Inertial Fusion Energy (IFE) Update: National IFE Ecosystem & LLNL

2024 Fusion Power Associates Annual Meeting

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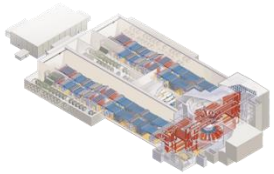
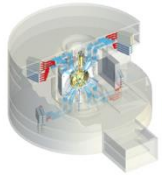
IFE is developing a highly coordinated national strategy to drive towards FPPs in the 2030's, founded on $B's + 70 yrs investment in ICF

Foundations





- Robust, repeatable ignition
- At-scale facility (NIF) to study burning plasma and demonstrate concepts
- Multiple historical plant studies to build from
- $B's investment in ICF

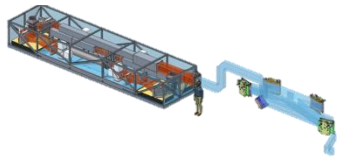
Going Forward

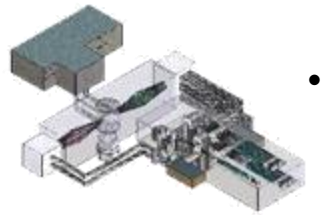
IFE STAR

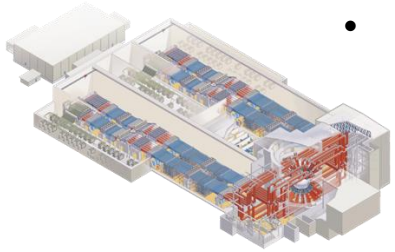
XCIMER
FOCUSED ENERGY
fuse
LONGVIEW FUSION ENERGY SYSTEMS
PACIFIC FUSION

- Priority Research Opportunities as defined by 2022 IFE BRN
- Balanced mix of basic and applied research
- IFE-STAR Ecosystem developing a coordinated national IFE strategy
- Milestone program + PPP's focused on FPP development

Future Facilities



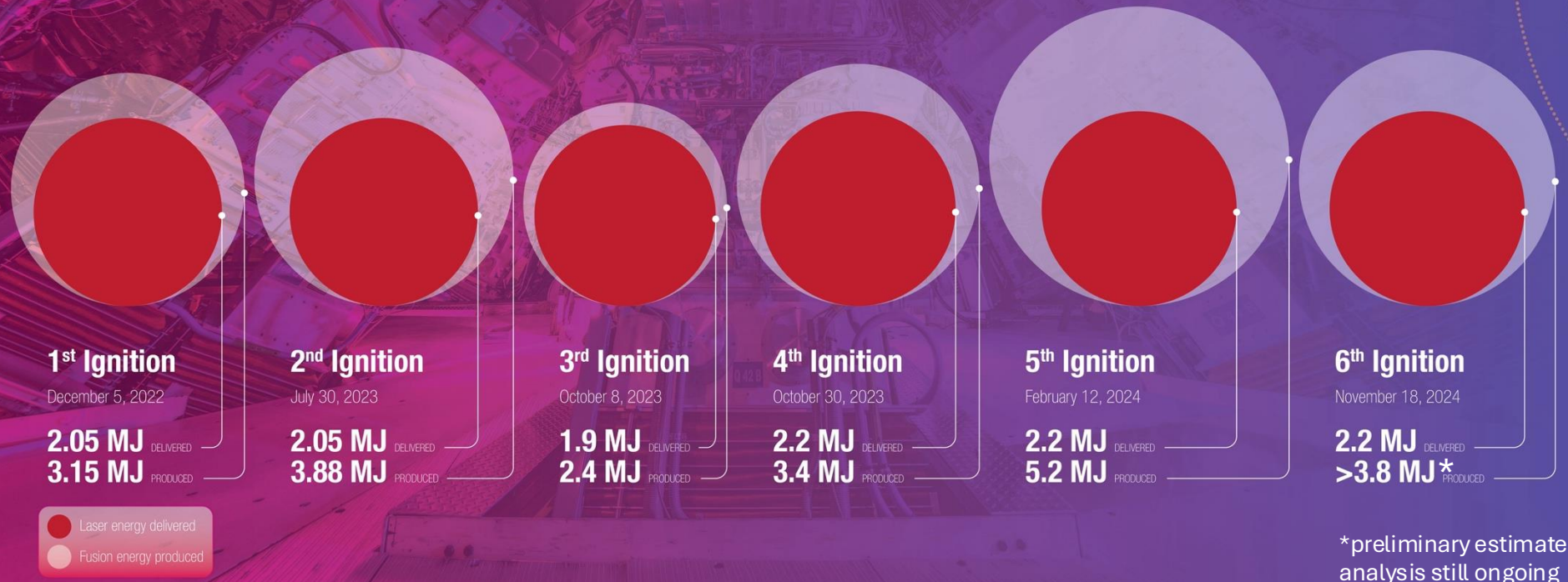




- Component Test Facilities
- Demo + Integration Test Facility
- NIF Expanded Yield Capability + High-Yield Facility

We must move faster! Will need to find innovative ways to partner, pool resources, and develop critical mass of funding and effort to accelerate progress in key technologies

Ignition has now been demonstrated 6x on the National Ignition Facility



*preliminary estimate; analysis still ongoing

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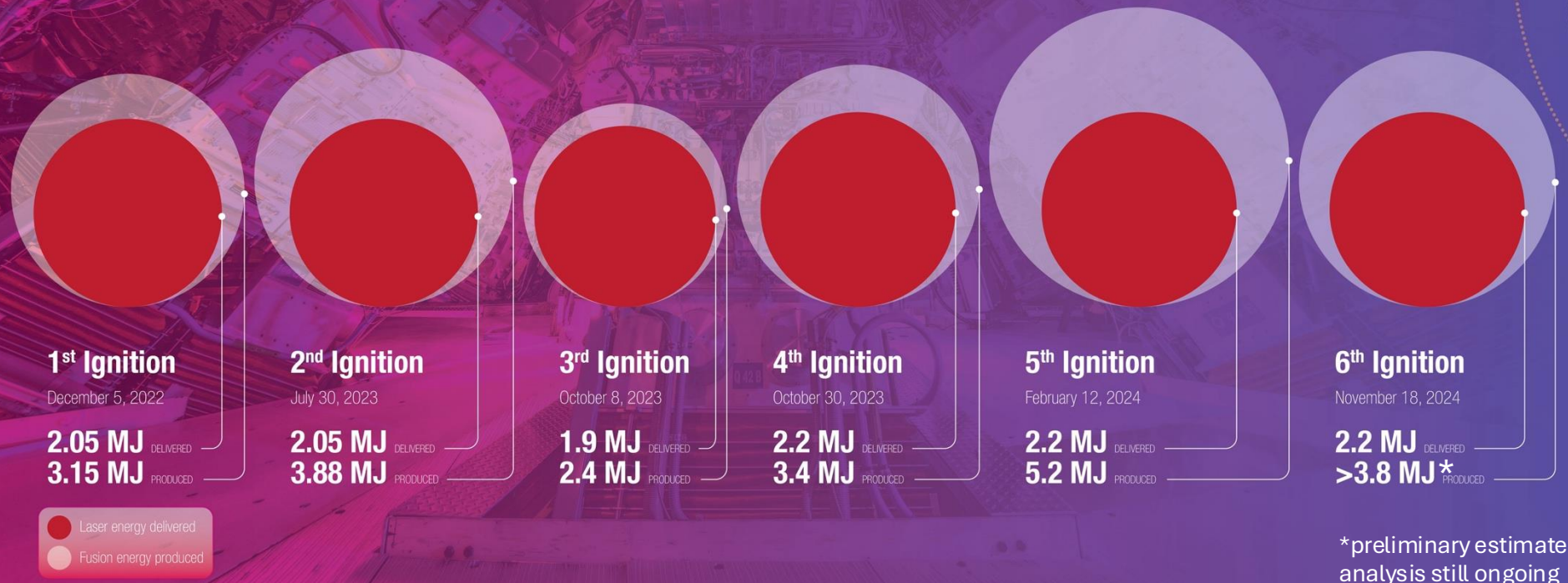

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- Highest target gain demonstrated to-date: **2.35x**
- The scale of driver required for ignition, burn and gain has been uniquely established with ICF
- NIF is the only experiment that operates in burning and ignited plasma regimes — can be used to test IFE target designs and retire one of the most significant risks

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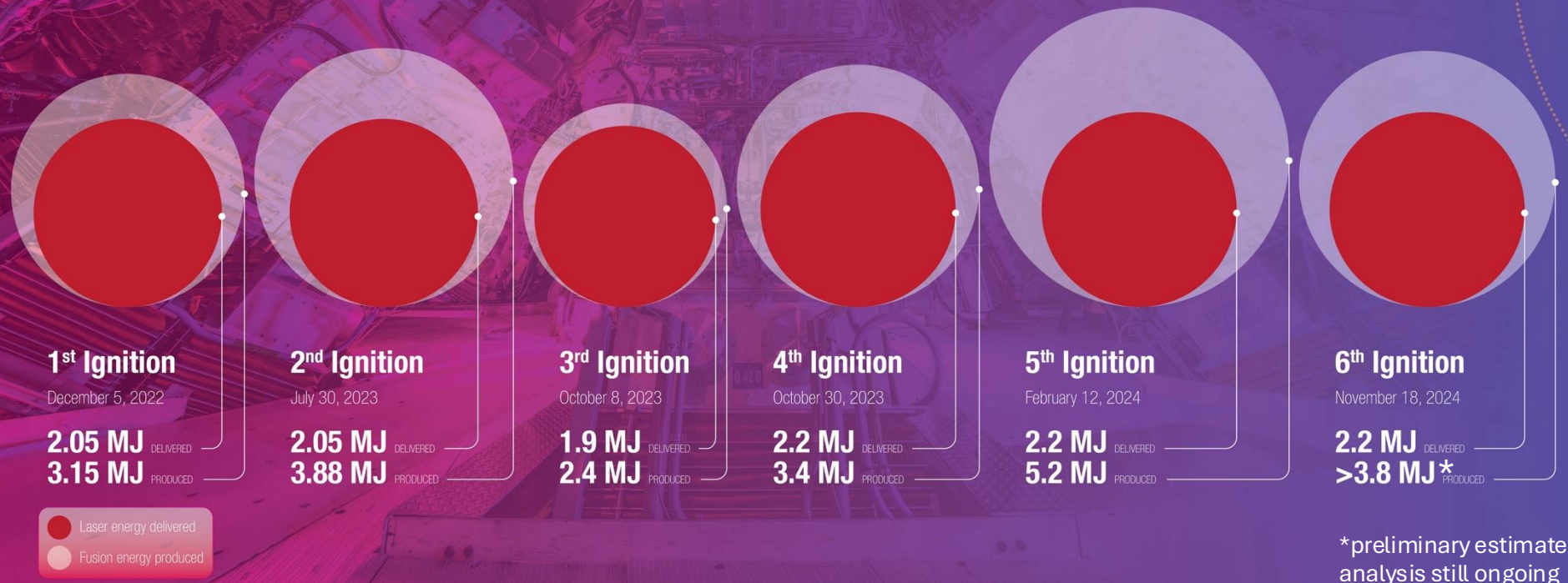
The Future of the National Ignition Facility

- A proposal to install new laser glass will raise NIF's laser energy, enabling new applications for stockpile stewardship.



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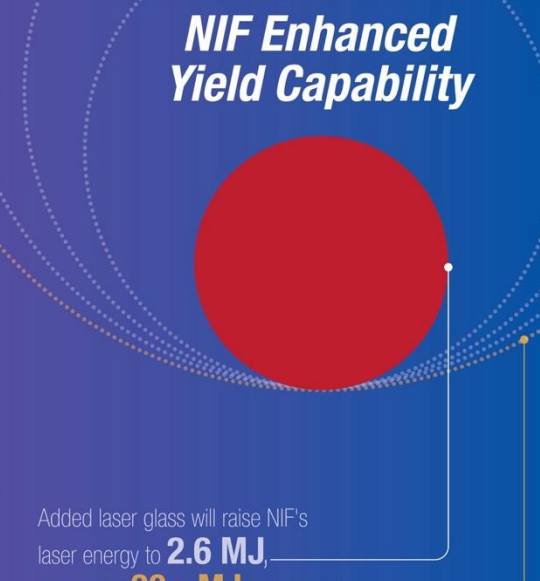


Promising paths exist to address well-known technology challenges of IFE

plasma → electrical conversion

Plasma & Diagnostics

- Experiments and modeling of burning, ignited plasmas
- Hardened, rep-rated, automated diagnostics & control systems

Target Design & Fabrication

- High yield, high gain, survivable designs
- Scale up to ~1M targets/day
- Production at ~$0.25-0.50 each

Target Injection

- ~1-10 Hz at 50-200 m/s
- Tracking to lasers at <25 um

Chamber System

- First wall protection (buffer gas, liquid wall,…)
- Long lifetime radiation resistant materials

Drivers

- kJ-level, rep-rated, 10-20% efficient lasers
- Economical diode scale-up
- Survivable final optics
- Improve reliability of high-power switching and capacitor energy storage

Tritium Fuel cycle

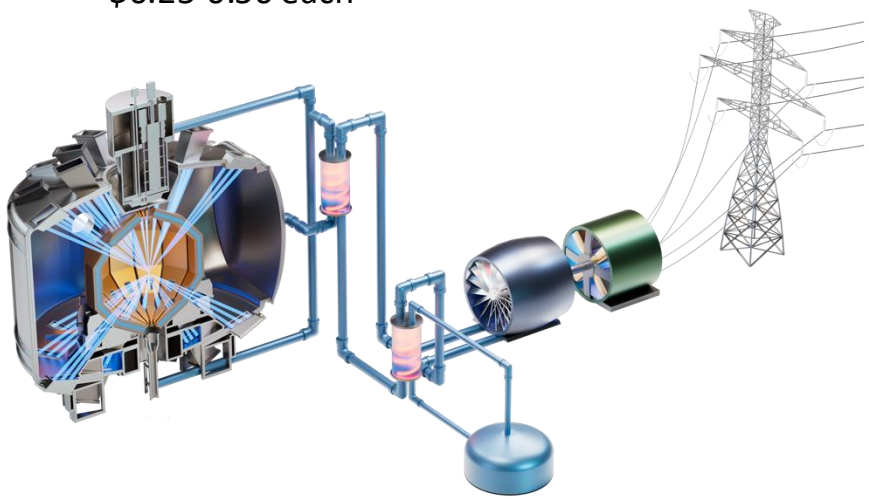
- ~1 kg/day DT flowing through system
- Blanket and tritium breeding
- Tritium recycling
- Materials constraints

Recycling & waste

- Target materials
- Debris and waste removal
- Isotopic separation

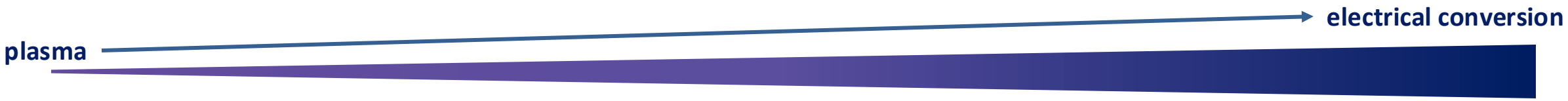
System engineering & plant operations

- System design and tradeoffs
- Modularity and RAMI



Each of these subsystems will need to be engineered with cost, operability, maintainability, and full system integration in mind in order for economical energy production

LLNL is advancing the TRL of key IFE technologies



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LDRD

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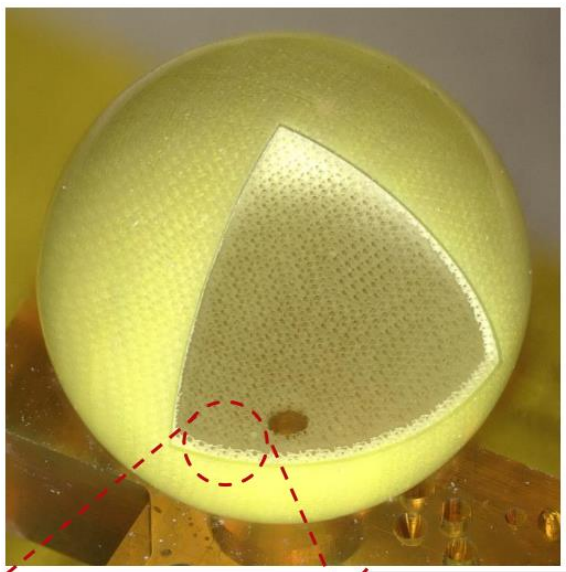
STARFIRE

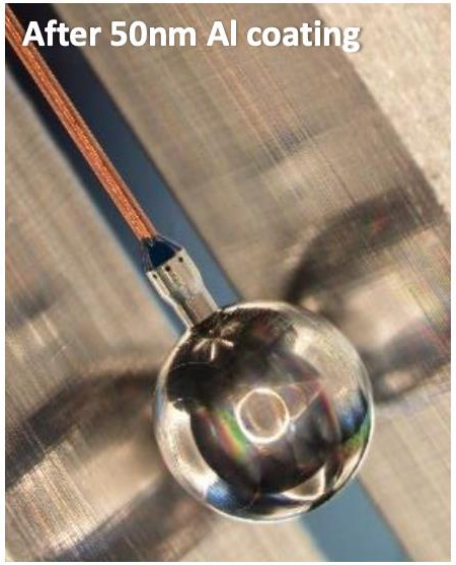
arpa·e

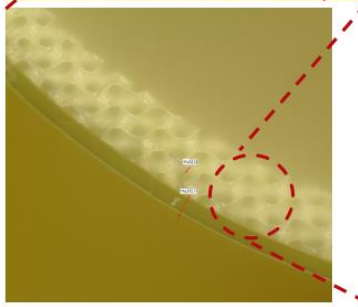
CHADWICK

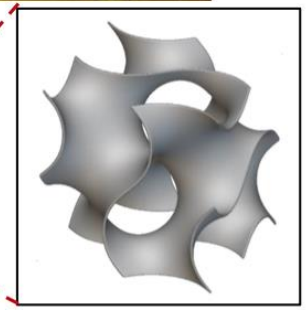
Public-private partnerships

S&T Highlight: In FY24, we successfully shot two entirely 3D-printed foam capsules on NIF under polar direct drive with D_2 fill





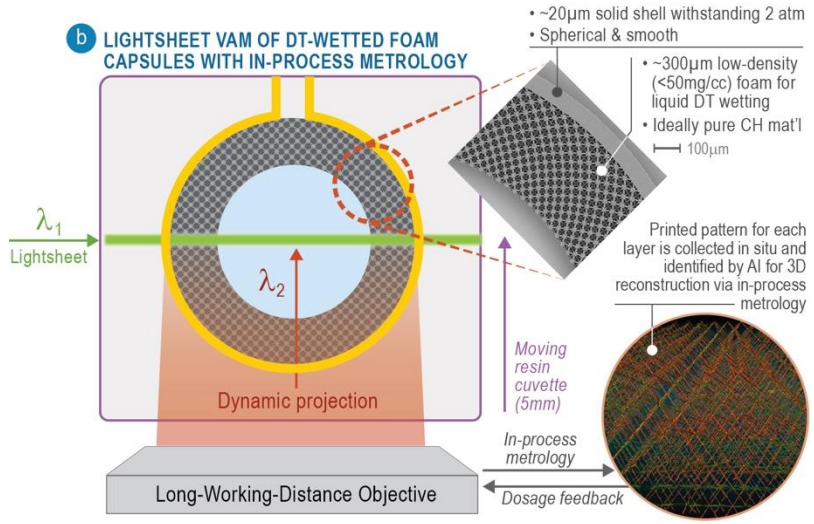




- 3mm OD PDD capsule
- 15μm leak-tight shell
- 120um inner foam layer
- Gyroid foam: 220mg/cc
- Lattice foam: 70mg/cc

We are exploring **novel Advanced Manufacturing** strategies to:

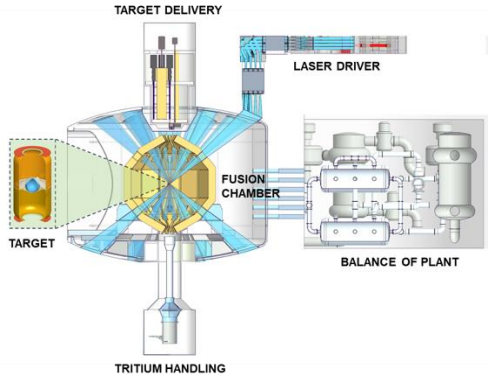
- Speed up printing of wetted foams
- Lower production cost
- Increase manufacturing volume
- Achieve higher resolution, improved quality

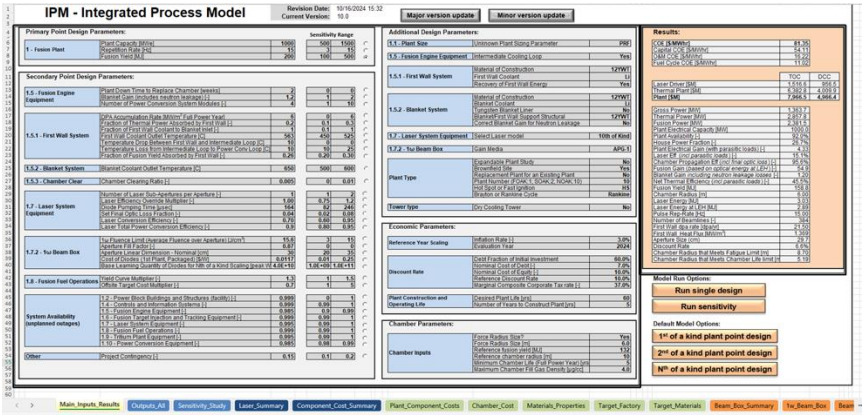


23-ERD-027 (Oakdale, Xia), 24-SI-003 (Maclaren), 23-FS-018 (Kemp)

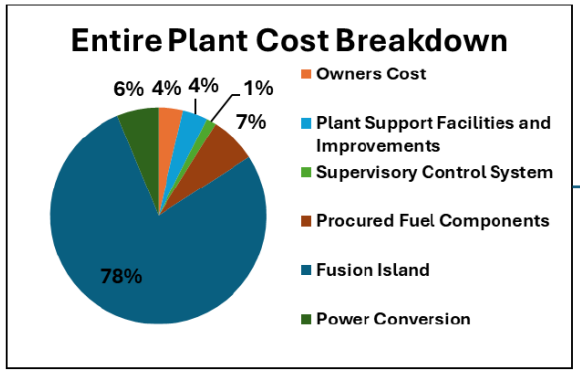
The demonstration of viable wetted foam scalable to mass production will benefit all IFE approaches

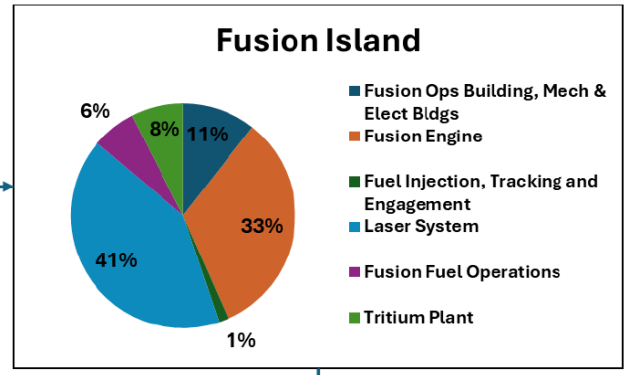
S&T Highlight: We are developing a next-gen power plant design and assessment framework

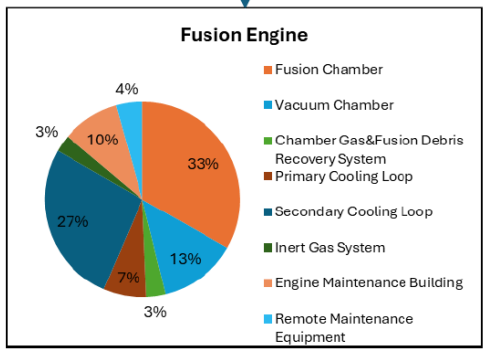


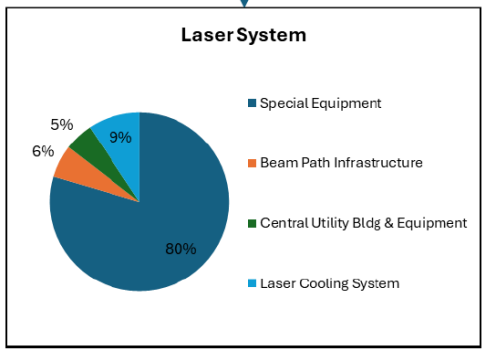


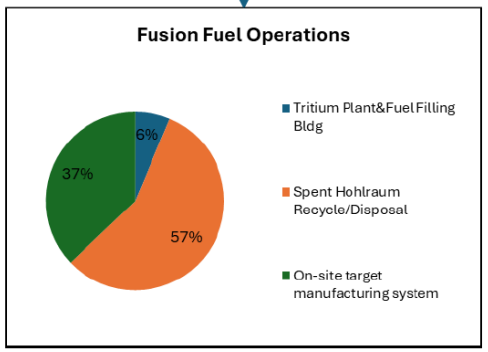
The Integrated Process Model is a simulation-guided and experimentally anchored integrated systems model









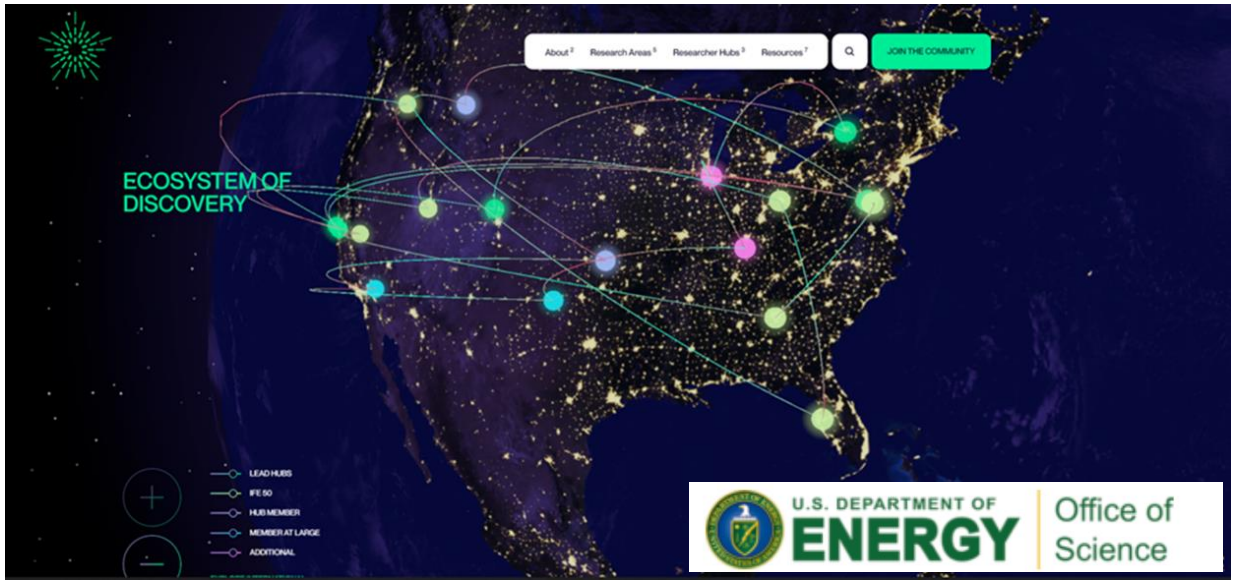


IPM generated cost breakdown for a 500 MWe Fusion Plant

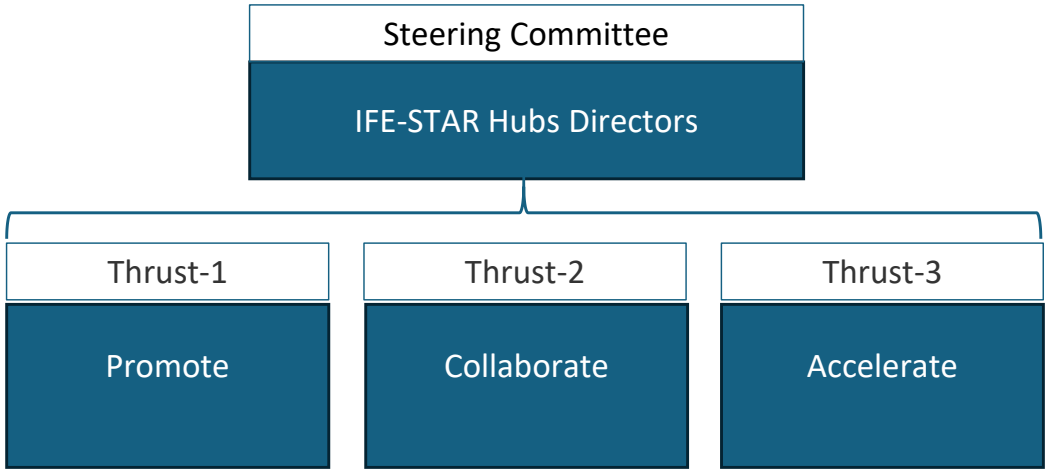
The Integrated Process Model will allow us to develop and assess design options with sensitivity studies

STARFIRE is one of three STAR hubs being organized into an ecosystem that will serve as the coordinating structure for the U.S. IFE program

STARFIRE RISE IFE-COLoR



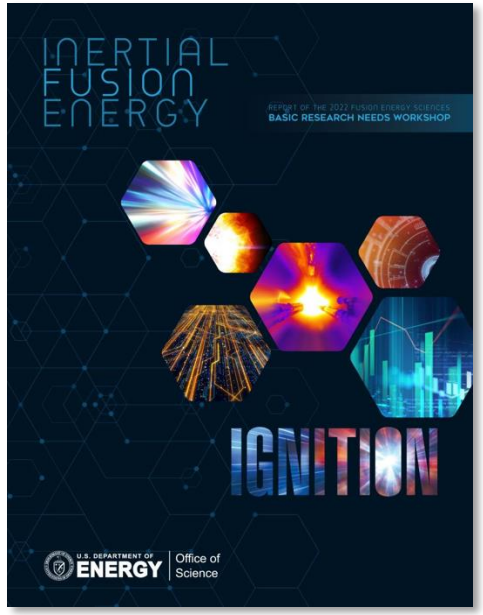
IFE STAR



The IFE STAR Ecosystem requires a network that connects the nation, and which will include more partners such as FIRE centers and public-private partnerships

To accelerate IFE, we are developing a common national strategic plan that supports all major IFE approaches

This plan will initially be guided by:



Priority research opportunities identified in the 2022 IFE BRN report

STARFIRE

IFE-COLoR

RISE

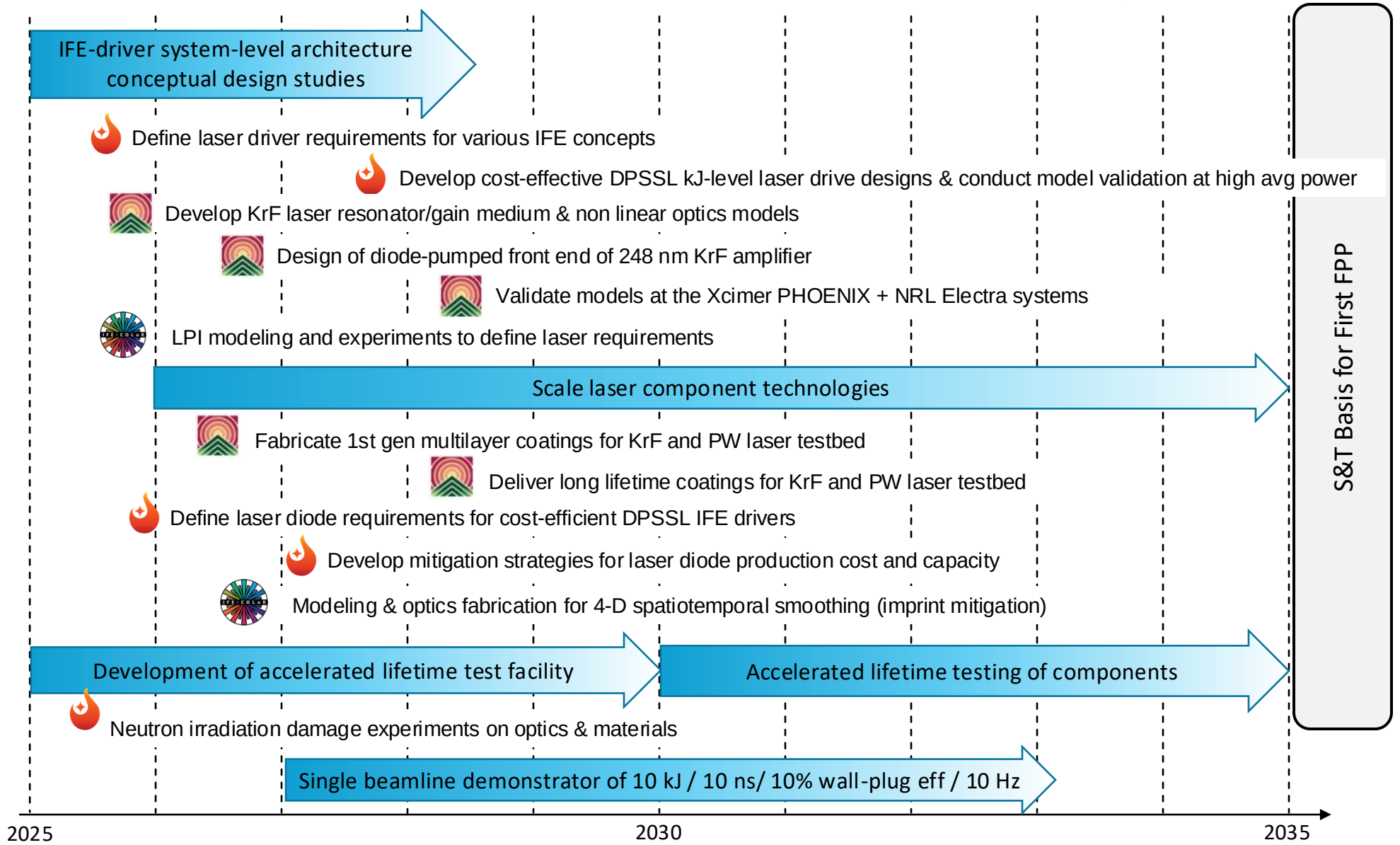
IFE Hubs' milestones

- Goal is to lay out the guideposts, milestones, and nominal timeline for the key IFE technologies that pave the way toward a first IFE pilot plant on the decadal timescale
- To guide ourselves as we focus on de-risking technologies and closing physics gaps
- Partially at request of, and designed to support the industry
- This metrics-driven plan will help IFE stakeholders to understand the common directions and most effectively make use of resources to make rapid progress
- Will hold community workshops in the spring to gather input

We have a concrete vision for securing the S&T basis for a first pilot plant by 2035

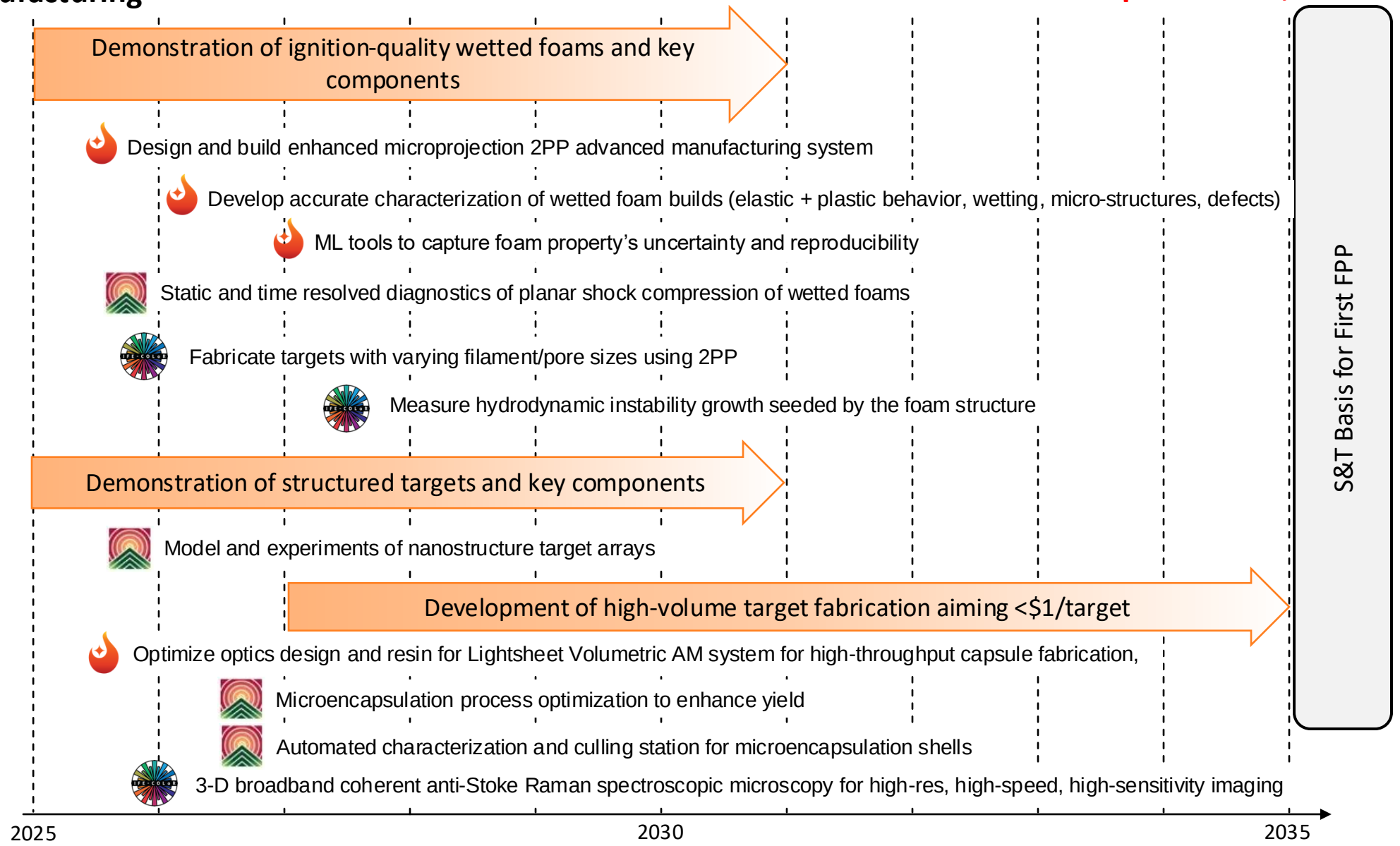
Advanced Laser Demonstrator

Not complete - work in progress!
Need to incorporate FIRE, INFUSE, privates, etc!

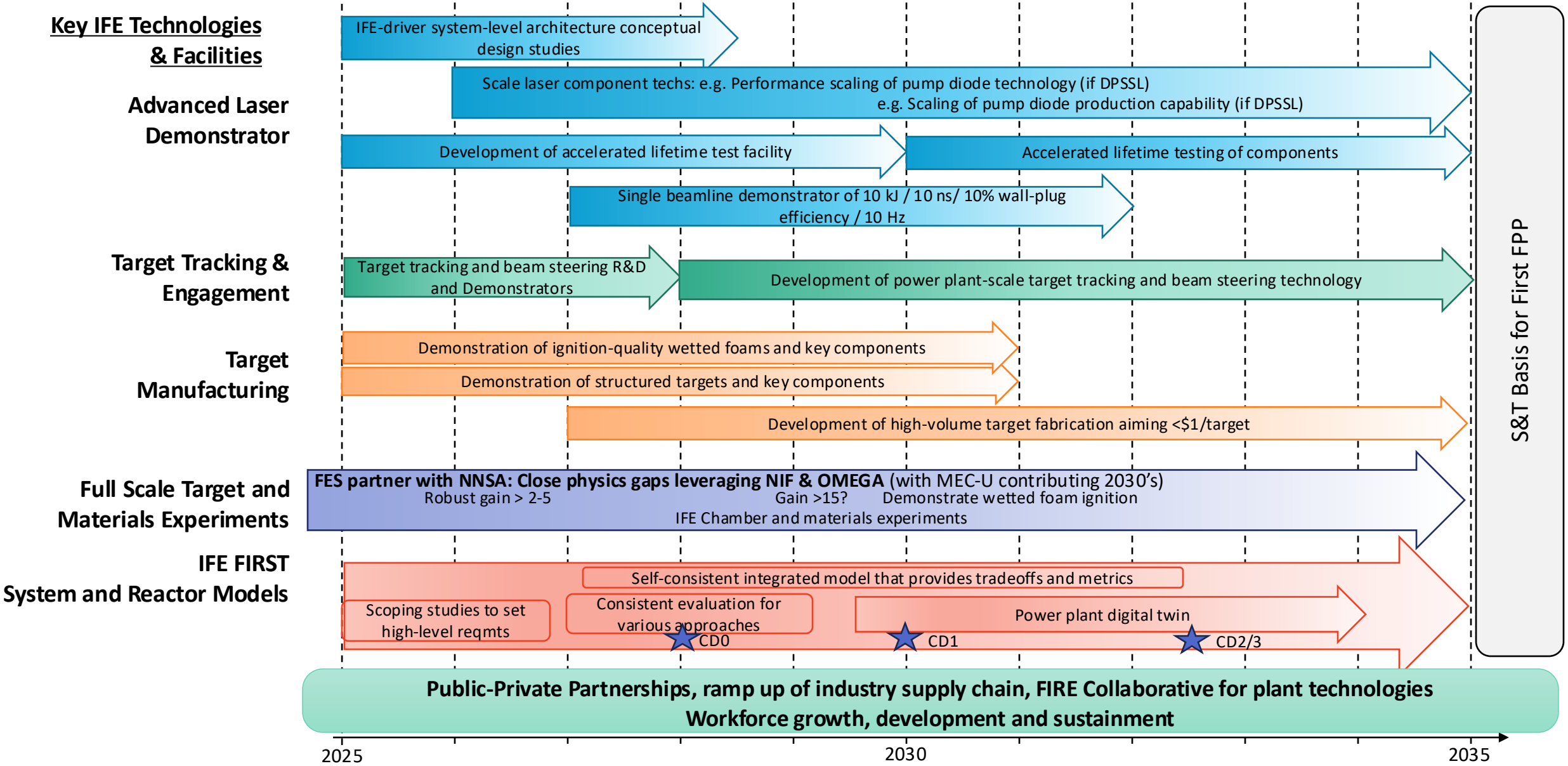


Target Manufacturing

Not complete - work in progress!
Need to incorporate FIRE, INFUSE, privates, etc!

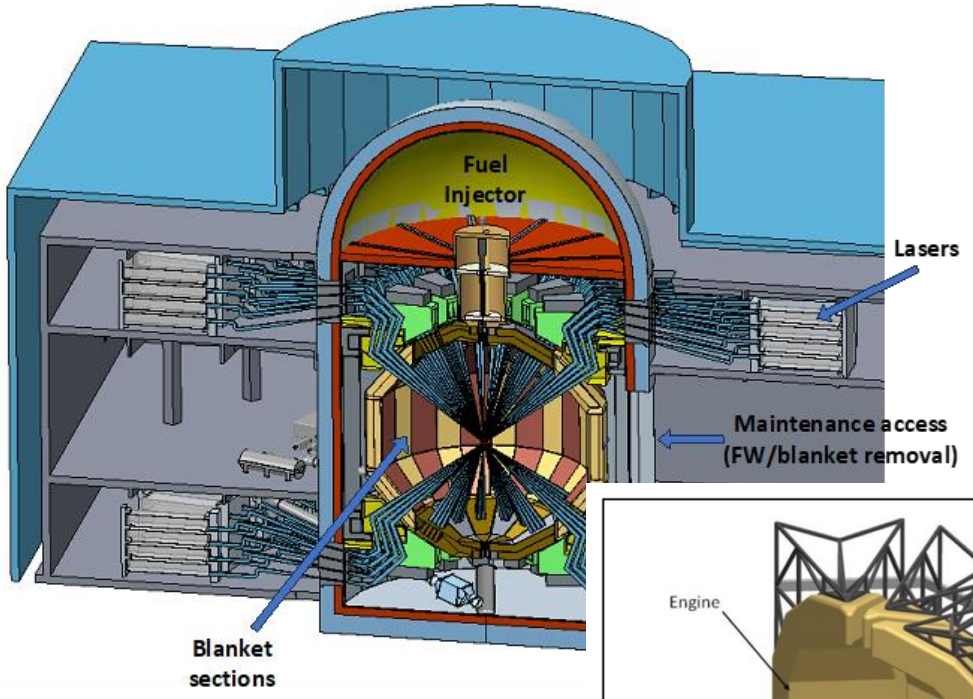


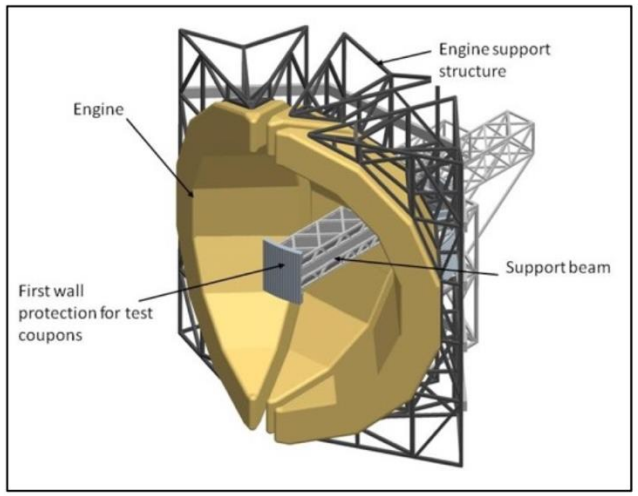
An aggressive national strategy to accelerate IFE begins to emerge – need to incorporate far more input and all approaches



Still requires far more definition, discussion, and input - very much a work in progress!

Laser Driven Fusion Integration Research and Science Test Facility (LD-FIRST) in works with IFE community



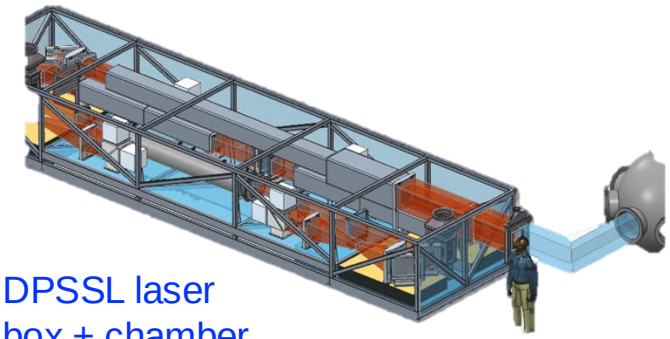


Nominal cross-section of LD-FIRST facility, leveraging LIFE designs

- Envisioned as an integrated test facility which encompasses the key research capabilities provided by many single purpose test facilities, serve as a full-scale testbed for technologies needed for MFE and IFE
- Laser-driven option for FIRST could be self-sustaining at ~gain 15
- LD-FIRST (operating with DT) would address S&T gaps:
  - Full-scale testing of matls and components under integrated fusion conditions
  - Test the nuclear performance of candidate blankets operating at-scale
  - Test all aspects of the fuel cycle
  - Establish the basis for a robust concept of operations
  - Potentially close the power cycle
  - Provide tailorable irradiation rates w/ DPA/yr >10
- Likely will require a public-private venture
- Two community workshops held in 2024 to develop LD-FIRST needs and requirements

An LD-FIRST, on the path to an IFE FPP, will serve as a point design to guide R&D across the many IFE subsystems in development

We are exploring a public-private partnership Livermore Valley Open Campus facility to build a laser beamline demonstrator



DPSSL laser box + chamber

- Utilize LVOC to facilitate 4-way partnership (LLNL/NNSA – private – academia – DOE-FES)
- Facility would address many of the critical ST&E needs en-route to the demonstration of an IFE power plant

Jupiter Laser Facility

Advanced Manufacturing Laboratory (AML)

Integrated Bio Resilience Lab (proposed)

National Ignition Facility

Office space and collaboration center

Prototyping enclave (proposed)

Proposed laser facility location #2

University of California Livermore Collaboration Center (UCLCC)

Proposed laser facility location #1

There remain significant challenges as we build up a national IFE program

Do not yet have critical mass in the public sector IFE program

- $18M FY24 FES program in IFE is a great start, but difficult to make significant progress
- How can we best pool resources and coordinate?

DOE partnership mechanisms are not agile

- Exploring consortiums, LLC's, regional hubs

We have no dedicated IFE facilities

- NIF is a highly oversubscribed NNSA facility
  - IFE shots awarded this year through Discovery Science!
- Need IFE facilities to tackle key IFE technical challenges

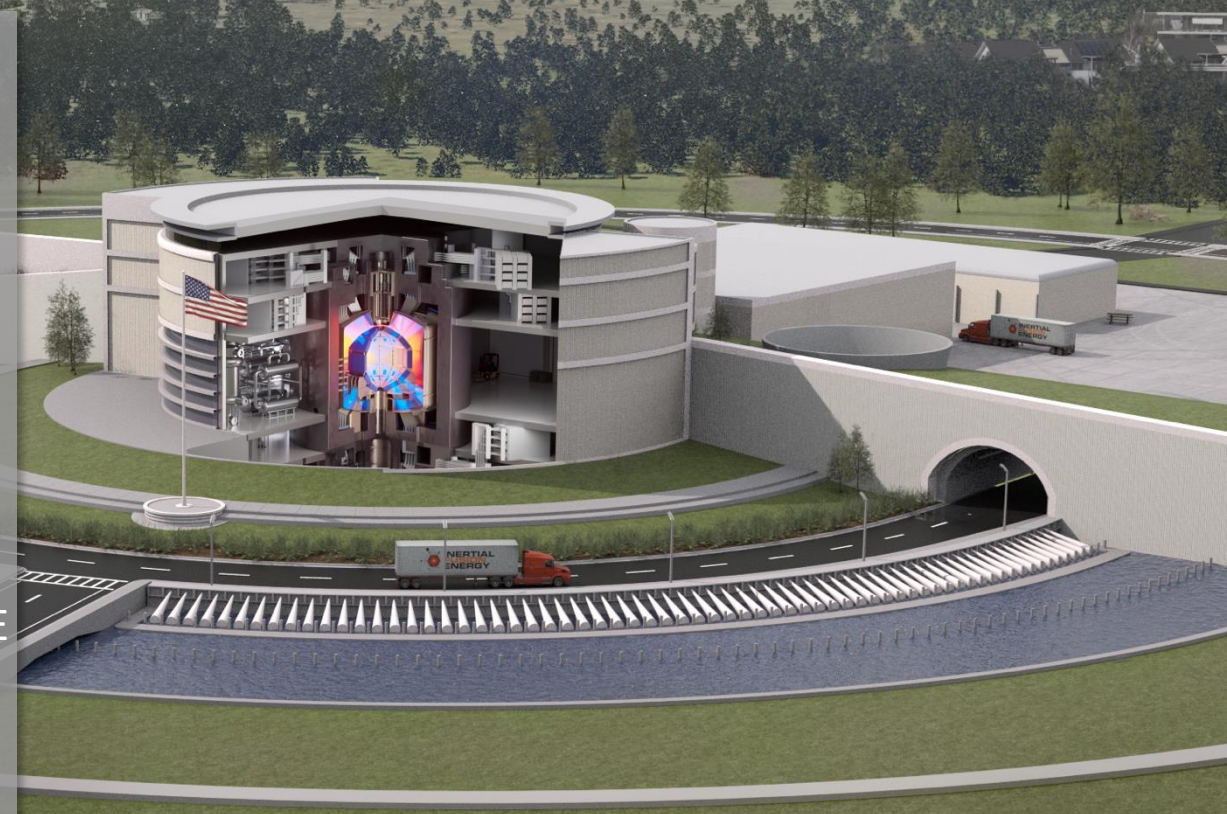
Limited workforce

- Significant attrition from the national labs – starting to impact the national security missions
- Under IFE-STAR + other initiatives, we have launched IFE summer schools, internship programs, PhD programs, IFE curricula, sabbatical programs
- Need to work together to recruit and train!

The success of IFE requires bringing together the many national efforts through coordination, advocacy, and collaboration

In FY24 we advanced the science, technology, and community of IFE:

- Ignition now achieved 6x on NIF
  - Only limited by target production and shot opportunities
- LLNL and the STAR hubs are advancing the TRL of key IFE technologies
- The IFE-STAR ecosystem coordinating structure has been established
- An integrated, coordinated community-driven national IFE technology development plan toward an FPP will accelerate IFE and drive forward the IFE ecosystem
- LD-FIRST and driver test facility are in development with the community



We are building an ecosystem and bridging the gaps to go from ignition to IFE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