Status of Inertial Fusion Energy (IFE) in the U.S.

2023 Fusion Power Associates Annual Meeting

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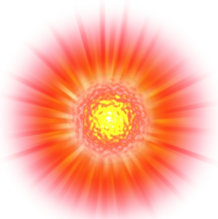
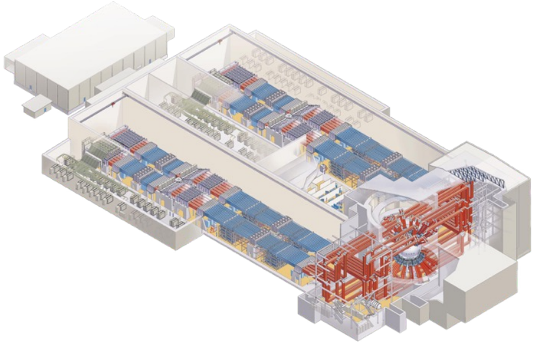
IFE has an emergent, highly coordinated national strategy to drive towards FPPs in the 2030’s, founded on $B’s investment in ICF

Historical foundation



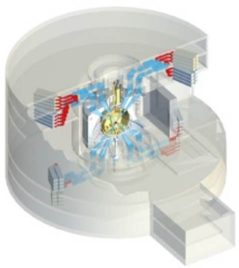
Robust, repeatable ignition

4x $E_F > E_{las}$, only limited by target production and available shot opps



At-scale facility (NIF) to study burning plasma and demonstrate concepts

e.g. wetted foams, LPI

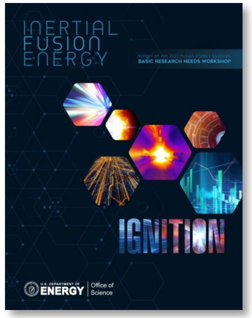


Multiple historical plant studies to build from

Self-consistent and with credible materials solns

Going forward

Priority Research Opportunities as defined by 2022 IFE BRN



HUBS coordinate national effort to support critical technology development

IFE STAR

Milestone program focused on FPP development

FOCUSED ENERGY

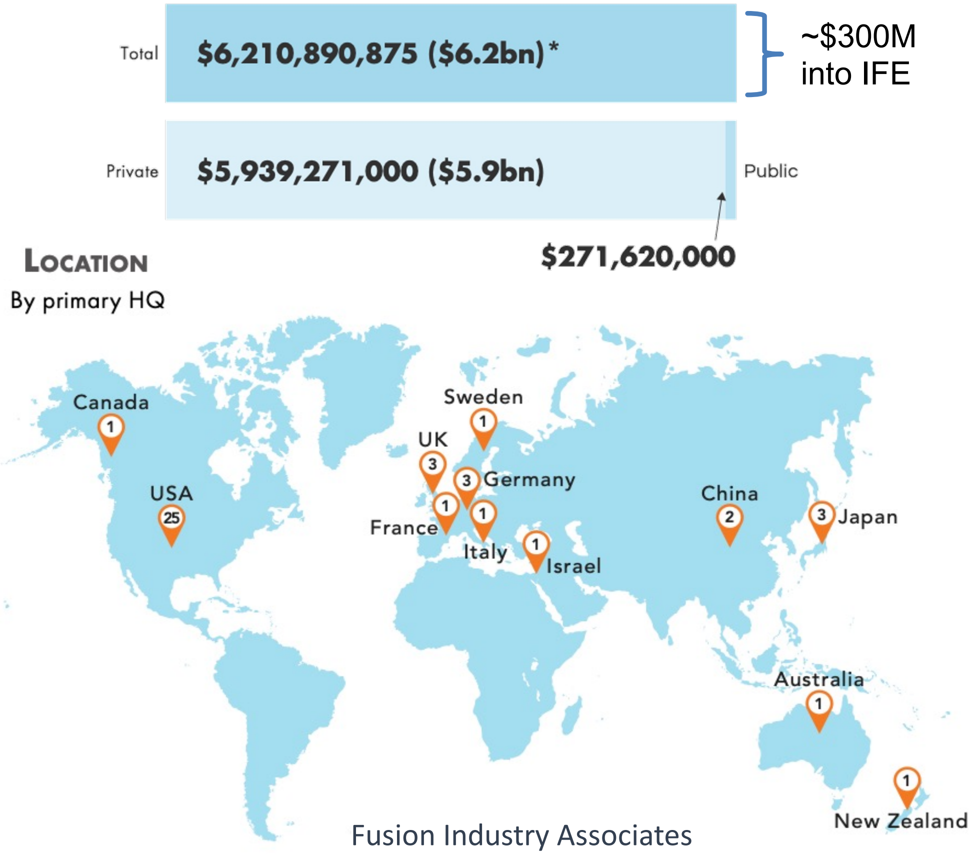
XCIMER ENERGY CORPORATION

Longview Fusion Energy Systems

The time is right for a serious drive to IFE FPP. The path to commercially viable fusion energy will require a level of investment and commitment on par with what it took to get to ignition.

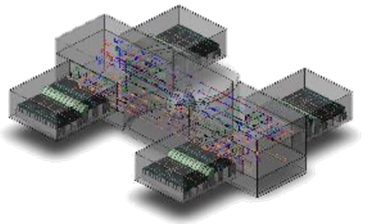
IFE is a national need that requires a national plan, program, and team, and sustained commitment

Funding for private fusion companies

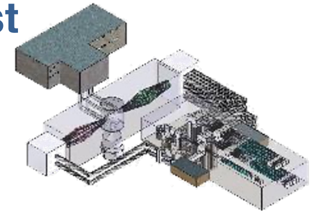


Fusion Industry Associates
The Global Fusion Industry in 2023

Economically Viable Commercial Power Plant



Demo Facilities and First Pilot Plants (2030-40)

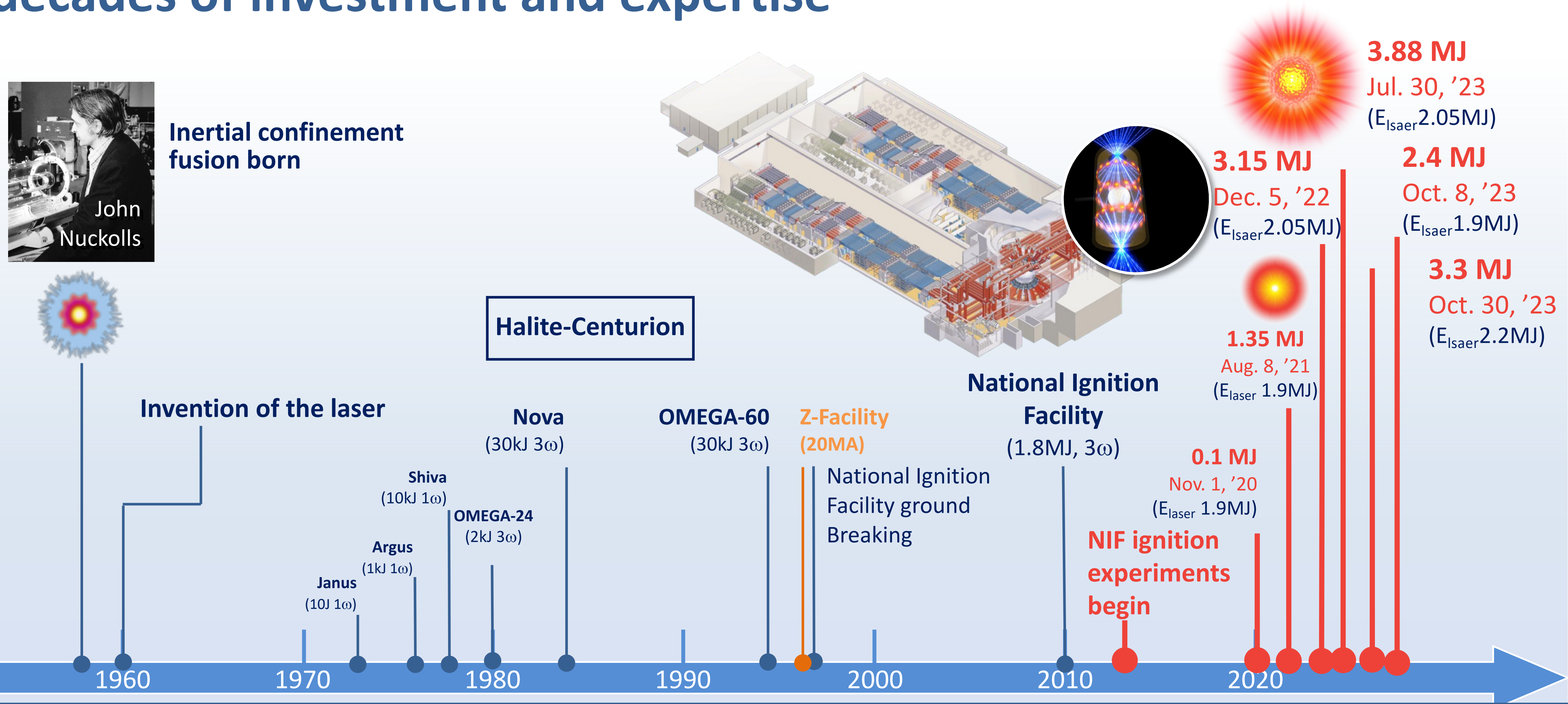


Technology maturation and workforce development (start now)

- Public-led hubs for component R&D
- Leverage existing facilities for target R&D (NIF; Laboratory for Laser Energetics, University of Rochester)
- Private-led PPPs: pilot plant designs
- Dedicated IFE facilities

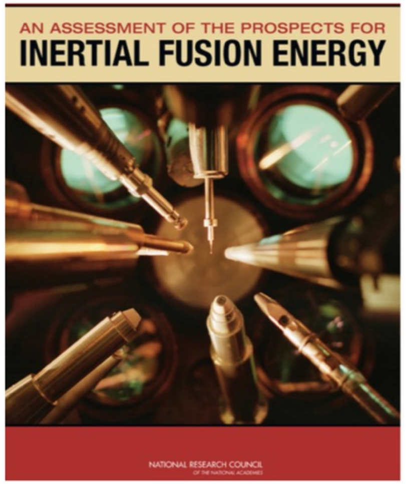
Each step of the plan will require significant public-sector investment and private sector partnerships as well as significant resolve

We have now achieved ignition four times on the NIF – built on decades of investment and expertise

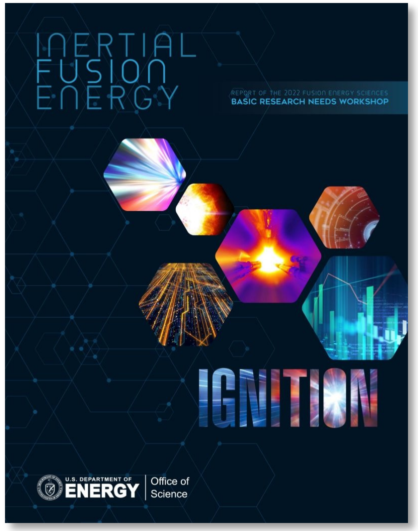


ICF infrastructure developed over many decades is extensive, and can be leveraged to significantly accelerate IFE

We are at a pivotal moment in fusion research, with a well organized community poised take advantage of recent successes! It is the ideal time to focus on IFE



2013 → 2023



"The appropriate time for the establishment of a national, coordinated, broad-based inertial fusion energy program within DOE would be when ignition is achieved."
- NASEM 2013

"The U.S. is the recognized leader in IFE science and technology because of the decades of investment under the national security mission."
"Private industry is driving the commercialization of fusion energy in the U.S."
"Accelerating IFE will require a suite of dedicated, new, and upgraded facilities"
- IFE BRN 2023

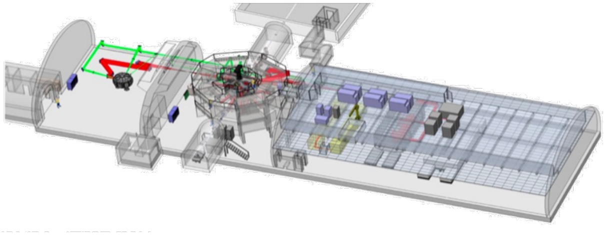
"This position paper on fusion research is intended to provide guidance…and lay the foundations for a national programme, open to all technologies, that can promote magnetic and laser fusion."
- BMBF Position Paper 2023

IFE BRN Overarching **Priority Research Opportunities**

1. Take advantage of and spur **emerging technologies** (exascale computing, artificial intelligence (AI) and machine learning (ML), advanced manufacturing, high-rep-rate laser systems, etc.) to accelerate progress toward the goal of a fusion pilot plant (FPP).
2. **Employ system-level integrated studies** to guide the IFE R&D in a coordinated fashion with the objective to advance the different areas of IFE science and technology towards the goal of building and operating an FPP.
3. **Develop scoping studies to evaluate the various IFE concepts**. With input from the energy industry and fusion science and technology experts, identify the most promising concepts to guide downselection and to inform directions of technological development.
4. **Accelerate the pace of IFE and reduce risk through the pursuit of parallel development paths.**
5. Leverage **existing facilities** (including LaserNetUS), expertise, and **international collaboration** to advance IFE S&T. Explore ways to expand shot time on existing U.S. facilities and develop upgrades to meet IFE-specific needs.
6. Assess how to **optimally and securely access and use ICF codes for IFE development**, and how to leverage the deep code expertise that resides at the NNSA-funded labs. Carry out the assessment with NNSA input.

LaserNetUS

MEC
Petawatt
Upgrade



2022 IFE Basic Research Needs defined TRL levels for five IFE concepts for the seven aspects critical for any development path

IFE Concepts → / *Critical aspects for IFE development ↓*	Laser Indirect Drive	Laser Direct Drive (including Shock Ignition)	Fast Ignition	Heavy Ion Fusion	Magnetically Driven Fusion
Demonstration of ignition and reactor-level gain	**4**	**3**	**2**	**1**	**3**
Manufacturing and mass production of reactor-compatible targets	**2**	**2**	**2**	**2**	**1**
Driver technology at reactor-compatible energy, efficiency, and repetition rate	**4**	**4**	**3**	**2**	**3**
Target injection, tracking, and engagement at reactor-compatible specifications	**2**	**2**	**2**	**2**	**1**
Chamber design and first wall materials	**1**	**1**	**1**	**1**	**1**
Maturity of Theory and Simulations	**3**	**3**	**2**	**2**	**2**
Availability of diagnostic capabilities for critical measurements	**3**	**3**	**2**	**2**	**2**

TRL 1 = Basic principles observed

TRL 2 = Technology concept formulated

TRL 3 = Proof of concept

TRL 4 = Component validation in lab environment

TRL 9 = Demonstration plant

Table adapted from Report of the 2023 Inertial Fusion Energy Basic Research Needs Workshop.

FY24 will mark the rebirth of the U.S. national public IFE program; numerous funding calls are supporting IFE

U.S. DEPARTMENT OF ENERGY | Office of Science

IFE-STAR establishes multi-institutional ”hubs”

IFE-STAR will award **$42M** over 4 years and provide a framework that leverages expertise and capabilities to advance foundational S&T using integrated and self-consistent solutions

Milestone-Based Program encourages teaming to develop fusion pilot plants

Department of Energy Announces $50 Million for a Milestone-Based Fusion Development Program

This new public-private-partnership program is the first step toward realizing the Administration’s bold decadal vision for commercial fusion energy

Several calls center around foundational S&T

INFUSE (Innovation Network for Fusion Energy) to provide industry access to capabilities at DOE-funded institutions

INFUSE Innovation Network for Fusion Energy

ARPA-E fusion programs

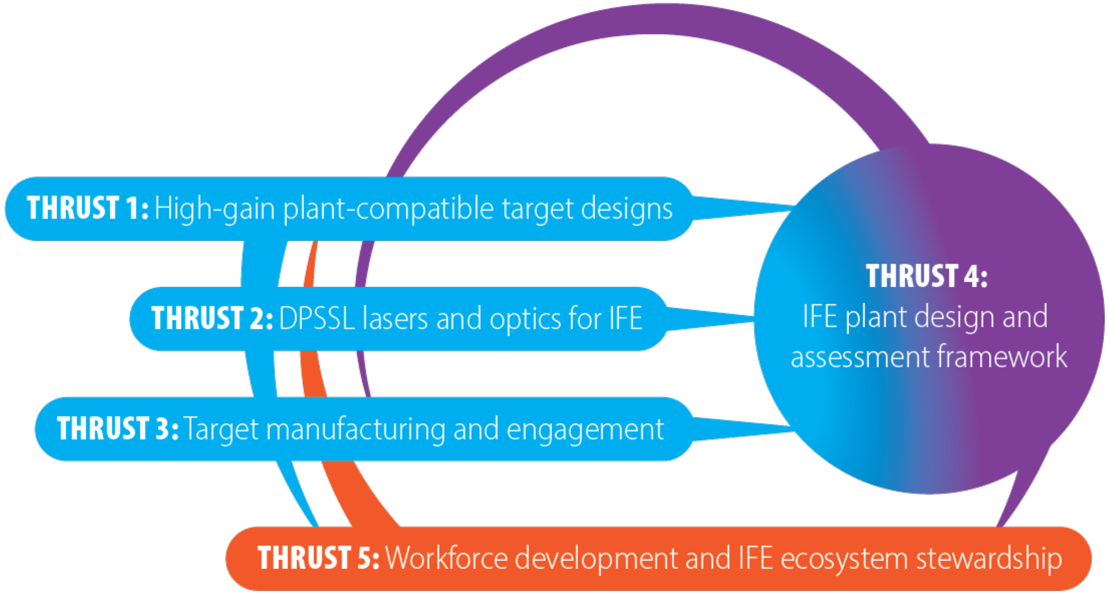
arpa·e

DOE has awarded LLNL $16M over four years to launch IFE Hub

STARFIRE

Science & **T**echnology **A**ccelerated **R**esearch for **F**usion **I**nnovation & **R**eactor **E**ngineering

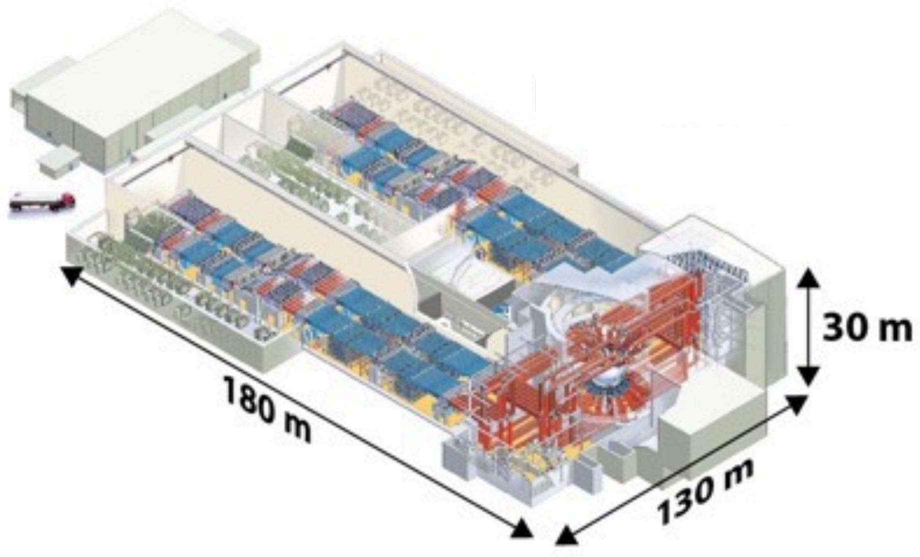
Partners	In-Kind Contributors	Consultants
LLNL	Fraunhofer ILT	Livermore Lab Foundation
GA	TRUMPF	SLAC
UC San Diego	Leonardo Electronics	Xcimer
UC Berkeley		Focused Energy
University of Rochester		Longview Fusion Energy
MIT		ORNL
Univ. of Oklahoma		SRNL
Texas A&M		
UCLA		



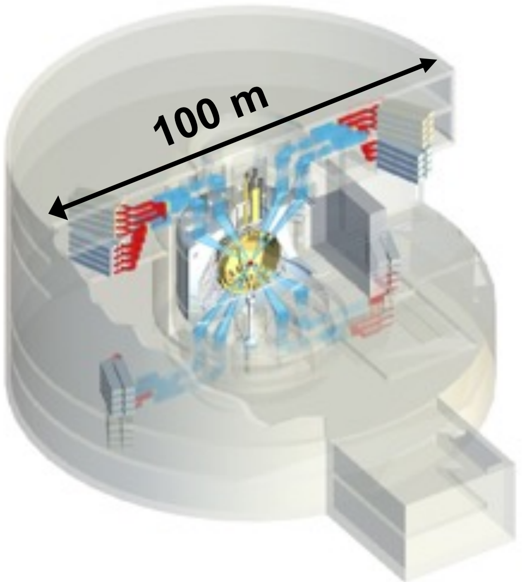
STARFIRE is one of 3 multi-institutional hubs (other winners: CSU & LLE).
We are working on a national "mega-hub" that combines the 3 national winners, and other DOE projects within IFE

The NIF is a scientific exploration facility, and different from what would be needed for an IFE power plant

NIF: Single Shot



IFE plant: >10 Hz



Gain of 1.9 has been achieved on the NIF

A gain of 15-16 is approximately what is needed for a self-sustaining plant

Over the past decade, we have improved our gains on NIF by factor 1000x

NIF provides a unique opportunity to experiment at “fusion scale” now, but there are yet many outstanding technical questions that must be solved to make IFE a reality

NIF is critical if we want to do IFE fast – must speed up path to 10s of MJ yields and high gain; need IFE access to shots!

NIF has not yet reached its full potential

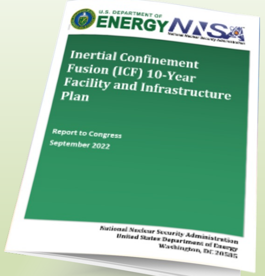
Few MJ → 10s of MJ → 100+ MJ??

2023

Routine MJ-yield operations and ignition

2023–2028

Long-term sustainment



Increase energy and power

2030–2040

Explore high-yield, high-gain regime

- Near-term target physics paths of demonstrating a robust, repeatable high-gain platform are synergistic & identical
- NIF is the only game in town for next 5-10 years
- Only place to demonstrate target design, gain scaling, understand failure modes & margins, facility ops at yield conditions

But currently no IFE allocations on NIF – additional NIF shots is the only credible near-term option to resolve key IFE technical challenges!

2023 was a year of significant progress in IFE!

- We are now in a new regime of fusion – robust, repeatable ignition on the NIF!
- IFE BRN lays out the gaps, challenges, and priority research opportunities
  - Spurring interest and follow-on funding from governments around the world
- NIF sustainment and upgrade will push towards 10’s MJ yields
- MEC-U can be a near-term materials research capability: on path to CD-2
- 3 DOE IFE-STAR Hubs awarded at $42M / 4 years
  - LLNL STARFIRE Hub will establish foundational S&T for all laser-based approaches, guided through a systems framework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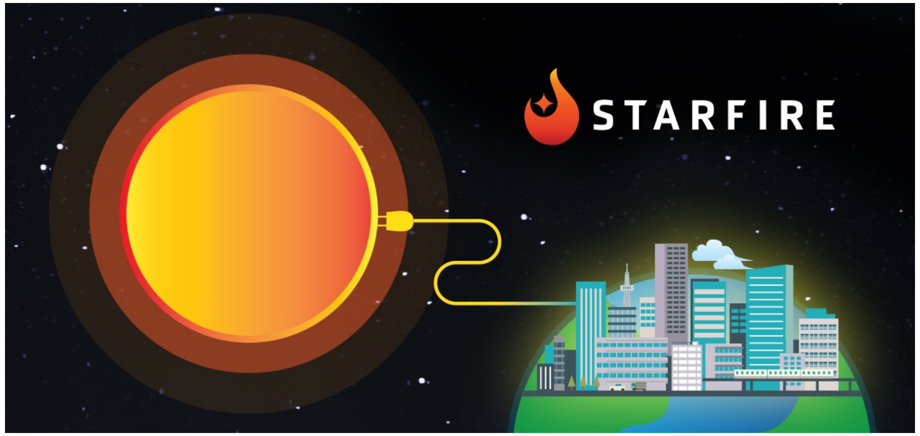
NEWS | 15 December 2023 | Correction 17 December 2023

US nuclear-fusion lab enters new era: achieving ‘ignition’ over and over

Researchers at the National Ignition Facility are consistently creating reactions that make more energy than they consume.

By Jeff Tollefson



“We have a unique opportunity right now to grow the national program by nourishing and leveraging our leadership in ICF with unique and world-leading competencies in the science and technology that underpins IFE” – IFE BRN

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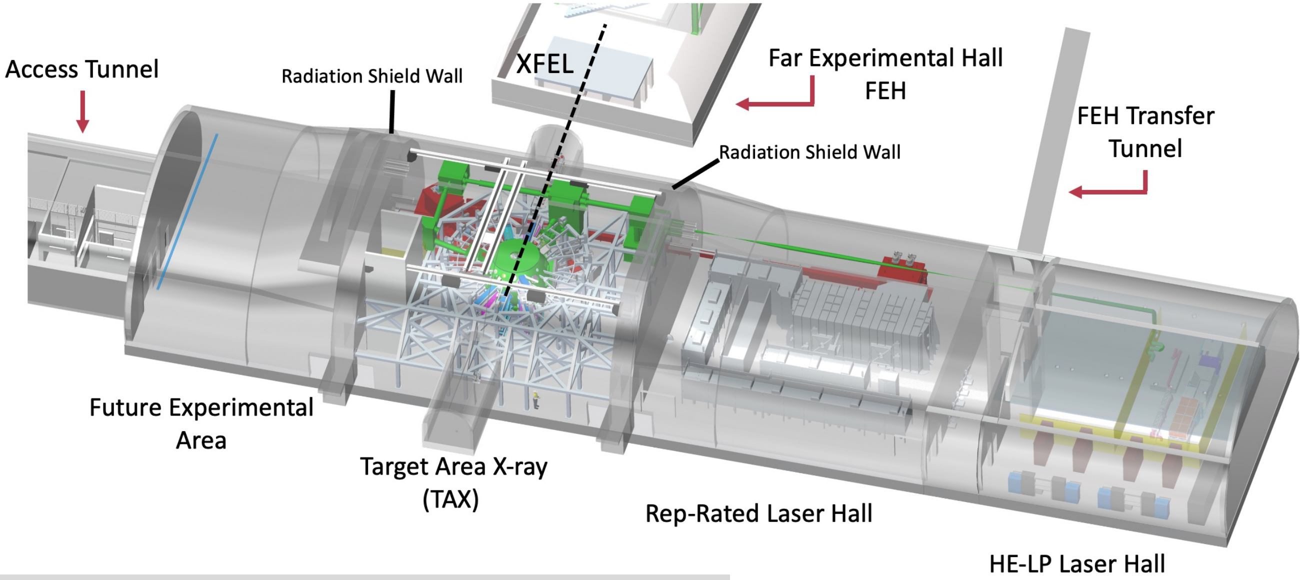
MEC-U will provide an internationally preeminent combination of high-energy lasers with LCLS XFEL for near-term enablement of fusion materials research



Laser systems

- High rep-rate laser (LLNL)
  - Short pulse: 10 Hz, 150 J, 150 fs, 1 PW
  - Long pulse: 10 Hz, 200 J @ 2w @ 10 ns
- High energy long pulse laser (LLE)
  - ~2 shots/hr, 1 kJ @ 2w @ 10ns
- LCLS XFEL (5 to 45 keV)

U.S. DEPARTMENT OF ENERGY
Office of Science

Key Technical Opportunities

- Applicability to key science:
  - Radiation damage cascades
  - Ion stopping power in dense plasmas
  - Impulsive stress and damage
- Plus practical operational experience
  - Rep-rated high-power laser operations
  - Diagnostics and controls

An appropriate MEC-U budget and funding profile is a path to enable very high productivity scientific output of relevance to HED Science and IFE