Reaching for the Brightest Light: Opportunities in the Science, Applications, and Technology of Intense Ultrafast Lasers

A study under the auspices of the
U.S. National Academy of Sciences, Engineering, and Medicine

Howard Milchberg, member, on behalf of the committee

The study was supported by funding from the DOE Office of Science, NNSA, ONR, and AFOSR.

Accessing this report:

- Three-page highlights for science policy-makers:

nap.edu/resource/24939/RH-lasers.pdf

Consensus Study Report

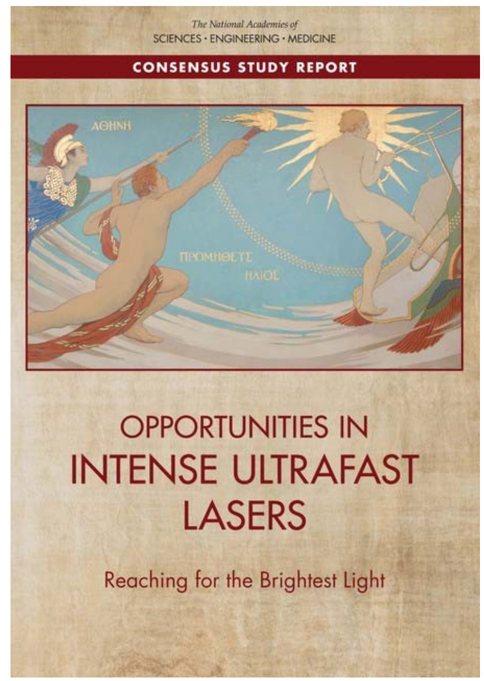
December 2017 HIGHLIGHTS

Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light

The laser has revolutionized many areas of science and society, transforming the ways we investigate science and enabling trillions of dollars of commerce. Now a second laser revolution is underway with pulsed petawatt-class lasers (1 petawatt: 1 million billion watts) that deliver nearly 100 times the world's total power consumption in less than one-trillionth of a second. Such light sources create unique, extreme laboratory conditions that can accelerate and collide intense beams of elementary particles, drive nuclear reactions, heat matter to conditions found in stars, or even create matter out of the empty vacuum. They also deliver applications beyond scientific discovery, in medicine, industry, and the stewardship of the nuclear weapons stockpile. Very powerful lasers were originally developed in the United States, and their successes prompted funding agencies in Europe and Asia over the last decade to invest heavily in new facilities that will employ these high-intensity lasers for fundamental and applied science. No similar investment has occurred in the United States, so the vast majority of high-intensity laser systems are located overseas.

OPPORTUNITIES IN INTENSE ULTRAFAST LASERS

- Full report (280 pages)
- http://nap.edu/24939



Committee membership

- **Phil Bucksbaum** (NAS), Stanford University/SLAC, Chair, strong field AMO physics
- **Riccardo Betti**, University of Rochester, high energy density physics.
- **John Collier**, Rutherford Appleton Laboratory, high intensity laser-matter interactions and laser-driven particle acceleration
- **Louis F. Dimauro**, The Ohio State University, strong field nonlinear optics.
- **Elsa Garmire** (NAE), Dartmouth College, nonlinear optics and optoelectronics.
- **Jacqueline Gish** (NAE), Northrop Grumman Aerospace Systems, chemical and diode pumped solid state lasers and laser systems.
- **Ernie Glover,** Gordon and Betty Moore Foundation, strong-field nonlinear x-ray interactions.
- **Marshall Jones** (NAE), General Electric Global Research, high power lasers for materials processing and manufacturing.
- **Henry C. Kapteyn** (NAS), University of Colorado, Boulder, high average power short pulse laser technology.
- **Andrew Lankford**, University of California at Irvine, experimental high energy physics.
- **Howard Milchberg**, University of Maryland, high intensity lasers and ultrafast laser spectroscopy.
- **Steve Milton** Colorado State, electron accelerators/FELs.
- **Peter Moulton** (NAE), MIT Lincoln Laboratory, laser materials.
- **C. Kumar Patel** (NAS/NAE), Pranalytica, Inc., laser systems, laser spectroscopy.

Motivation for this study

The concept for this study was developed beginning in 2011 by the Committee on Atomic, Molecular, and Optical Sciences (CAMOS), a standing activity of the National Academies that operates under the auspices of the Board on Physics and Astronomy

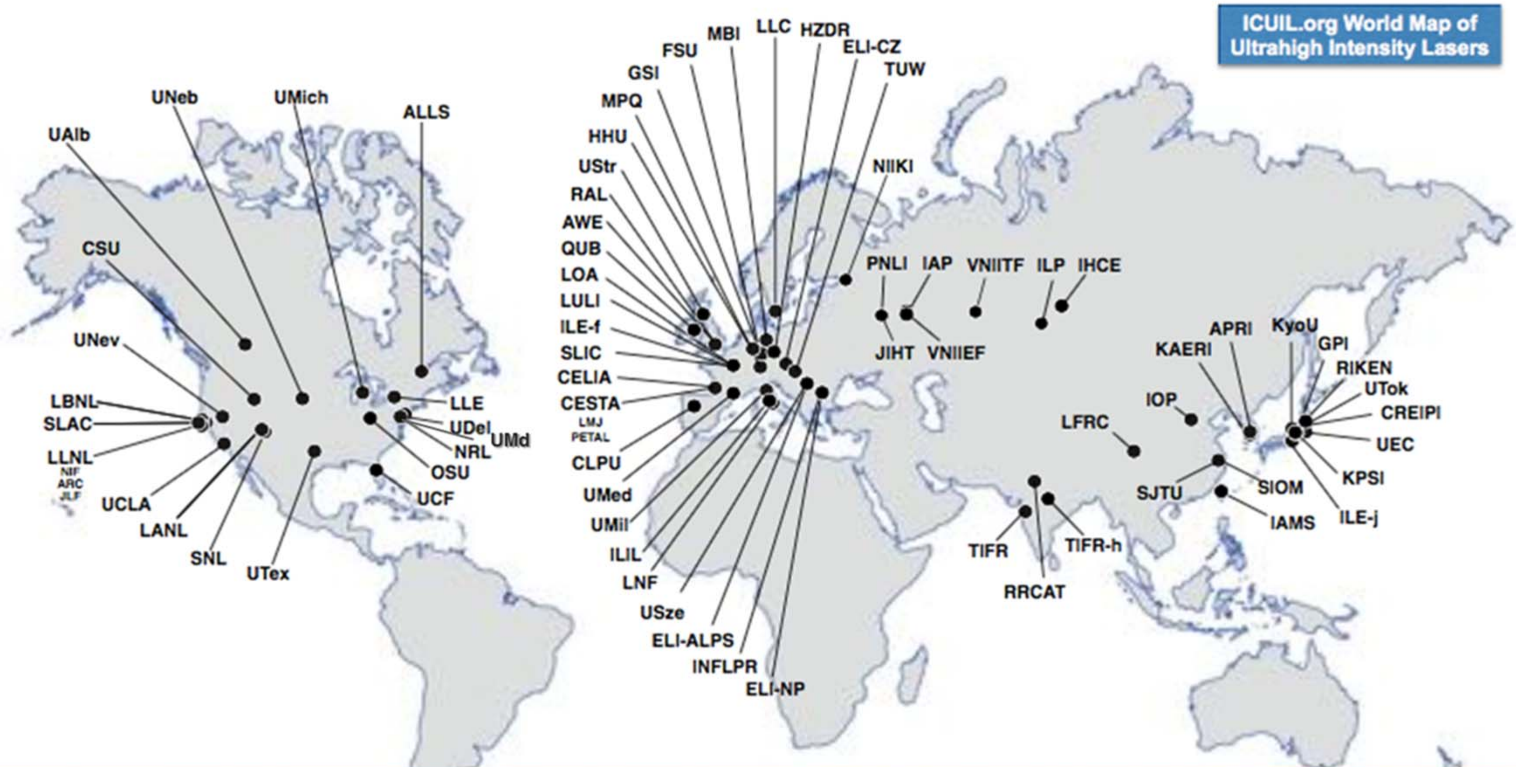
Study motivated by three factors:

1. Increasing exciting activity in science and applications using intense lasers and advances in ultrafast high-power laser technology;
2. More than a decade of community network building in Europe with programs such as LaserLab-Europe;
3. Initiation of the Extreme Light Infrastructure (ELI) project to build multiple petawatt and associated facilities at three sites in Europe

Examples of science & applications of PW-class lasers

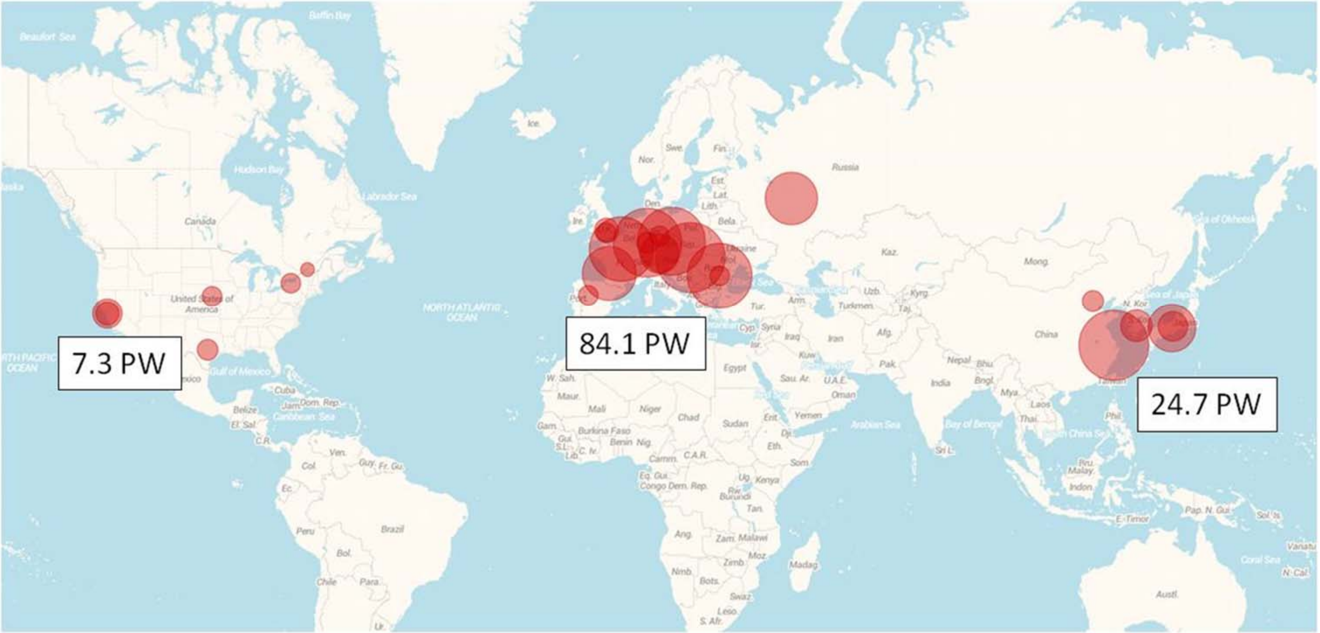
- Laser-based accelerators
- Nonperturbative vacuum-laser interactions
- Attosecond pulses from relativistic plasma mirrors
- X-ray backlighters
- Creation of extreme conditions with applications to geophysics, astrophysics, materials science
- Combining with X-ray FELs or with relativistic electrons, or both
- Photon sources (Thomson backscattering, betatron, plasma emission
- Proton and neutron sources
- Gamma rays for nuclear physics
- …

Fierce International Competition



- The pursuit of ultrahigh intensity laser science & applications is now a world wide activity
- Capabilities have evolved beyond the single PI scale to that of international user facilities
- Ultrahigh intensity laser projects now total more than $4B and involve > 1500 FTE's

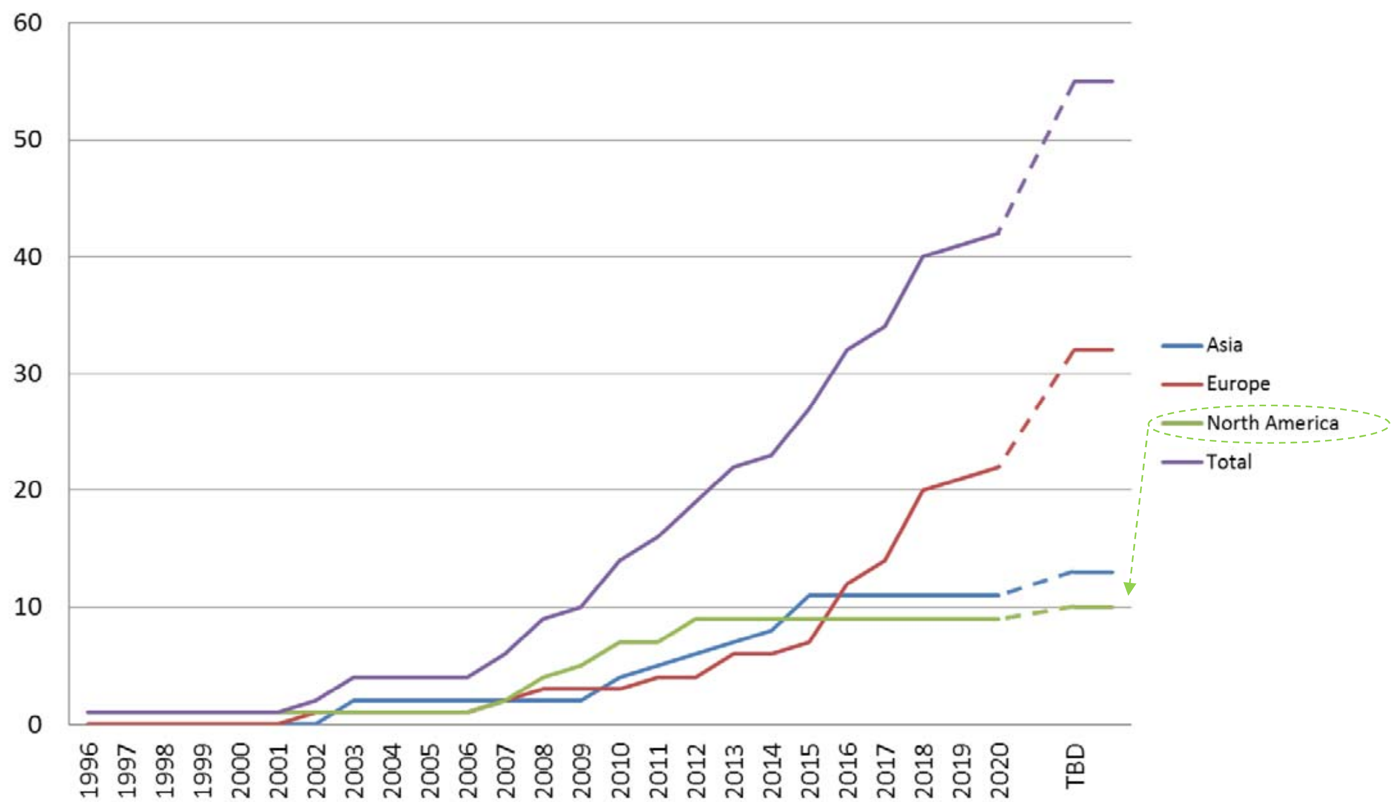
PW-class lasers: concentrated in Europe



Operational PW-Class* Systems

*(>~100TW)

Report Fig. 4.3



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European Union Strategic Investments in intense laser science and technology

Laserlab Europe: 33 institutions from 16 EU countries, with an annual budget of €10 million, funded under the EC's Horizons 2020 program as an 'integrating activity'.

A network to:

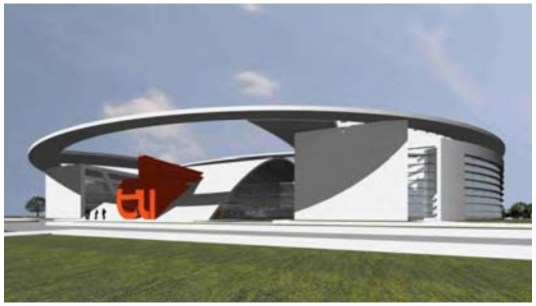
- maintain a competitive, interdisciplinary network of European laboratories;
- promote laser research and training across Europe, offering transnational access to high-quality facilities
- push lasers into new applications

EU Funding frameworks and Community Advocacy

- Horizons 2020: Ties S&T to economic health
  - €80 billion of funding over 7 years (2014 to 2020).
  - Establishes lasers & optics as one essential element of the EU economy in upcoming decades.
  - One of only a few major technology areas chosen for significant new investment
- Photonics^{21}: An advocacy group
  - 2500 members; Combines industry, universities, professional societies, and labs across EU
  - Pools community resources to help shape federal and EU policies for investment.

European ELI project (~ € 850M)

(European Regional Development Funds (ERDF) + local govt. funds)



Attosecond Light Pulse Source (Szeged, Hungary)
(ELI-ALPS)

- Ultrafast light sources, and coherent x-ray sources
- PW drive laser
- Several beam lines, from 10KHz 100 mJ to 0.1 Hz 300J

High Energy Beam-Line Facility (Prague, Czech Republic)
(ELI-Beamlines)

- Beam lines from -200mJ to 1.3kJ lasers, including 2 10PW lasers;
- Six experimental areas, including acceleration, x-rays, materials science.

Nuclear Physics Facility (Magurele, Romania)
(ELI-NP)

- 2 multi-petawatt, 200J, 0.1Hz, <30fs lasers
- Compton backscatter gamma ray source
- Experiments aimed at nuclear physics.

Summary Statement of Task
requested by DOE-SC/AFOSR/ONR/NNSA

1. *Survey high intensity science and related technology*

- Frontier science opportunities in high intensity science.
- Impact of applications associated with high intensity science.
- Status of high-powered laser technology in the US.

2. *High intensity science R&D in the US compared to international efforts*

- Is there national stewardship strategy? If not, what would be appropriate and what roadmap should the United States follow?
- Is there a case for a large-scale initiative to go well beyond the state of the art?
- Is there a case for forefront U.S. multi-petawatt facilities? What parameters or capabilities should be included?

Study Schedule

- In-person meetings
  - First meeting: December 4-5, 2015, Washington, DC
  - Second meeting: March 7-8, 2016, Palo Alto, CA
  - Site visit to ELI-Beamlines, June 28-29, 2016, Prague, CZ
  - Third meeting: July 14-15, 2016, Rochester, NY
  - Final Meeting: October 27-28, 2016, Irvine, CA.
- Video telecon speakers
- Public input
- Bi-weekly or weekly phone calls
- Approx. 35 position papers written
- Draft report written by chapter subcommittees
- Final editing over December-February
- Draft Report delivered to Academy for review, April 2017.
- Study released, December 2017

Study conclusions

1) The science is important.
2) Applications exist in several areas.
3) The community is large but fragmented.
4) No cross-agency stewardship exists.
5) The US has lost its previous dominance.
6) Co-location of intense lasers with existing infrastructure is essential; key US advantage over ELI
7) University/Laboratory/Industry cooperation is necessary to retain and renew the talent base.

Study recommendations

The committee recommends specific actions *by the study sponsors and the U.S. funding agencies they represent* that will enable and strengthen U.S. participation in high-intensity laser research.

1) DoE should lead formation of a network,
2) Research agencies should engage the community to define facility parameters, driven by science opportunities
3) Develop an interagency stewardship strategy,
4) **<u>Develop a strategy leading to one or more major open access facilities, leveraging existing infrastructure</u>**
5) Create programs that engage the commercial and academic communities of interest.

FAQs since the Dec. 2017 study release

- **What is the ballpark deployment cost of a multi-petawatt laser facility?**

  ***Approx. $100M, far less than current flagship facilities operated by DOE*.**

  - (ELI deploys ~10 multi-PW lasers in three greenfield sites for €850M). High intensity sources are much lower cost than high energy pulsed lasers (A PW laser like BELLA is tens of joule-class; a high energy laser like NIF is megajoule-class.)

- **What are the benefits of co-location of high intensity lasers with existing facilities at DOE laboratories?**

  Considerable benefits

  - Intensity boost of up to a billion simply by colocation; Multi-mode probes combine particle and x-ray beams with PW laser beams.

- **How rapidly is the technology progressing internationally?**

  Peak power more than 10x in the coming decade

  - ELI deploying 10PW beams; China is building the first 100PW system for deployment in the next decade.

Events since the Dec. 2017 NAS study release

Events following "Reaching the Brightest Light" NAS Report

U.S. DEPARTMENT OF ENERGY
Office of Science

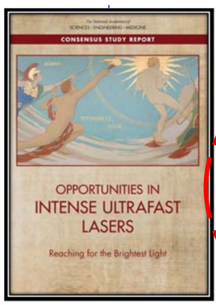
HEDSA Workshop

FES Long-Range-Strategic Planning

DOE-SC, NNSA, NSF, NPI   Location: OSA

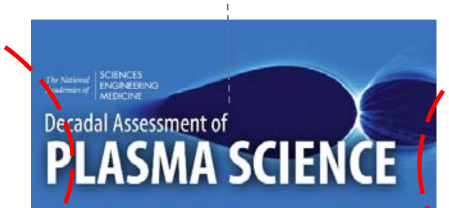
Brightest Light Initiative Workshop

Dec. 2017 | Feb. 2018 | Aug. 2018 | Oct. 2018 | Oct. 2018 | Dec. 2018 | Jan 2019 | March 2019 | May 2019



NAS Report Released

LaserNetUS Established by FES
NAS Recomm. 1



First public committee meeting was held on October 15

CD-0 Approval for A Petawatt Laser Facility
NAS Recomm. 4

Plasma Science Facilities Workshop

NSF, DOE-SC, ONR, AFOSR
Location: UMD

K. Akli (NIF-JLF user group meeting presentation), Feb. 4^{th}, 2019

U.S. DEPARTMENT OF ENERGY

Office of Science

A new initiative was introduced by FES at LaserNetUS First Annual Meeting

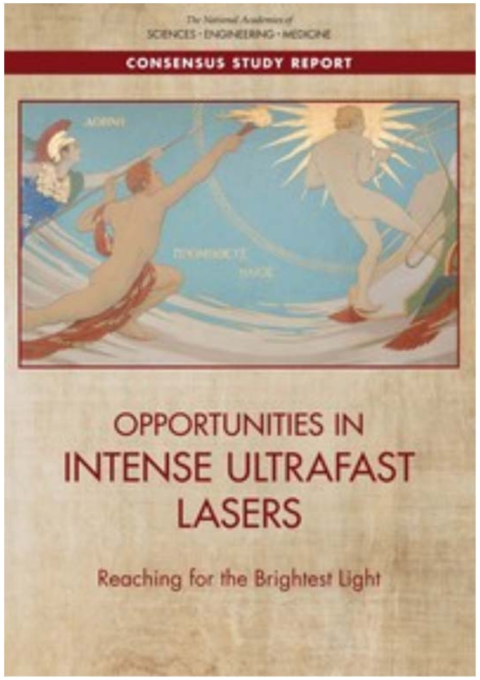
University of Nebraska-Lincoln (August 20-21, 2018)

At this meeting, LaserNetUS initiative was established by FES to provides "Broad access to state-of-the-art facilities for the entire community" as recommended by NAS Intense Ultrafast Lasers report

LaserNetUS

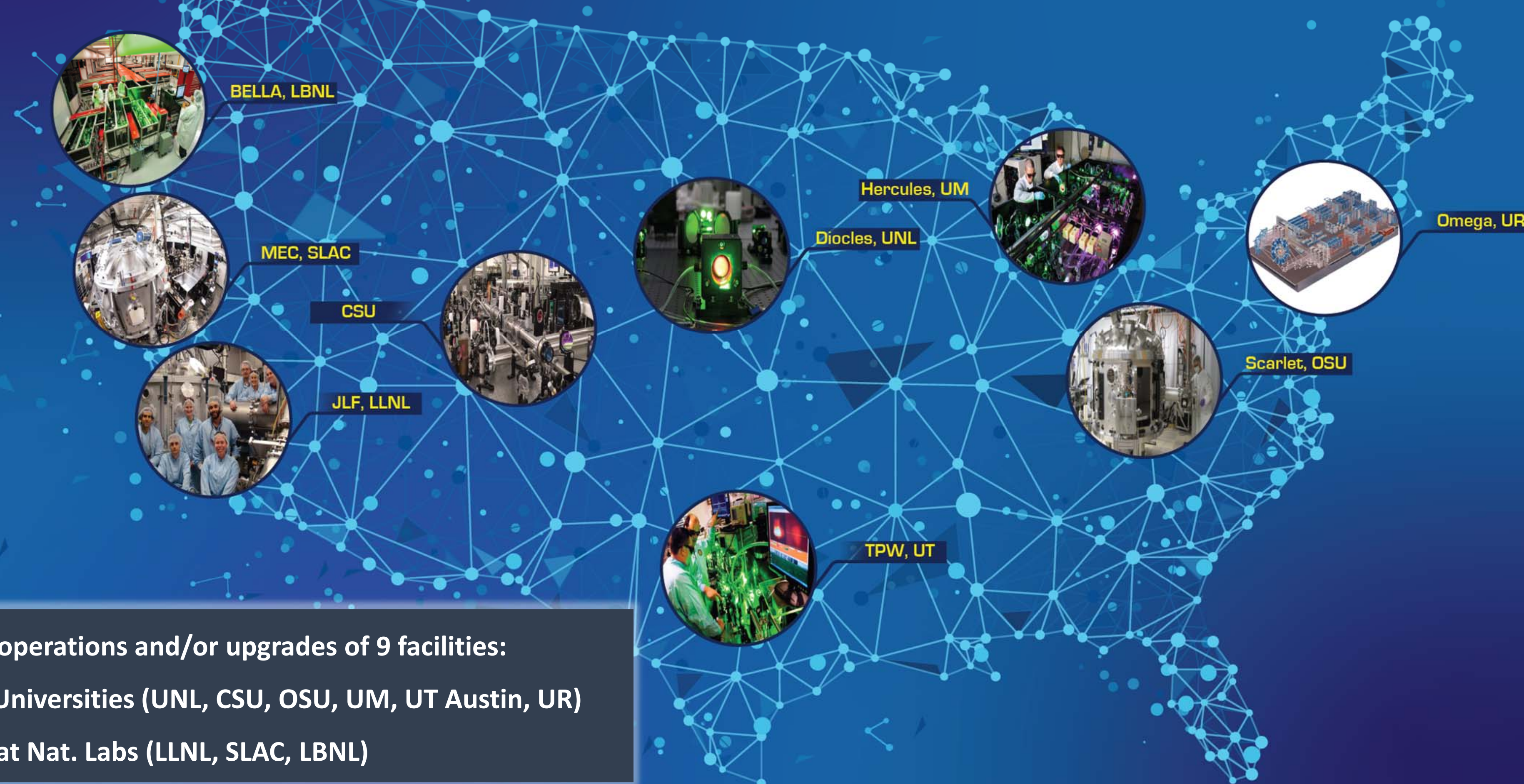
Recommendations

1. DOE should create a broad national network (universities, industry, government labs) in coordination with OSTP, DOD, NSF, and others.



LaserNetUS

https://www.lasernetus.org/



FES Funds operations and/or upgrades of 9 facilities:

- Six at Universities (UNL, CSU, OSU, UM, UT Austin, UR)
- Three at Nat. Labs (LLNL, SLAC, LBNL)

Proposal Submissions

Latest proposal schedule

Cycle	Type	Proposal deadline	Cycle begins	Cycle ends
1	LaserNetUS standard proposal call	March 18, 2019 **4pm PST**	Jul 2019*	Dec 2019

Proposals are submitted through the **LaserNetUS User Portal**

*Earliest start date will depend on facility readiness and proposal feasibility.

Submitting LaserNetUS Proposals

LaserNetUS encourages scientists from diverse fields to propose experiments utilizing the consortium's wide-ranging capabilities.

LaserNet US intends to be open to international users. However, during the first year of operation, LaserNet US applications will be restricted to PIs from US institutions. International collaborators are welcomed. Start date for acceptance of applications from international PIs will be announced in the future.

There is no cost to submit proposals or conduct experiments at the participating institutions. Users are generally responsible for their own travel and target expenses as well as any extraordinary consumables required by the experiment, though a request for supplemental funding from FES can be requested in proposal submission, if needed.

Register as a spokesperson and submit a proposal through the LaserNetUS Portal

Proposal preparation guidelines are given below. Users will want to review the **laser facility descriptions** and contact local POCs to discuss technical capabilities and proposed experiments.

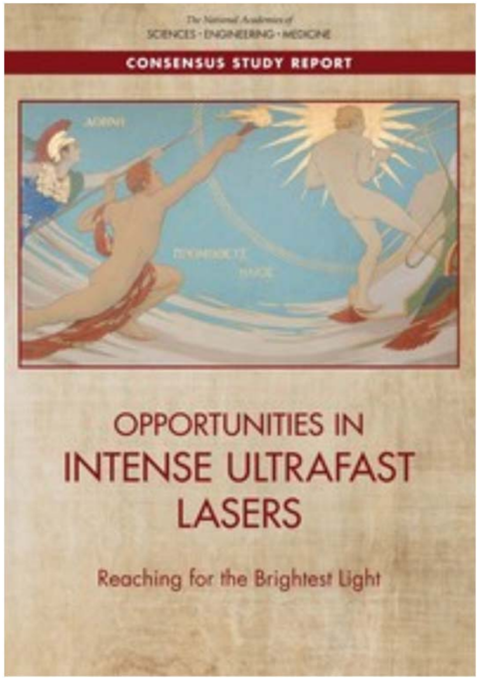
Proposal Preparation Guidelines

We recommend that scientists describe well-posed experiments. Proposals must include brief discussions of the expected scientific or technological impact and

<u>Recommendations</u>

1. DOE should create a broad national network (universities, industry, government labs) in coordination with OSTP, DOD, NSF, and others.

4. DOE should plan for at least one large-scale open-access, high-intensity laser facility that leverages other major science infrastructure in the DOE complex.



Brightest Light Initiative (BLI) Workshop – March 27-29, 2019

Co-sponsored by DOE-SC, NSF, NNSA, and NPI

UR LLE

Workshop Chairs: Roger Falcone (UCB)

Co-Chairs/Science: Felicie Albert (LLNL)
Farhat Beg (UCSD, HEDSA)
Siegfried Glenzer (SLAC)

Co-Chairs/Technology.: Todd Ditmire (UT Austin)
Constantin Haefner (LLNL)
Jon Zuegel (UR)

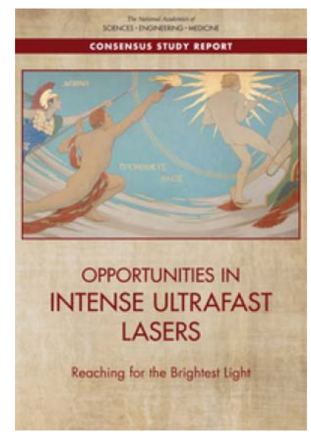





CHARGE:

The purpose of the Brightest Light Initiative workshop is to organize the U.S. intense laser community:

- Articulate a community response to the 2017 National Academy of Sciences report *Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light*,
- Identify compelling science, fundamental, and applied research opportunities that exploit high-intensity lasers leading to high impact over the next decade and beyond,
- Define new and upgraded facility and laser capabilities that will enable compelling science, emphasizing parameters beyond the current state of the art, and
- Identify laser research and development to realize both ultrahigh intensities and high repetition rates, as well as high-average powers needed for applications.



Brightest Light Initiative (BLI) Workshop – March 27-29, 2019

Co-sponsored by DOE-SC, NSF, NNSA, and NPI

Scientific Research Needs (SRN) topics:

- **High-energy-density (HED) and basic plasma physics**
  Bedros Afeyan (Polymath)
  Sean Finnegan (LANL)
- **Material, planetary, astrophysical sciences**
  Frederico Fiuza (SLAC)
  Dustin Froula (LLE)
- **Laser wakefield acceleration and applications**
  Cameron Geddes (LBNL)
  Mike Downer (U. Texas at Austin)
- **Particle acceleration: neutrons, ions, protons, positrons**
  Doug Schumaker (OSU)
  Scott Wilks (LLNL)
- **High-field physics, QED, and Attoscience**
  Alec Thomas (U Michigan), Alexei Arefiev (UCSD)
  Lou DiMauro (OSU)
- **Nuclear photonics**
  Markus Roth (Darmstadt)
  Igor Jovanovic (U. Michigan)

Technology Research Needs (TRN) topics:

- **Achieving the highest intensities (beyond 10^{22} W/cm^2)**
  Jake Bromage (LLE)
  Erhard Gaul (National Energetics)
- **Pushing high-energy (10 J < *E* < 10 kJ), high-intensity lasers to average powers**
  Alan Fry (SLAC)
  Tom Spinka (LLNL)
- **Producing femtosecond systems with the highest average powers (>1 kw per beam)**
  Peter Moulton (MIT LL)
  Almantas Galvanauskas (Univ. Michigan)
- **Upgrading/extending performance of existing (mid-scale) facilities**
  Jorge Rocca (Colorado State Univ.)
  Csaba Toth (LBNL)

https://ireap.umd.edu/Workshop-on-Opportunities-May2019

Workshop goals:

- Identify and discuss compelling topics in plasma physics that require facilities larger than typically operated by single-PI groups.
- Discuss lessons learned from the operation of open user facilities, collaborative facilities, user networks, and larger single/few PI facilities in the plasma physics and related scientific communities. Extract from the discussion guidance to be offered to potential future facilities, NSF, and other agencies regarding what works well.
- Discuss advantages and disadvantages for investments in user facilities under constrained resources.

Workshop on Opportunities, Challenges, and Best Practices for Basic Plasma Science User Facilities

<u>Co-chairs:</u> Howard Milchberg, Univ. Maryland & Earl Scime, West Virginia Univ.

- ***Quantum properties of dense plasmas***
  Gilbert Collins (Univ. Rochester), Sam Vinko (Oxford Univ.)

- ***Plasma in super-critical fields***
  Alec Thomas (Univ. Michigan), Stepan Bulanov (LBNL)

- ***Single component plasmas, dusty plasmas, and matter-antimatter plasmas***
  Joel Fajans (UC Berkeley), Eve Stenson (Max Planck)

- ***Laboratory astrophysics***
  Carolyn Kuranz (Univ. Michigan), Petros Tzeferacos (U. Chicago)

- ***Relativistic laser- and beam-plasma interactions***
  Felicie Albert (LLNL), Warren Mori (UCLA)

- ***Coherent structures and energy dissipation in plasmas***
  Jim Drake (Univ. Maryland), Mike Brown (Swarthmore)

- ***Controlled production of chemical reactivity***
  Mark Kushner (Univ. Michigan), Steve Shannon (NCSU)

Thank you!