August 01, 2022

Creating tiny stars on Earth in the quest for fusion power

by Christopher Young[1] | Staff Scientist

[1]: Lawrence Livermore National Laboratory

This Break was edited by *Margaux Héritier* - TheScienceBreaker

ABSTRACT
At the Lawrence Livermore National Laboratory (USA), we have recently produced record performance in laser-driven fusion experiments. Exploring and manipulating these extreme conditions brings us one step closer to harnessing fusion reactions for carbon-free energy production.

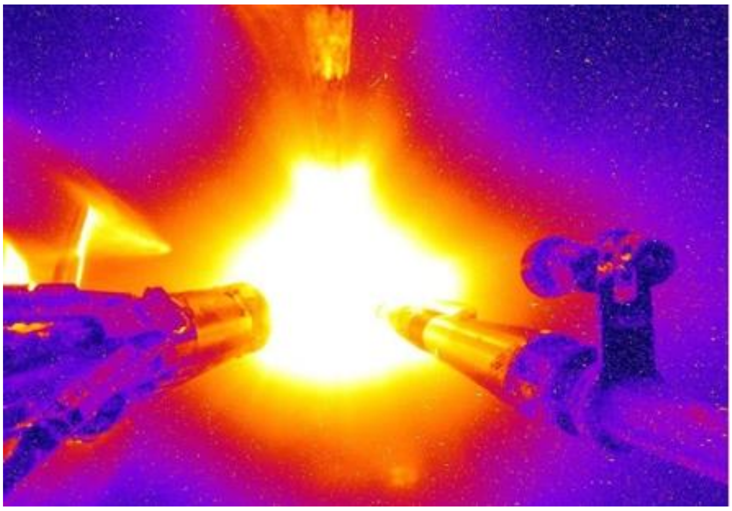

Image credits: Lawrence Livermore National Laboratory

Fusion is the physical process that powers the stars and harnessing this capability on Earth for carbon-free power generation is a grand challenge of modern physics. The potential payout is enormous – each gallon of seawater contains enough naturally-occurring fusion fuel (a special type of atom called deuterium, or heavy hydrogen) to produce as much energy as burning 300 gallons of gasoline – but initiating and sustaining fusion reactions requires extreme conditions.

The sun is our closest example of a fusion reactor. Being 333,000 times more massive than Earth, it confines its fuel at temperatures of 15 million degrees Celsius and pressures of 265 billion bar under the sheer crush of its own gravity. To reach such extreme conditions on Earth, we turn to specially shaped magnetic fields and intense lasers.

The past few years have seen great progress in fusion research, with record-setting conditions achieved in both magnetic fusion devices (Europe's JET Tokamak and China's EAST reactor) and laser-driven fusion experiments carried out at the world's largest and most energetic laser, the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory in the USA.

While primarily an experimental tool for national security applications, NIF also conducts experiments relevant to fusion energy production. NIF is an extraordinarily complex facility, generating 192 individual laser beams in a building the size of three American football fields. After traveling one and a half kilometers through thousands of computer-controlled optics, the beams illuminate a one-centimeter-sized fusion target with the precision of the width of a human hair.

In a NIF fusion experiment, we load fusion fuel (deuterium and its heavier relative tritium) into the center of a plastic or diamond sphere. The sphere's outer layers absorb the energy provided by the laser and blow up, causing the rest of the target to implode inwards at immense speeds of 400 kilometers per second. This heats and compresses the fusion fuel to the extreme conditions where fusion reactions occur. For less than a billionth of a second, we have created a tiny star in the laboratory, five to ten times hotter than the sun.

In the deuterium-tritium fusion reaction, the two hydrogen isotopes join together to create two new particles: a fast neutron and a slower alpha particle (the nucleus of a helium atom without its electrons). While the neutrons escape the target, the alpha particles can become trapped in the surrounding material and redeposit their energy. In the right conditions, a feedback loop arises that rapidly increases the temperature of the system: fusion reactions make alpha particles, which become trapped and add energy, leading to exponentially more fusion reactions and energy produced.

Fusion experiments have been conducted at NIF since its inception in 2010, but recent improvements in the target manufacturing quality and our ability to finely control various aspects of the implosion process have resulted in vastly more fusion energy produced than ever before.

In a series of experiments from late 2020 – early 2021, we observed the first signs of alpha particle trapping starting to ramp up, much more than before. We had reached a new physical state called a "burning plasma," in which fusion reactions themselves become the primary source of heating in the fuel. This was the first demonstration of a burning plasma in any laboratory fusion experiment.

A burning plasma is one step away from fusion "ignition," where energy produced by the fusion reactions outstrips all energy losses and the alpha particle feedback loop kicks into an even higher gear. A record experiment on August 8, 2021 did just that, generating 70% of the initial laser energy back through fusion reactions and demonstrating that fusion ignition is indeed possible in the laboratory.

These recent experiments are incredibly exciting for the fusion community and resulted from decades of hard work and dedication by a large collaboration across many facilities and institutions. There is still much work to be done to explore the burning plasma and ignition regimes and understand what it will take to further reduce losses and improve performance.
Only then will we reach the holy grail of net energy gain – one of the last key demonstrations on the long and tantalizing road to bringing commercial fusion power generation to a city near you.
Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-JRNL-833472.