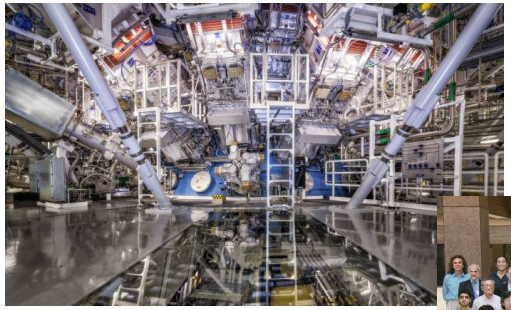
February 2022 IFE Workshop Summary and Perspectives

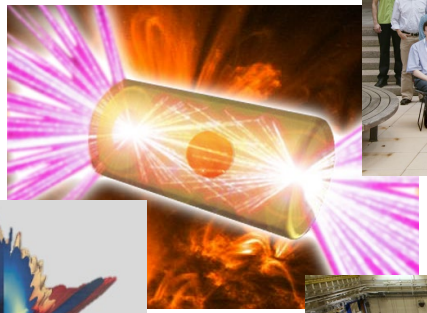
Erik Gilson, Igor Kaganovich

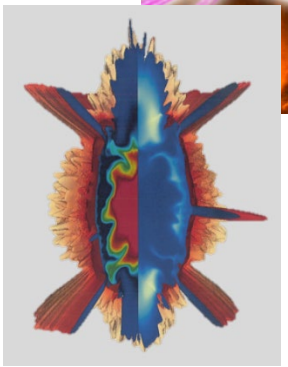
NSTX-U Physics Meeting
Monday, March 14, 2022

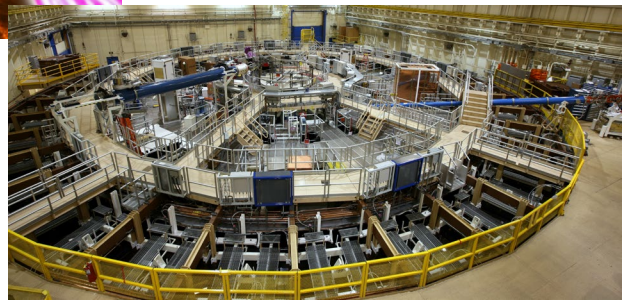
Outline

- Executive Summary
- History and Context
- Perspectives of Sponsors
- Perspectives of Attendees
- Opportunities for PPPL
- Basic Research Needs Workshop
- Summary









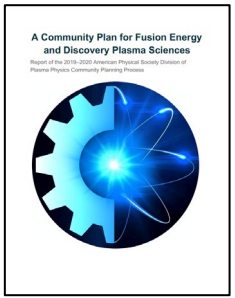
Executive Summary – Community Support for US IFE Program and There are Opportunities for PPPL

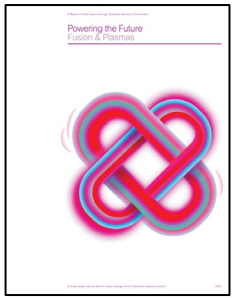
The February 23—24, 2022 IFE Workshop* (> 80 white papers, > 200 attendees) brought the community together to discuss the question:

Should there be a National IFE Program and if so, what should it look like?

Workshop participant answer: YES!

PPPL answer: we can lead and contribute with strong background and experience in beam/plasma dynamics and HEDLP





Why now…

- High-profile news: NIF results, JET DT, CFS HTS and private funding
- Administration discussion of the energy transition
- Public and private (VC) interest in climate and energy technologies
- Recent fusion community activities (CPP, FESAC long range strategic plan)
- Congressional budget actions (Build Back Better: $140M over five years for IFE)

What's next...

- The output of the Workshop will be a report that informs a Basic Research Needs Workshop to be held May 3 – 5, 2022.

*https://lasers.llnl.gov/nif-workshops/ife-workshop-2022

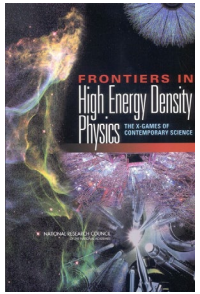
History and Context – There is no US IFE Program

Reminder – these are separate, but overlapping areas:

ICF – Inertial Confinement Fusion

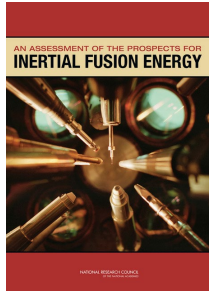
IFE – Inertial Fusion Energy

HEDLP – High Energy Density Laboratory Physics



A trip down memory lane…

- 1963 ICF is budget item in weapons program
- 1976 Al Mashke HIF proposal
- 1980's Nike KrF laser
- 1983 DOE creates HIFAR program
- 1992 Nuclear testing ends Stockpile Stewardship Program (SSP) launched
- 1996 Z-pinch machine
- 1997 NIF construction
- 2000 NNSA established
- 2003 NAS HED report*
- 2003 OFES redirects its IFE program to HEDLP
- 2010-2013 National Ignition Campaign
- 2013 NAS IFE report**
- 2013 FES divests from IFE
- 2019 CPP
- 2020 FESAC Strategic Plan
- 2021 1.35 MJ NIF shot



Timeline based on S. Dean, *Search of the Ultimate Energy Source*, 2013 & Wikipedia, courtesy of Tammy Ma (LLNL)

*https://www.nap.edu/catalog/10544/frontiers-in-high-energy-density-physics-the-x-games-of

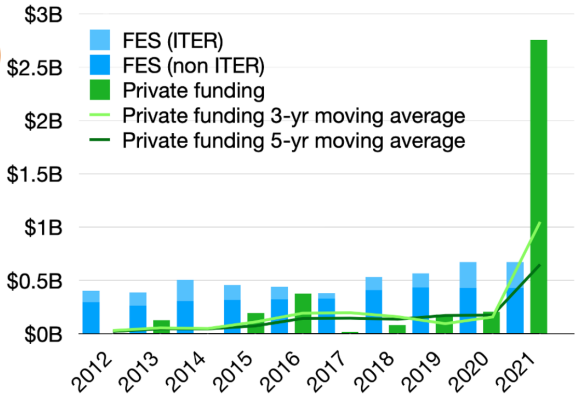
**https://www.nap.edu/catalog/18289/an-assessment-of-the-prospects-for-inertial-fusion-energy

Perspectives of Sponsors (1/2)

- Jim Van Dam, Kramer Akli – DOE OFES
  - The NNSA/OFES Joint Program in HEDLP is not an IFE program
  - OFES will partner with ARPA-E in areas of common interest
  - IFE should be aware of MFE. Leverage and avoid duplication
- Ann Satsangi – NNSA
  - NNSA is in the business of SSP
  - Past – LLNL LIFE (2008 – 2013); GAO audit; Congress appropriates funds for IFE via HAPL; DOD wariness of ICF utility to SSP persists
  - Present – NIF ignition-regime; DOE SC exploring IFE; great public interest in energy solutions; private funding presents new opportunities and challenges for ICF and SPP

Perspectives of Sponsors (2/2)

- Scott Hsu – ARPA-E
  - Unofficial view: Fusion is “Plan B” now (< 2050) and “Plan A” later (> 2050)
  - ARPA-E guided by “market-aware, techno-economic metrics”
  - ARPA-E fusion starting in 2013 ($130M w/ $20M from FES)
  - Initiatives – ALPHA 2015, BETHE 2020, GAMOW (with SC/FES) 2021
  - Shout-out to ONRL/PPPL-PFRC collaboration
  - ARPA-E takes note of NIF, JET, CFS and sees private funding ramping up
- Carly Anderson – Prime Movers Lab (VC)
  - Managing risk: science, engineering, commercial
  - VC looks at the landscape and sees growing electricity demand, the energy transition, the increasing pace of technology
  - Advice: encourage the use of grant programs, boot camps, incubators, accelerators, pitch competitions, and advisors
  - Private funding is not fixed



Perspectives of Attendees – Now is the Time for a US IFE Program

3-Day Workshop – Plenary talks followed by AM and PM breakout rooms (10 – 20 people per room)

- Topic 1: Programmatic Discussion
- Topic 2: Drivers
- Topic 3: Targets
- Topic 4: Engineering
- Topic 5: Wrap-up Discussions

Even without a US IFE program, IFE science and technology continued to develop over the last 10 years

- Advances in laser technology
- Growth of advanced computing, including AI/ML
- Ongoing HEDLP research (PPPL, SLAC MEC, LBNL, LLNL, SNL, etc.)

There are many synergies with MFE research

- Systems studies
- Liquid metals

Perspectives of Attendees – Now is the Time for a US IFE Program

An electricity-producing IFE power plant would require:

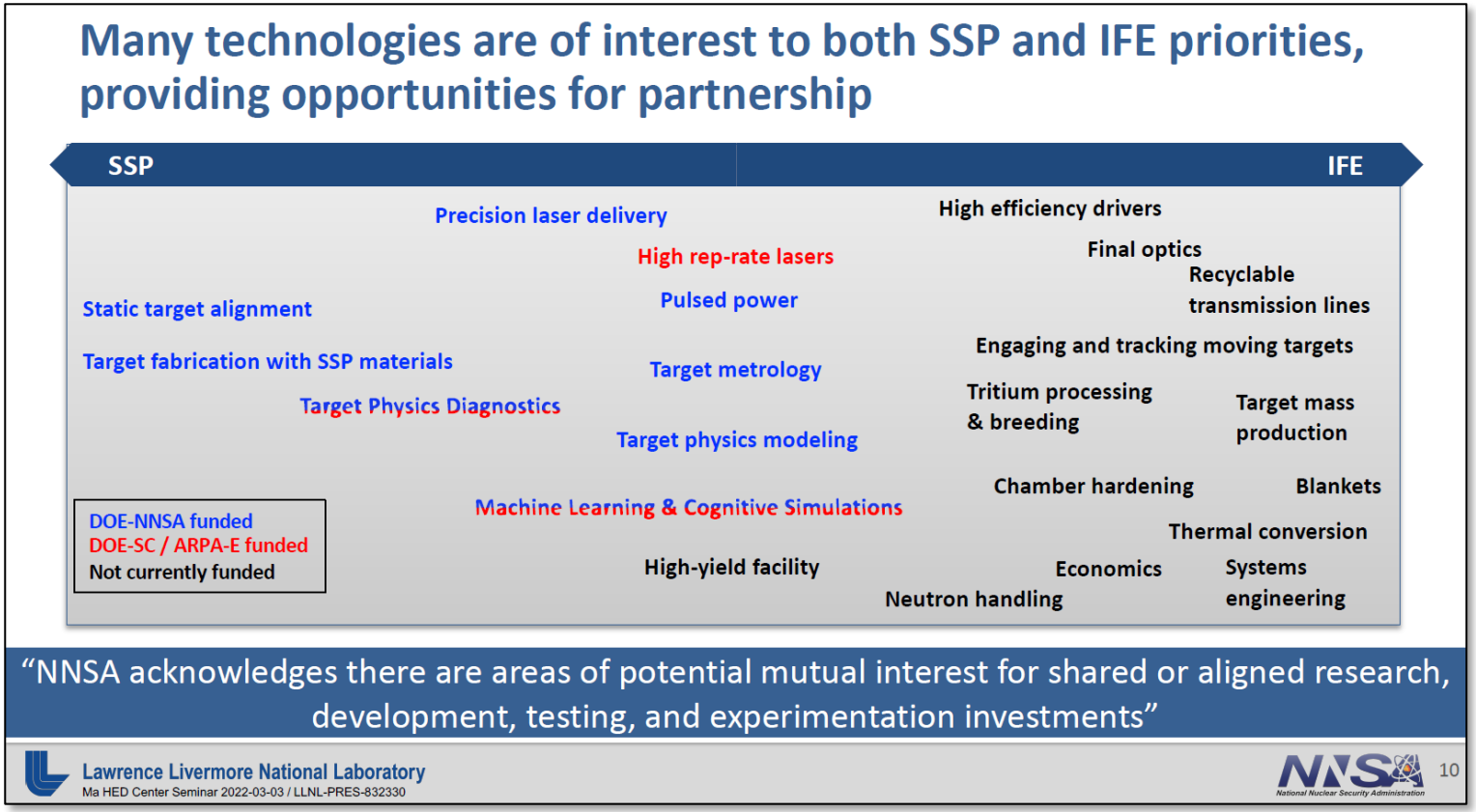
- A more robust, high-margin ignition scheme
- A high-efficiency, high rep-rate driver
- Mass-production of robust targets
- High rep-rate target injection and tracking
- Energy conversion system
- Robust first walls and blankets for wall protection
- Tritium processing and recovery
- Remote maintenance systems
- Viable economics

IFE technical challenges include:

- Ignition and fusion energy gain
- Fuel system delivery and cost
- Lifetime of the fusion chamber and optics
- Safety and licensing – tritium and any activated materials
- High availability plant operations

Perspectives of Attendees – Now is the Time for a US IFE Program – Lots to do

Just considering drivers alone: diode-pumped solid state lasers, ~~KrF~~ ArF lasers, heavy-ion accelerators, pulsed power



Slide courtesy of Tammy Ma (LLNL)

Opportunities for PPPL

PPPL IFE Research Opportunities…

- Experiments on generating, transporting, compressing, focusing, and neutralization of intense negative ion beams
- Advanced numerical simulations of nonlinear effects in HIF drivers and chamber propagation including beam/beam and beam/plasma effects
- IFE chamber liquid metal experiments and modeling
- HEDLP for improved physics basis for target design and optimization
- Others…

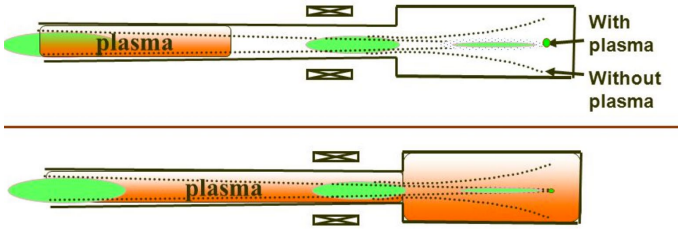
Two White Papers submitted…

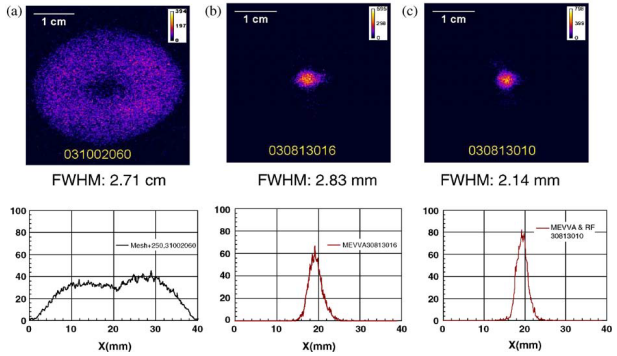
- Igor Kaganovich *et al.* (PPPL/LBNL/LLNL) Collective Effects and Intense Beam-Plasma Interactions in Ion-Beam-Driven High Energy Density Matter and Inertial Fusion Energy
- Sophia Malko (PPPL/CLPU/U. Alberta/CEA, DAM, DIF/LLNL/LANL/LLE/SNL/UCSD/GA/CELIA) Importance of Ion Stopping Power Research for IFE

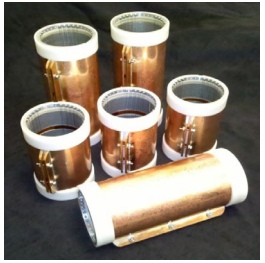
Opportunities for PPPL

Build on two decades of successes

- Nonlinear theory for quasi-steady-state propagation of an intense ion beam pulse in a background plasma
- Plasma source development for beam neutralization and focusing

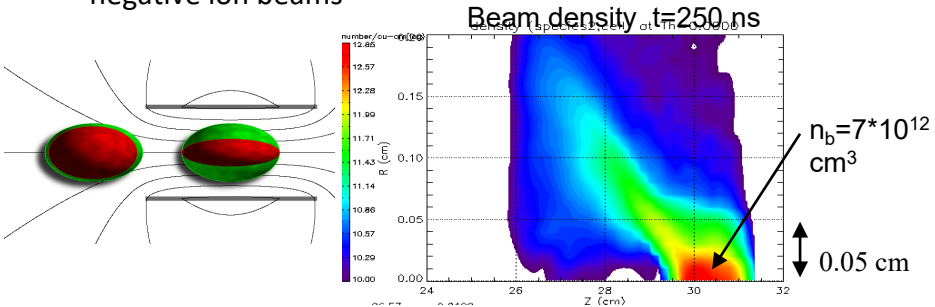


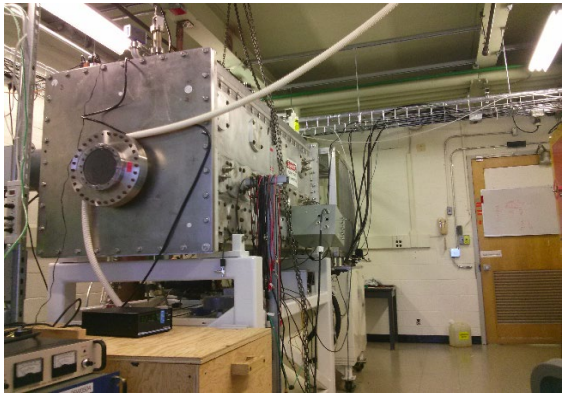




Develop mitigation strategies for beam/plasma instabilities

- collective focusing
- negative ion beams





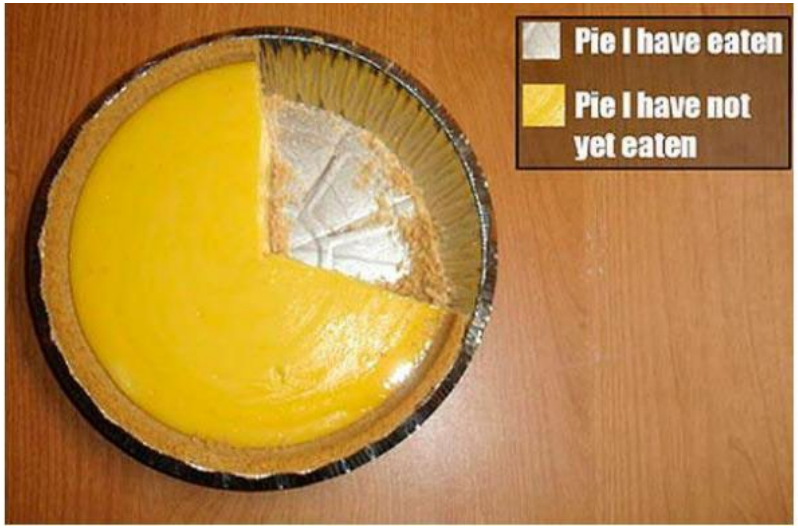
PPPL 100 kV Test Stand for ion beam experiments

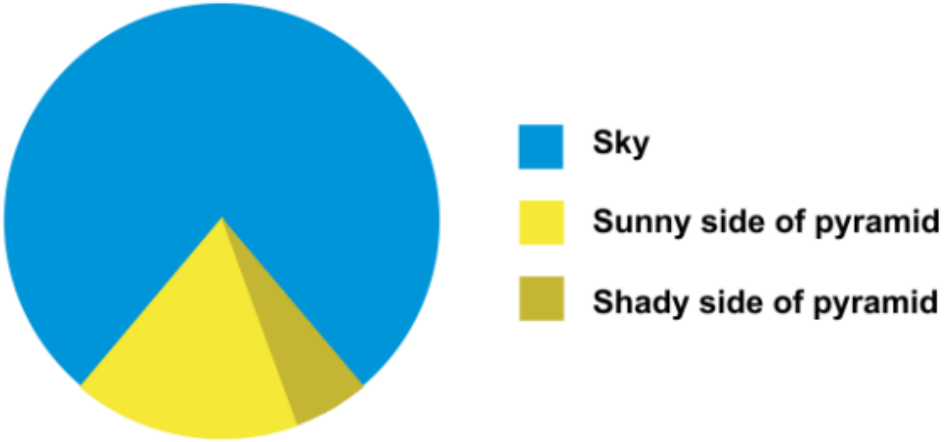
- Assess and summarize the status of science and technology in IFE in the US and abroad
- Assess enabling science and technologies common to ICF and IFE and define a set of proposed priority research opportunities that address the research and R&F challenges unique to IFE, along with evaluation criteria to assess ongoing progress in an IFE technology development program
- Assess the maturity and potential of the various IFE concepts toward a path to a viable IFE fusion power plant. Use Technology Readiness Level (TRL) methodology to guide the R&D demonstration of ignition and reactor-level gain for each concept: Manufacturing and mass production of reactor-compatible targets; Driver technology at reactor-compatible energy, efficiency, and repetition rate; chamber design and first wall materials;…
- Identify MFE efforts in the US and abroad that could be leveraged to advance IFE (e.g. blanket, structural, and plasma-facing materials development, DT fuel cycle processing, remote handling technology, safety analysis tools, waste stream management, modeling, etc.) and identify where there are substantive differences in these systems that's require IFE-specific development
- Assess the role of the private sector, including public-private partnerships in a National IFE Program

Summary

- Workshop calls for a US IFE program
- An IFE program should address technical challenges and power plant requirements
- An IFE program will include public/private partnerships
- An IFE program presents an opportunity for PPPL
  - Experiments on generating, transporting, compressing, focusing, and neutralization of intense negative ion beams
  - Advanced numerical simulations of nonlinear effects in HIF drivers and chamber propagation including beam/beam and beam/plasma effects
  - IFE chamber liquid metal experiments and modeling
  - HEDLP for improved physics basis for target design and optimization
- BRN Workshop in May

Happy Pi Day


Pie I have eaten
Pie I have not yet eaten


Sky
Sunny side of pyramid
Shady side of pyramid