football fields, scientists produce powerful reactions by smashing together — or fusing — hydrogen atoms into helium, using lasers.

The lasers generate intense pressure and heat, causing a rocket-like implosion that creates more than double the pressure at the core of the sun and sends temperatures soaring to more than 150 million degrees Fahrenheit, just like the sun, releasing a massive amount of energy.

The experiment had been performed dozens of times before.

But on Dec. 5, for the first time in history, the process stayed hot enough, dense enough and lasted long enough that it ignited — making 54% more energy than it used. National Ignition Facility’s lasers consumed 2.05 megajoules of energy from the grid, and generated 3.15 megajoules.

The hope is to build commercial reactors that can maintain this fusion without injecting heat — and create electricity that is cheaper and far cleaner than that from natural gas or coal.

That is within reach, but not yet practical, said lab director Budil. The National Ignition Facility is a scientific facility, not a commercial reactor that is affordable, self-sustaining and capable of producing many ignition events per minute.

“I don’t want to give you a sense that we’re going to plug into the grid: That is definitely not how this works,” said Budil. “A few decades of research on the underlying technologies could put us in a position to build a power plant.”

Members of the research team said that news of the 1:03 a.m. breakthrough — through phone calls and texts — was thrilling.

“I got a call from my boss, saying ‘I think we got ignition,’ and I burst into tears,” said Tammy Ma, a plasma physicist at the National Ignition Facility. Waiting for a flight at San Francisco International Airport, “I was jumping up and down in the waiting area — that crazy person.”

But the news stayed largely secret as lab officials brought in members of the research team and external experts from around the country to verify the data.

“When you ignite, it’s unambiguous that something big happened,” said Budil. But before releasing the numbers to the public, “it was important … that we get them right.”

Fusion is a process that is constantly underway in the core of the sun, where high temperatures and extreme pressures fuse 500 million metric tons of hydrogen each second.

But here on Earth, until now it's been an unfathomable process to replicate and control. Its complexity derailed hundreds of projects, both private and public. Slowly, over time, scientists have improved tools and techniques.

The lab's National Ignition Facility, founded in 2009, is the ideal place to undertake such an endeavor.

It was conceived to study fission, another nuclear process, used in nuclear weapons. As part of the nation's Nuclear Security Administration's Stockpile Stewardship Program, the facility studies the operation of modern nuclear weapons because underground testing is now off-limits.

Such research can be conducted safely under the facility's high-pressure conditions in a controlled environment. Its experiments use extremely tiny amounts of test material, barely visible to the naked eye.

But fusion and fission are very different. Fusion is the joining of atomic nuclei; fission is the splitting of atomic nuclei. Fusion produces far more energy than that created by fission. And fusion, unlike fission, does not create harmful radioactive byproducts that need to be stored for thousands of years.

Lawrence Livermore National Lab's success is due to its creation of the world's most precise and reproducible laser system.

Nearly 200 powerful laser beams are focused and fire simultaneously onto two sides of a small metal cylinder, holding a capsule about half the size of a BB.

In a powerful multistep process, extreme heat and pressure cause two forms of hydrogen atoms inside the capsule to fuse into helium and release high-energy neutrons and other forms of energy in a controlled thermonuclear reaction. In a fraction of a nanosecond — about a billion times faster than the blink of an eye — the lab generated a huge amount of energy.

There was no guarantee of success. "Any one thing going wrong can be enough to prevent ignition," said team member Alex Zylstra. "Everything has to be right. So we really have to sweat the small stuff."

In recent years, even as skeptics doubted its potential, lab physicists worked to increase the experiment's energy and power. "Many said it was not possible," said Budil. "The laser wasn't energetic enough. The targets would never be precise enough. Our modeling and simulation tools were just not up to the task of this complex physics."

In August 2021, an experiment made a significant step toward ignition, putting researchers at the threshold of success. The design was modified, and an improved project was conducted last September.

"Going forward, we know we will make further breakthroughs. We'll have further setbacks," said Prabhakar. "But all of this is in the interest of promoting national security, pushing towards a clean energy future and redefining the boundaries of what's possible."

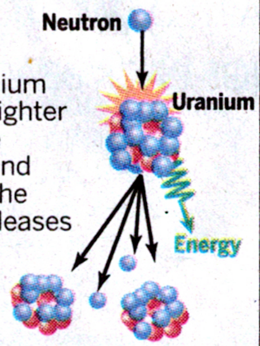
FUSION: ENERGY'S FUTURE?

There are two ways to harness nuclear energy from atoms: fission and fusion. While both are able to produce energy without carbon emissions, the latter is seen as the future for energy production because of these key differences:

Fission

Splitting atoms

1. A neutron is shot into a uranium atom

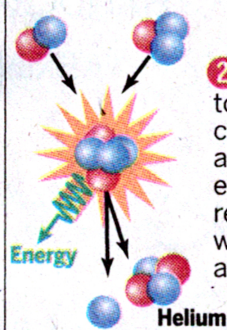


2. As uranium splits into lighter radioactive elements and neutrons, the reaction releases energy

Fusion

Joining atoms

1. Hydrogen atoms with extra neutrons are put under extreme heat and pressure



2. Atoms fuse together causing large amount of energy to be released along with helium and a neutron

	Fission	Fusion
Fuel used	Uranium, plutonium	Hydrogen
By-products	No carbon emissions, but produces nuclear waste	No carbon emissions. More environmentally friendly because helium is the main byproduct.
Use	Already in use for decades. Used in nuclear power plants and naval vessels	Still under development
Energy	1 million times greater than other energy sources such as oil and wind power.	3-4 times greater than fission

Source: Department of Energy

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