Proposal to Build an Academic IFE High Energy Laser Research Facility as a Public-Private Partnership

Todd Ditmire– Dept. of Physics, University of Texas at Austin, and Focused Energy Inc.
Contact: tditmire@physics.utexas.edu
Markus Roth – TU Darmstadt and Focused Energy Inc.
Sandra Bruce – Center for High Energy Density Science, University of Texas at Austin
Ahmed Helal – Center for High Energy Density Science, University of Texas at Austin
Manuel Hegelich - Dept. of Physics, University of Texas at Austin
Mike Downer - Dept. of Physics, University of Texas at Austin
Juan Fernandez – Applied Sciences Enterprises and Focused Energy Inc
Kurt Schoenberg – Applied Sciences Enterprises and Focused Energy Inc

Executive Summary

Mid-scale laser facilities such as those in the LaserNetUS network can play a central role in in the development of inertial fusion energy (IFE), but a significant capability gap exists. We propose here to fill that gap by developing a laser facility at the University of Texas in Austin (UT) as a private-public partnership, using the laboratory high bay space of the existing LaserNetUS Texas Petawatt facility, that can serve as a focus on IFE-relevant high-energy density (HED) physics research. To further the expected new IFE subprogram in the US, we propose to offer access to this new facility through the LaserNetUS network.

The facility envisioned will deploy four parallel, synchronized beams, each constructed from liquid-cooled flashlamp pumped Nd:glass slab amplifiers which can operate with at least one shot every 3 min. With these amps, seeded by a programmable pulse-shaped front end seeding few-ns pulses (up to 20 ns duration) over 3 kJ per beam in each of four beams will be possible. Frequency conversion to second harmonic at 527 nm will yield 2 - 3 kJ (depending on chosen pulse duration and shape) and up to 2 kJ at 3ω if desired. When a beam is operated with a chirped pulse amplification (CPA) front end, up to 1 kJ per beam will be possible (after compression) with pulse duration down to ~ 400 fs, and tunable up to many picoseconds.

The IFE and HED science that can be carried out on this facility ranges widely. Some examples of relevant IFE science include:

- Laser-plasma instabilities and cross-beam energy transfer study and mitigation
- Hydrodynamic drive efficiency and other hydrodynamic studies
- Particle acceleration for fast ignition approaches
- Charge particle stopping distances in pre heated, compressed plasma
- Diagnostic development and data analysis techniques

There is a window of opportunity to meet the considerable costs of such a facility (~$100M) by leveraging investment from a private company and to partner with the LaserNetUS network for operations funding. This IFE laser facility can serve as a center for the training of graduate students and post-docs in technique relevant for furthering IFE explicitly and will aid in developing a pipeline to meet the demand for IFE trained experimentalists.

I. The Science Needs for an Academic IFE Laser Facility within LaserNetUS

With the establishment of the new IFE program in the US, it is clear that the laser facilities now open to US and international researchers through the LaserNetUS network will play a central role in providing mid-scale laser capabilities to the IFE community for examining key pieces of physics relevant to ICF. At present, LaserNetUS offers a diverse suite of facilities with capabilities ranging from femtosecond pulse, modest energy Ti:sapphire lasers such as those at OSU, CSU, LBNL and Nebraska, through higher energy Nd:glass lasers like the Texas Petawatt and LLNL Titan lasers, up to the large scale, single shot Omega EP laser at LLE. The IFE science community unanimously agrees that the field of HED plasma science is data-starved due to limited number of facilities and low laser repetition rate. Therefore, the IFE science community would benefit if one of the LaserNetUS sites were to upgrade its system to provide capabilities designed to address specific problems in IFE and construct such a high energy laser facility with sufficient repetition rate to enable systematic experiments, perhaps aided by machine learning, that have not been possible up to now with the single shot type lasers that are currently available.

We propose here the development of a laser facility at the University of Texas in Austin (UT), using the laboratory high bay space of the existing LaserNetUS Texas Petawatt facility. The facility would be designed and constructed with the intent of providing capabilities to address a range of physics issues relevant to laser-driven IFE or aspects of magnetized plasma IFE (such as the MagLIF concept).

As discussed below, there is an opportunity to meet the considerable costs of such a facility (~\$100M) by leveraging investment from a private company and to partner with the LaserNetUS (which presently funds the operations of the existing TPW facility). The details of such a proposed laser are discussed below. Given some of the science questions that will need to be addressed in the various IFE approaches, it is clear that such a facility needs to have multiple, high-energy beams (4 beams in the present proposed facility) that are synchronized and can interact in various configurations in a flexible target chamber. The laser beams should have the capability of operating in either pulse-shaped long pulse mode or CPA, picosecond (or down to ~160 fs) short pulse mode. The beams should have high energy per beam (up to 3 kJ per beam at 2ω in the present proposed design and up to 1 kJ per beam in CPA mode at the fundamental, 1054 nm). It is very desirable for a next generation research machine like this to have reasonable repetition rate (we are proposing a design that would enable full energy operation of all 4 beams at faster than 1 shot/3 min.)

The IFE and HED science that could be conducted with such a multi-beam high energy facility is quite broad. Some examples of relevant IFE science able to be studied include:

<u>Laser-Plasma Instability and Cross-Beam Energy Transfer (CBET) Study and Mitigation:</u>
In most IFE approaches, whether they be indirect or direct-drive based, laser-plasma instabilities (LPI) are a major problem. There is considerable talk in the ICF/IFE community of wanting to switch the drive laser from the 3ω beams employed at NIF and Omega to drive in the green at 2ω, greatly easing the stresses of optics damage which plague operations of a laser in the near-UV. The challenges of LPI growth and CBET with the longer wavelength could be studied at relevant drive intensities on the proposed laser which would have four ~3

kJ pulse shaped beams. Effects of color as well as mitigation techniques such as imparting bandwidth or use of STUD pulses could be studied on the proposed IFE Facility.

Hydrodynamic drive efficiency and other Hydrodynamic studies:
Having multi-kJ beams that operate at either 2ω or 3 ω would permit study of hydro-drive efficiency and ablation pressure systematically as a function of intensity in the range relevant to direct drive scenarios or a various drive colors (again 2 ω vs 3 ω).

Particle Acceleration for Fast Ignition Approaches
Implementation of fast ignition in IFE is potentially quite desirable to access higher gain (G>100) designs needed for economically viable energy production. The proposed IFE laser would allow study of proton or electron production in regimes closer in relevance to IFE than has been studied with existing facilities. For example, in the proton fast ignition approach, the high conversion efficiency from laser light to MeV protons needed (≥10%) needs to be studied in the regime of multiple, kJ-class picosecond laser overlapped on a target. Electron and proton transport at high current density and in through pre-heated plasma could also be studied with the proposed laser given the availability of multiple long and short pulse beams.

Charged particle stopping distances in pre-heated, compressed plasma:
A key element to success of a fast ignition approach to IFE is understanding in detail the energy deposition rate of MeV particles in the pre-compressed ICF fuel. While the facility proposed here will not be able to reach the compressed densities that occur in an ignition scale fusion pellet, fundamental data on stopping powers of protons and electron can be measured. These experiments can couple with models of warm and hot dense plasma to yield better estimates for the energy densities that could be achieved in fast ignition.

Diagnostic Development and Data Analysis techniques:
The facility proposed here would be the first multi-kJ laser in the US operating with any significant repetition rate. This will make it the ideal place for the development of advanced diagnostics that could be fielded on the large laser machines (NIF and Omega). This facility can also serve a good place to develop Machine Learning algorithms that can be applied to next generation MJ-class ignition machines.

II. Education and Workforce Development with an Academic IFE Laser Facility

Since the academic HED community in the US does not have a well-formed IFE component, as the field progresses there will be a growing need for trained scientists who have worked explicitly in IFE. In particular, as private companies work on IFE approaches, they will need to hire large numbers of scientists with background in IFE physics and experimental techniques. This IFE laser facility can serve as a center for the training of graduate students and post-docs in technique relevant for furthering IFE explicitly and will aid in developing a pipeline for the demand of IFE trained experimentalists needed for the large scale effort that will inevitably have to develop to demonstrate high gain ignition for IFE. The facility will also become the flagship node in LaserNetUS as a very high visibility user facility. It will become a center for the interaction of graduate students from LaserNetUS user universities with IFE researchers from the national labs and with private companies.

III. Background and Role of the Current Texas Petawatt Laser within LaserNetUS

One compelling reason to site such an IFE laser at the University of Texas is the existence on campus of high-bay lab space that is ideal to site a laser of the scale proposed. The UT Center for High Energy Density Science (CHEDS) has operated the Texas Petawatt Laser (TPW) in a high bay facility on campus at UT for 13 years as an academic research facility. UT operated a user-collaborator program between 2012 and 2017, and since 2018 the TPW has been a central member of the LaserNetUS national laser network. As a result, UT has considerable experience in handling outside academic users and helping them be successful using a mid-scale facility. The plan is to deactivate the Texas Petawatt during 2022 to begin renovations and retask the TPW staff to design and construct the new proposed IFE facility.

IV. Specifics of the Proposed New IFE Laser Facility at the University of Texas

Our proposal is to situate the new IFE facility in the existing TPW lab, whose footprint is illustrated below. The University has recently transferred additional space to CHEDS so the entire high bay is now available for a new laser system. The core technology used in the laser will be flashlamp-pumped Nd:glass disk amplifiers, with aperture up to 30 cm. The amplifiers will be very similar to liquid cooled Nd:glass disk amplifiers developed in Austin at the company National Energetics for the L4 10 PW beamline at ELI-Beamlines outside of Prague. These amplifiers have been deployed in this laser for over a year and are currently operating at one shot/3 min with high beam quality. These amplifiers, pictured below in figure 2, will be employed in a 4-pass geometry, similar to the proven L4 design.

With these amplifiers, seeded by a programmable pulse-shaped front end seeding few-ns pulses (up to 20 ns duration) with 3 - 4 kJ per beam in each of four beams will be possible. Frequency conversion to second harmonic at 527 nm will yield 2 - 3 kJ (depending on chosen pulse duration and shape) and up to 2 kJ at 3ω if desired. When a beam is operated with a CPA front end, up to 1 kJ per beam will be possible (after compression) with pulse duration down to ~500 fs, and tunable up to many picoseconds. (We are also exploring the possibility of operating one beam if desired in a mode which delivers ~160 fs pulses at energy of ~300 J.) The four beams can be operated in either mode, permitting a flexible mix of long pulse and short pulse beams for users. The target chamber (anticipated to be ~4m) is likely to be housed in below- grade hall adjacent to the main high bay (see figure 1).

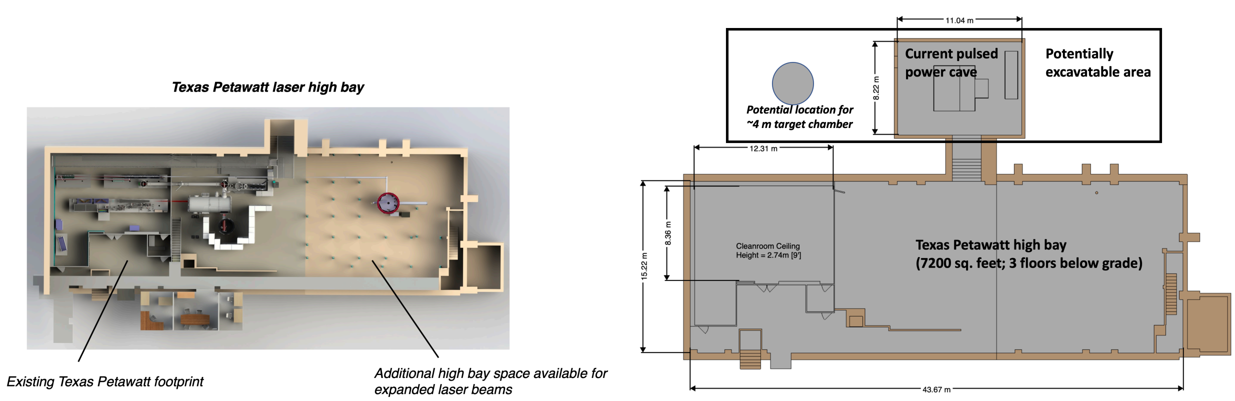

Figure 1: Illustration of the U. of Texas high bay in the PMA building with current TPW footprint (left) and space available for laser and target chamber (right).

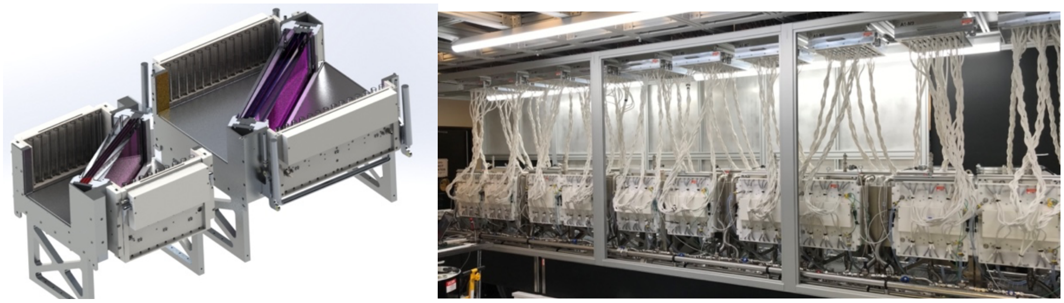

Figure 2: Cut-away view of the split-disk liquid-cooled Nd:glass disk amplifiers to be used in this facility with a photo of their deployment in the L4 laser at ELI-Beamlines.

V. Prospects for Public-Private Partnerships to Foster IFE Collaborative Research

One of the principal motivations for this proposal is that possibility of bringing to bear considerable funds from a private company to aid in the construction of the laser. The scope of what is being proposed here is certainly well out of the likely funding envelope of the new IFE program or LaserNetUS (~$100M). But the founding of a new company in IFE, Focused Energy (FE), with involvement by one of the UT faculty (Ditmire) opens the possibility that this facility could be funded as a public-private partnership between FE, the DOE and UT. In this way, the IFE academic community would have access to a machine of scope and rep. rate not likely available for many years in the US through only public funding streams, and private industry, (FE and other companies which are likely to come to the facility to perform their own experiments) would have an excellent venue for interacting closely with the academic and national labs IFE/HED community in collaborative experiments. We are in the process of soliciting community input to further define the facility to maximize its utility

VI. Funding Plan for the Proposed UT IFE Laser Facility

If such a public-private partnership could be arranged, we can deploy this facility very quickly by a combination of funding sources. The laser itself will be built in a renovated space in an underground high bay at UT. We would proceed by working toward a three-way MOU between UT, DOE FES and FE. The path forward would involve UT supporting the facility renovation (roughly $10-15M investment needed), FE paying for the majority of the construction (likely a $60M-$80M investment using private investor funds) and the DOE supplementing the construction and operating the facility at $5M a year (likely ramping up from the current $1.5M/yr support from the existing LaserNetUS cooperative agreement over a period of a few years). A time scale proposed and a possible allocation of shot time for this effort are described in the graph at right.