Inertial Fusion Energy at LLNL

Enabling a future where fusion is harnessed as a carbon-free, abundant, safe energy source for energy and climate security.

Introduction

Institutional Initiatives reflect Lawrence Livermore National Laboratory's (LLNL's) "team science" approach and support single institutional mission by anticipating issues of national importance.

Energy is at the heart of modern economies. As the world's energy demands continue to climb, new energy sources that are clean and plentiful are required. Fusion energy promises a virtually inexhaustible, safe, environmentally-friendly and universally-available energy source, capable of meeting this need.

Fusion energy has shined upon the earth for billions of years, but humankind has yet to harness it in a controlled manner. The achievement of fusion ignition at the National Ignition Facility (NIF) demonstrates the fundamental basis of Inertial Fusion Energy (IFE) and is a pivotal first step towards a fusion energy future.

Working in synergy with Lawrence Livermore National Laboratory's (LLNL's) stockpile stewardship mission, the IFE Institutional Initiative is enabling the U.S. national, technical, and community leadership needed to build the foundational science and technology for IFE and support the Department of Energy (DOE's) vision for accelerating the commercialization of fusion energy.

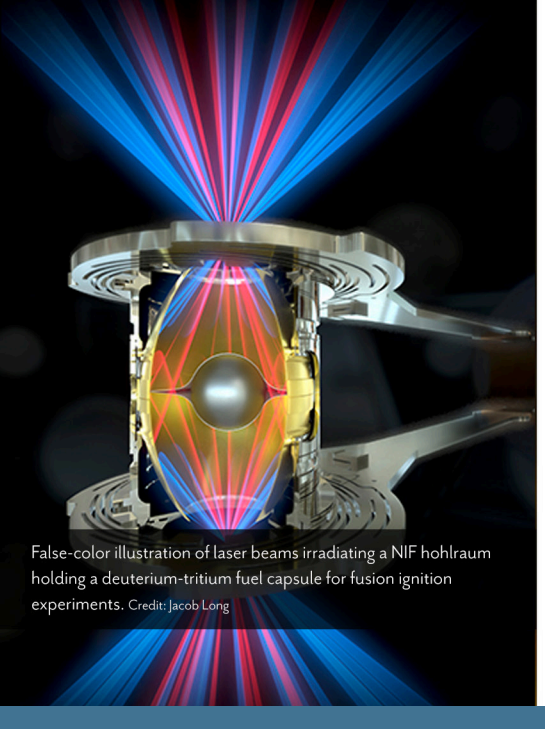
Applications

The U.S. is the world leader in both High Energy Density Science (HEDS) and Inertial Confinement Fusion (ICF). This is the result of significant, multi-decade investments by DOE and the National Nuclear Security Administration (NNSA) to sustain the nation's nuclear deterrent and the possibility of fusion energy.

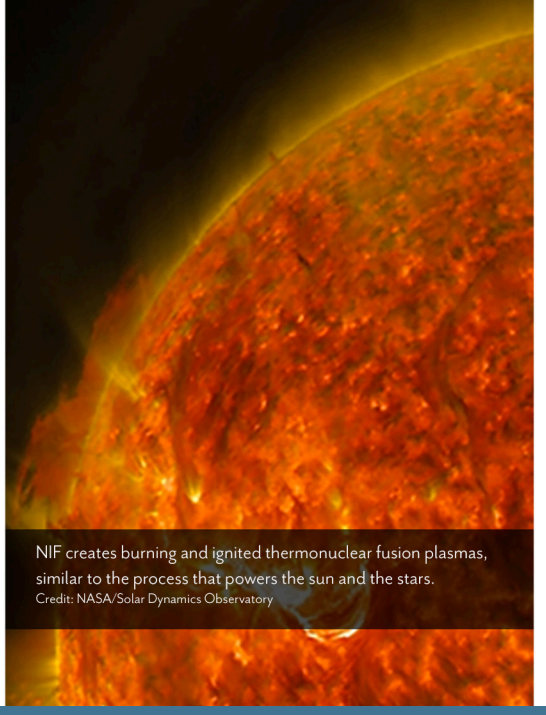
These investments led to the December 2022 achievement of fusion ignition at NIF. Ignition—since repeated multiple times—uniquely enables LLNL to support revitalization of a national IFE program with DOE Office of Science's Fusion Energy Sciences Program (DOE-SC/FES). Research and development (R&D) in IFE has numerous benefits to ICF and other efforts across the Laboratory that will strengthen its ability to achieve core missions.

These R&D projects include:

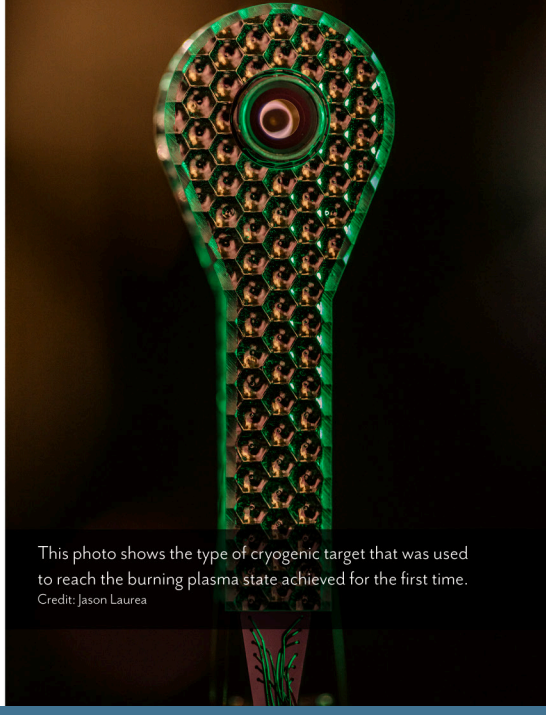
- Developing novel high gain ignition target designs that could also be applied to stockpile stewardship missions.
- Establishing advanced full plant modeling capability for trade space studies and requirements setting to guide the U.S.'s path toward a fusion pilot plant, building on LLNL's system engineering capabilities.
- Developing and demonstrating next-generation diode-pumped solid-state lasers capable of meeting power plant technical and cost requirements, with spin-off applications to national security areas.
- Enhancing our understanding of relevant reactor materials survivability and lifetimes in extreme fusion environments and advancing their technical readiness level.
- Developing viable scale-up paths for mass manufacturing of ICF targets.
- Advancing the forefront in high-repetition-rate HEDS by developing experimental subsystems capable of operating at greater than Hz rates with real-time feedback and optimization in partnership with the Cognitive Simulation Institutional Initiative.
- Developing a sustainable, world-leading IFE workforce that also strengthens LLNL's core mission delivery.
- Ensuring foundational technologies are spun out to industrial partners as appropriate.



False-color illustration of laser beams irradiating a NIF hohlraum holding a deuterium-tritium fuel capsule for fusion ignition experiments. Credit: Jacob Long



NIF creates burning and ignited thermonuclear fusion plasmas, similar to the process that powers the sun and the stars.
Credit: NASA/Solar Dynamics Observatory



This photo shows the type of cryogenic target that was used to reach the burning plasma state achieved for the first time.
Credit: Jason Laurea

Accomplishments

LLNL is enabling the national, technical, and community aspects of growing a robust U.S. IFE program. The Laboratory's IFE Institutional Initiative provides inclusive leadership on the national and international stage, builds up IFE efforts within LLNL in areas highly synergistic with stockpile stewardship, and supports the emerging public and private IFE landscape.

Building on the groundbreaking achievement of ignition, recent accomplishments include:

- Chaired and delivered the Inertial Fusion Energy Basic Research Needs report for the DOE-SC/FES, laying out priority research opportunities for the nation.
- Established an IFE Collaboratory with nine other national labs and institutions to facilitate public-private partnerships, including hosting two Industry Days.
- Completed an LLNL IFE Strategic Planning exercise and report with participants from across all directorates of the Laboratory.
- Developed a high-level roadmap toward an inertial fusion pilot plant for the U.S.
- Fostered an LDRD portfolio of six projects jointly supported by four LLNL directorates with R&D including high yield target designs, high-repetition-rate laser system technologies, and scalable 3D printing of foam targets.
- Selected as one of three national DOE-SC/FES IFE Hubs to provide an IFE framework that leverages expertise and capabilities across national laboratories, academia, and industry to advance foundational IFE S&T.
- Partnered and supported three private company awardees in the DOE Milestone program to design a pilot fusion power plant to bring fusion to both technical and commercial viability.
- Built relationships and advocacy for the national IFE program, in partnership with DOE-SC/FES.
- Organized an IFE summer school for undergraduate and graduate students and developed plans to strengthen pipelines for the future workforce.

LLNL-MI-858684
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
December 22, 2023

The Future

In achieving ignition, the U.S. has taken the first pivotal step to inertial fusion energy. Achieving fusion energy will require sustained, long-term investments and innovations in multiple fields to enable a viable energy source.

LLNL, in partnership with the community, will continue to grow a robust and coordinated U.S. IFE program spanning the public and private sectors to build the first pilot plants, with key components including:

- Integrated plant design to drive S&T to close existing gaps and set requirements for fusion pilot plant concepts.
- National hubs with the necessary new facilities to advance component technologies and foundational science.
- Access to unique, world-leading NNSA and DOE facilities to provide near-term data and reduce risk.
- A proactive workforce development effort spanning all levels, and inclusive public engagement about fusion.

U.S. leadership in IFE could profoundly transform long-standing energy geopolitics, strengthen energy and climate security, and bolster national security for the U.S. and allied partners. It is a worthy scientific and engineering grand challenge building on the historic achievement of fusion ignition.