Progress After "The Shot" at the NIF and the path towards Inertial Fusion Energy

Tammy Ma
Lead, Inertial Fusion Energy Initiative
NIF & Photon Sciences

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LLNL-PRES-
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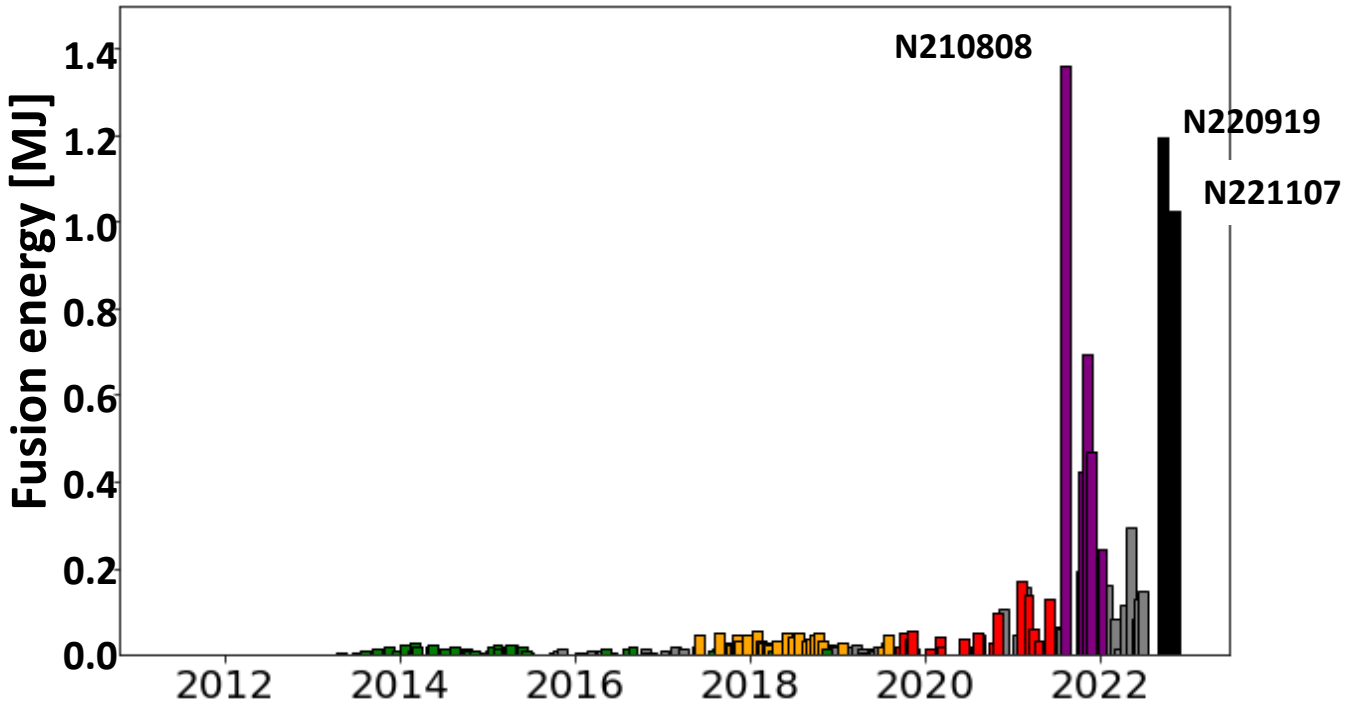
Lawrence Livermore National Laboratory

We have made great progress on our goal of fusion ignition in the laboratory

- On August 8, 2021, we entered a new performance and physics regime putting us on the threshold of ignition (1.37 MJ yield)
- Repeat attempts had yields in the 400 – 800 kJ range; the lower performance was largely due to small imperfections in the target
- Recently, capitalizing on what we learned from analyzing the attempted repeats and benefitting from laser improvements we have had two more experiments that exceeded 1MJ of fusion yield
- In the next 6 months we will field higher quality targets and perform more experiments with increased laser output
- These recent ICF successes provide fresh impetus in the exploration of inertial fusion as a path for clean energy
- LLNL has kicked off an Institutional Initiative in IFE to support the national program and decadal vision for accelerating fusion energy
- An IFE Collaboratory with 10 institutions has been formed to support the emerging public and private IFE landscape

NIF has demonstrated that laboratory ignition is possible – the time for a national, coordinated, broad-based IFE program is now!

On August 8, 2021, we entered a new performance and physics regime putting us on the threshold of ignition



H. Abu-Shawareb et al., PRL, 129, 075001 (2022)
A. L. Kritcher et al., PRE, 106, 025201 (2022)
A. B. Zylstra et al., PRE, 106, 025202 (2022)

Achieving such yields required a concerted long-term effort to improve our:

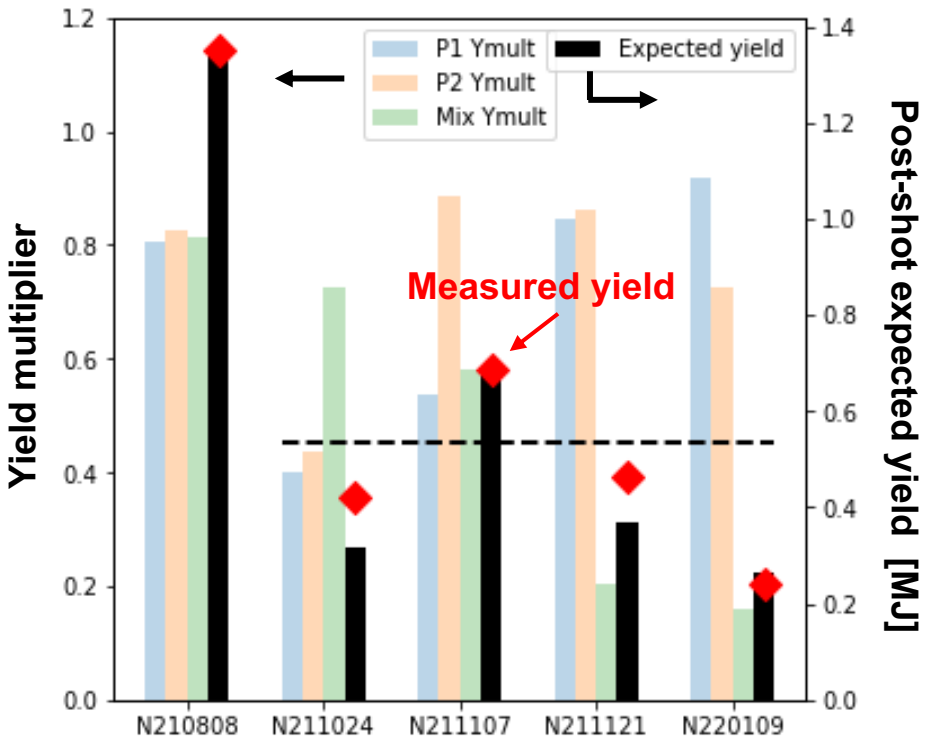
- Target quality
- Laser accuracy
- Diagnostic capabilities
- Design

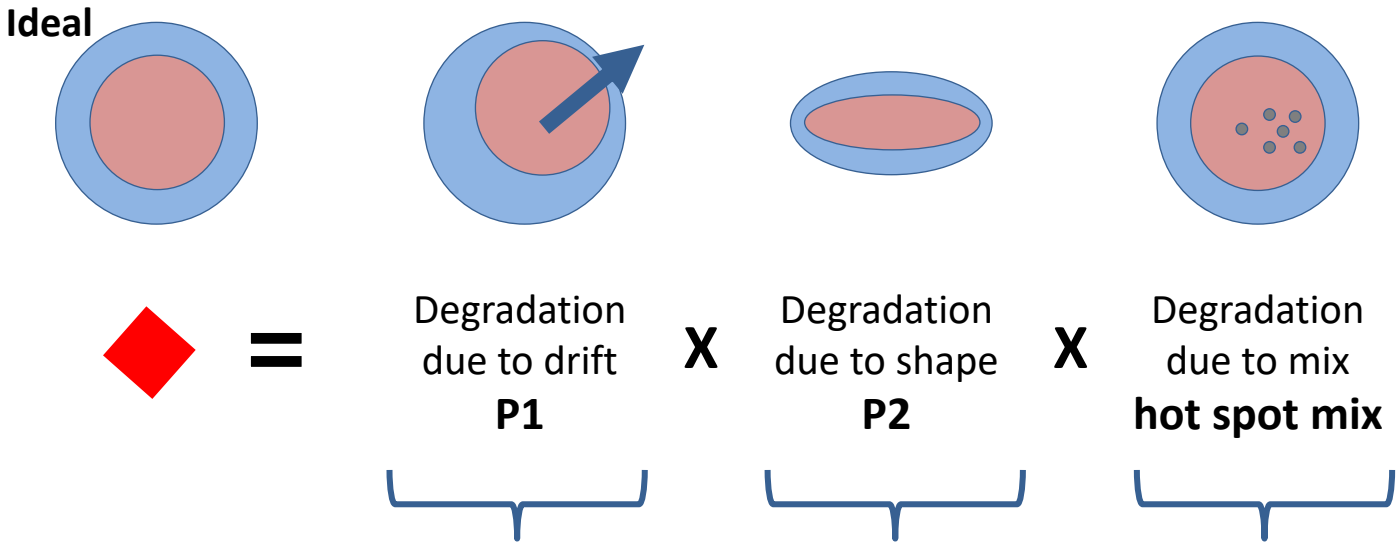
Repeat attempts had yields in the 0.4-0.8MJ range

Applying our wide suite of diagnostics, we have improved our understanding of this new regime

Improved understanding has led design refinements that have achieved 1.2MJ and 1.0MJ yields in two recent experiments

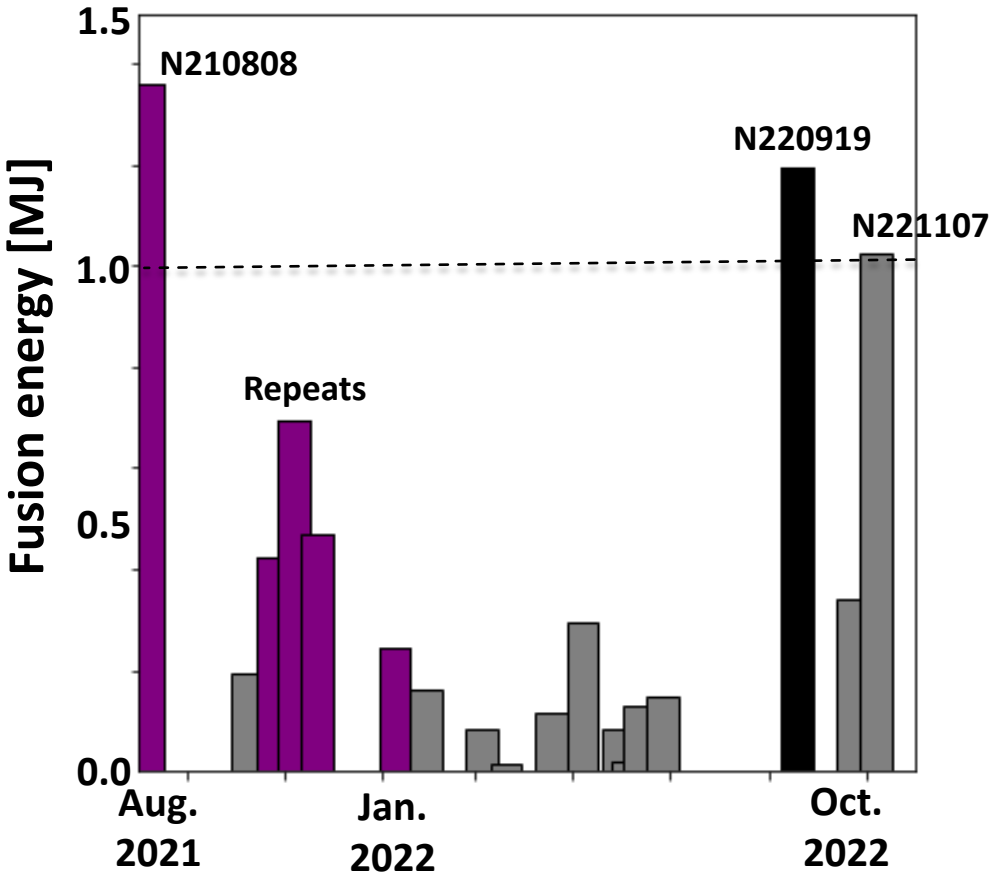
Three main sources of degradations that affect the fusion yield have been identified





Current variability is driven by mix and low mode asymmetry.
With current variability, average yield of N210808 ignition design is ~0.5 ± 0.2 MJ
If mix could be kept to N210808 levels, variability expected to be 1.1 ± 0.35 MJ

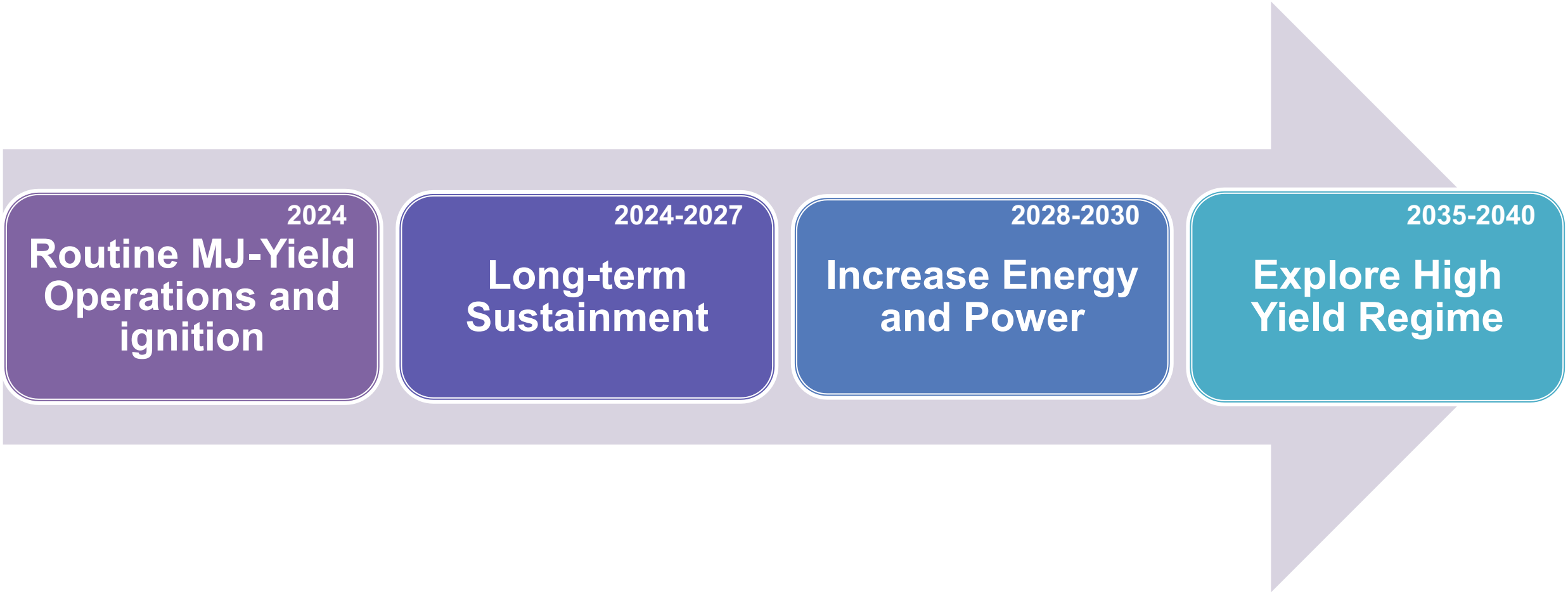
The “more stable design” path has produced two additional experiments yielding over a megajoule



- **1.35MJ yield:** 1.9MJ of laser energy and standard thickness
- **1.2MJ yield:** 2.05 MJ of laser energy and +6 μm thicker capsule
  - Higher laser energy and thicker targets provide a path to increased energy and less sensitivity to capsule fuel mix
- **1.0MJ yield:** 1.9MJ of laser energy and a denser capsule
  - Denser capsule increases dwell time at highest pressures

The first experiment with higher quality target capsules is scheduled for February 2023

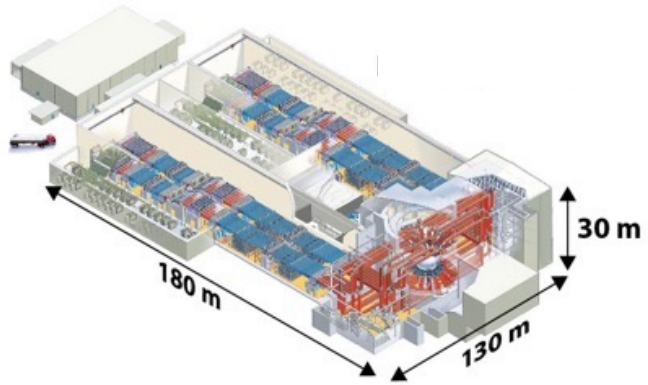
Near-term goal: achieve ignition while exploring design paths to high yields



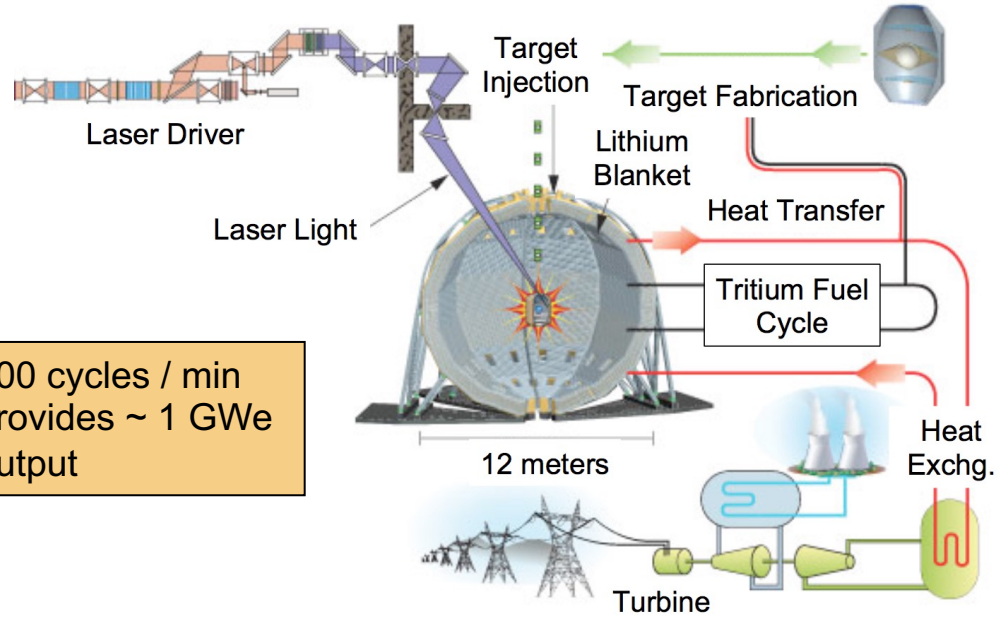
Recent ICF success provides fresh impetus in the exploration of inertial fusion as a path for clean energy

The leap from NIF to an IFE plant requires increased repetition rate and complexity, development of robust, repeatable, burning plasma platforms, and technological advances in many subsystems

NIF: Single Shot



IFE plant: >10 Hz



900 cycles / min provides ~ 1 GWe output

The path forward for IFE research will require different, but synergistic, technologies from the stockpile stewardship mission. How can IFE leverage and spur emerging technologies? How can we partner with the private sector? What does a national IFE program look like?

LLNL is ramping up an IFE Institutional Initiative

Why?

IFE could be a game-changing energy technology

- Bolsters American S&T leadership, security, and energy independence

LLNL has decades of ICF expertise we can build on to contribute to the national IFE program

- U.S. is clear world leader in ICF – need to capitalize for IFE
- Help establish the basis for a credible IFE development path

The time is ripe

- NIF has demonstrated that laboratory ignition is possible
- Unprecedented momentum in public and private spheres

Strategy

1. Provide inclusive IFE leadership on the national and international stage
2. Build up internal technical IFE efforts in areas highly synergistic with SSP and high yield needs via institution-wide LDRD portfolio and PPP
3. Establish a consortium with national lab, academic, and private industry partners

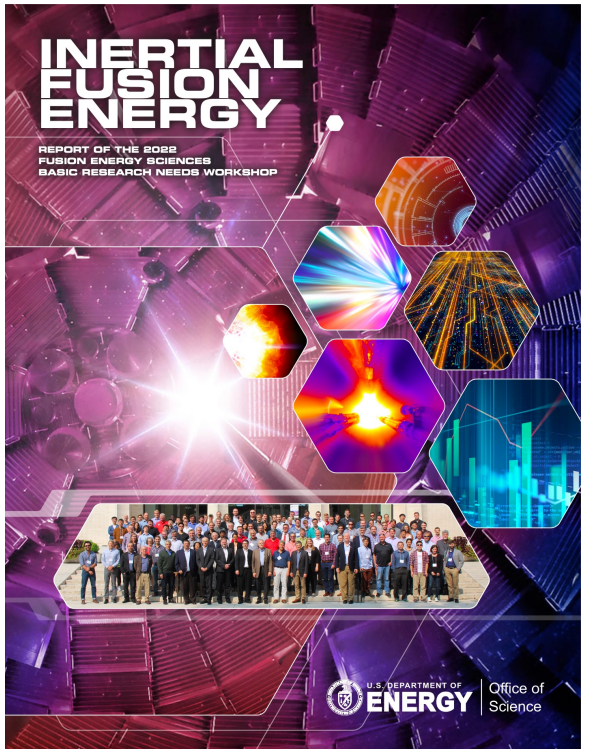
Working across the Lab and with the community, we seek to grow the national IFE program by nourishing and leveraging our leadership in ICF with world-leading competencies in underlying S&T

Multiple recent national and community reports have supported IFE and the pursuit of a fusion power plant

N210808, private sector interest, sustained advocacy and new legislation have created a supportive environment today for a revitalized US IFE program

The US DOE recently held a Basic Research Needs in IFE to define a new national IFE program

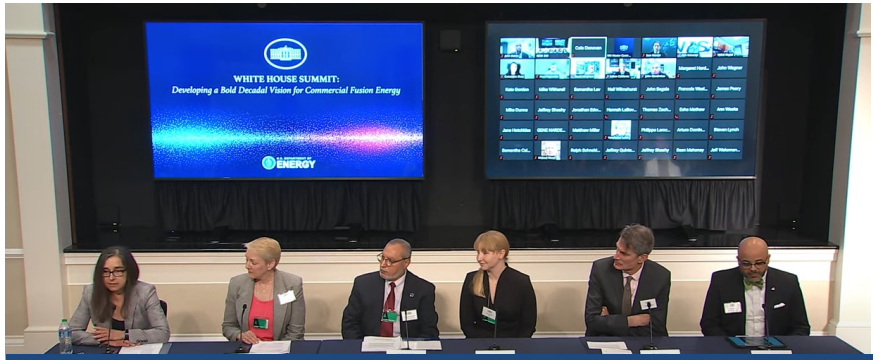
https://events.bizzabo.com/IFEBRN2022/home



Report to be released mid-December 2022

Report will provide a set of priority research opportunities that can inform future research efforts in IFE and build a community of next-generation researchers in this area

LLNL is working in close partnership with the broader community to support the emerging IFE landscape

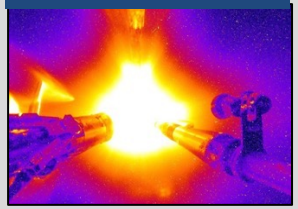


Supporting White House Fusion summits and DOE workshops

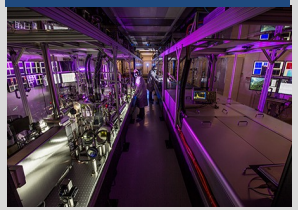
INERTIAL FUSION ENERGY COLLABORATORY

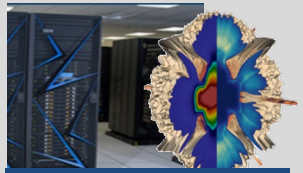
LLNL led multi-lab efforts to form IFE Collaboratory for facilitating public-private partnerships

Diagnostics



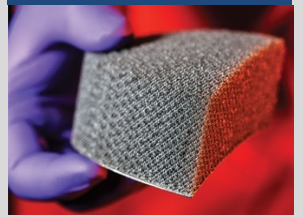
Frontier Laser Tech

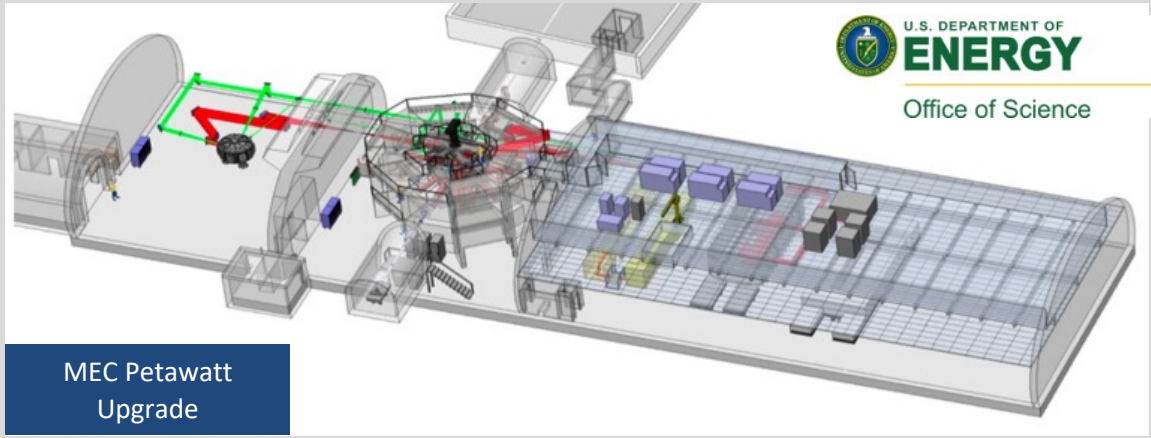




HPC & HED Codes/AI

Advanced Manufacturing





MEC Petawatt Upgrade

LLNL continues to drive underlying S&T required for both ICF and IFE

A multi-lab IFE Collaboratory was formed to facilitate public-private partnerships

INERTIAL FUSION ENERGY COLLABORATORY

Lawrence Livermore National Laboratory · SLAC National Accelerator Laboratory · Los Alamos National Laboratory · Sandia National Laboratories · Berkeley Lab · UR LLE · General Atomics · Savannah River National Laboratory · Oak Ridge National Laboratory

- Living website: *https://events.bizzabo.com/RFI-IFE/home*
- Collaboratory website lists capabilities
- A Request for Information (RFI) was issued and two Industry Days held (Oct 27: virtual, Capabilities & Project overview; Nov 10: in-person, crafting of SoW's + discussions)

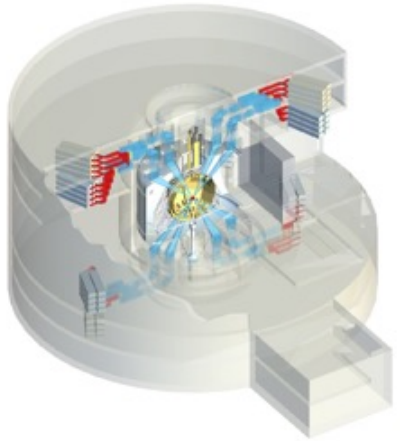
In-person Industry Day held Nov. 10, 2022 @ LLNL's UCLCC

By the numbers:

- 14 IFE companies + 9 Collaboratory institutions
- 41 in-person + 10 virtual participants
- 3 hub/center discussions
  - Targets
  - Lasers
  - Fuel Cycle/Blankets
- 9 breakouts w/ 39 pre-arranged meetings

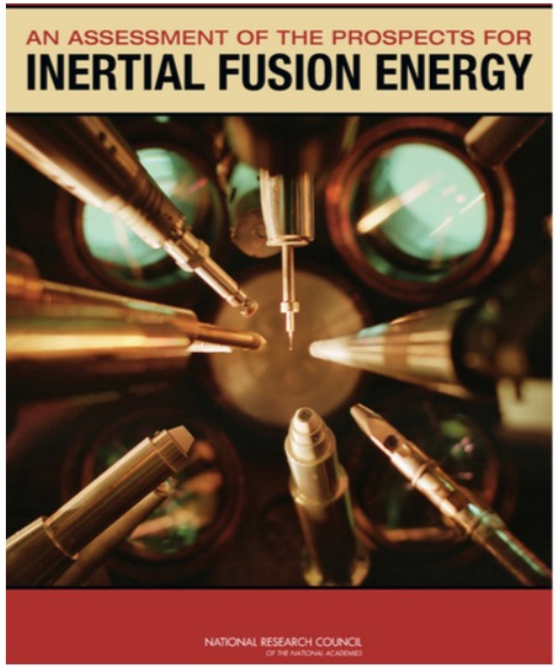
The Collaboratory promotes fairness of opportunity for partnerships, and ensures strategic alignment with Lab core missions

Why IFE? Why now?



Advantages of the <u>inertial</u> fusion energy (IFE) concept:

- Demonstration of (near) gain on NIF
- Separable components & highly modular
- Multiple target concepts with same driver
- High burn-up fraction of the DT fuel
- Attractive development path
- Technology and science spin-offs
- Multiple sponsors for key technologies (e.g., laser diodes, high neutron yield sources)



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

An Assessment of the Prospects for Inertial Fusion Energy, Committee on the Prospects for Inertial Confinement Fusion Energy Systems, NRC (National Academies Press, Washington, D.C., 2013)

The pursuit of IFE will be a multi-decadal endeavor. More government investment in the public sector is needed if we are to accelerate.

We are on the path to high gain demonstrations on the NIF, setting the stage for ambitious IFE development

- Multiple experiments on the NIF have exceeded 1 MJ of fusion yield
- The main sources of degradations that affect the fusion yield have been identified and variability quantified
- Over the next 6 months, we will field higher quality targets and perform more experiments with increased laser output
- These recent ICF successes provide fresh impetus in the exploration of inertial fusion as a path for clean energy
- LLNL is working in close partnership with the broader community to provide expertise, unique capabilities, and leadership to support the long-term success of IFE – part of LLNL IFE Institutional Initiative strategy
- IFE Basic Research Needs Report to be released imminently
- An IFE Collaboratory with 10 institutions has been formed to support the emerging public and private IFE landscape

We are at a critical juncture in IFE research: the growing scientific basis of fusion ignition, burn, and energy gain; significant growth from the private-sector and new PPP's; emerging technologies – the time is now to build a strong national IFE program as a potential path to energy and climate security

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