

# PLASMA DECADAL SURVEY

Thoughts from DOE Fusion Energy Sciences  
perspective

National Academy of Sciences  
October 15, 2018

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Acting Associate Director  
Fusion Energy Sciences  
Office of Science, USDOE



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**A brief overview of your plasma program (e.g., topics, number of PIs supported, relationship with other agencies)**



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# Fusion Energy Sciences

*Matter at very high temperatures and densities  
and the scientific foundations for fusion*

## Mission

The mission of the U.S. Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings.

## Objectives

- Advance the fundamental science of magnetically confined plasmas for fusion energy
- Support the development of the scientific understanding required to design and deploy fusion materials
- Pursue scientific opportunities and grand challenges in high energy density plasma science
- Increase the fundamental understanding of plasma science beyond burning plasmas



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The FES program structure reflects the scientific challenges of fusion and broader plasma science

## *Burning Plasma Science*

### Foundations:

Focusing on **domestic capabilities**. Theory and computation focus on questions central to understanding the burning plasma state

**Challenge:** Understand the fundamentals of transport, macro-stability, wave-particle physics, plasma-wall interactions

### Long Pulse:

Building on **domestic capabilities and furthered by international partnership**

**Challenge:** Establish the basis for indefinitely maintaining the burning plasma state

### High Power:

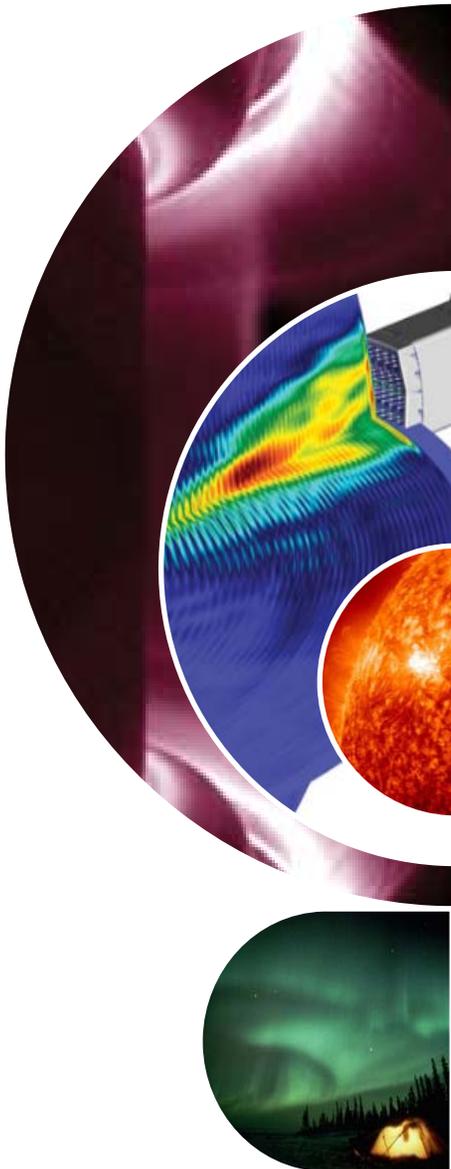
**ITER is the keystone** as it strives to integrate foundational burning plasma science with the science and technology girding long pulse, sustained operations.

**Challenge:** Establishing the scientific basis for attractive, robust control of the self-heated, burning plasma state

## *Discovery Plasma Science*

### Plasma Science Frontiers & Measurement Innovation

General Plasma Science, HEDLP, Exploratory Magnetized Plasma, and Diagnostics

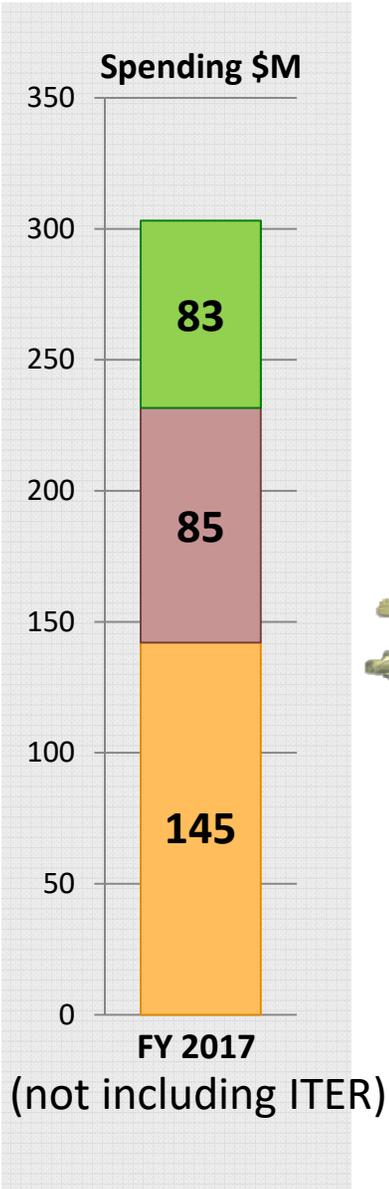




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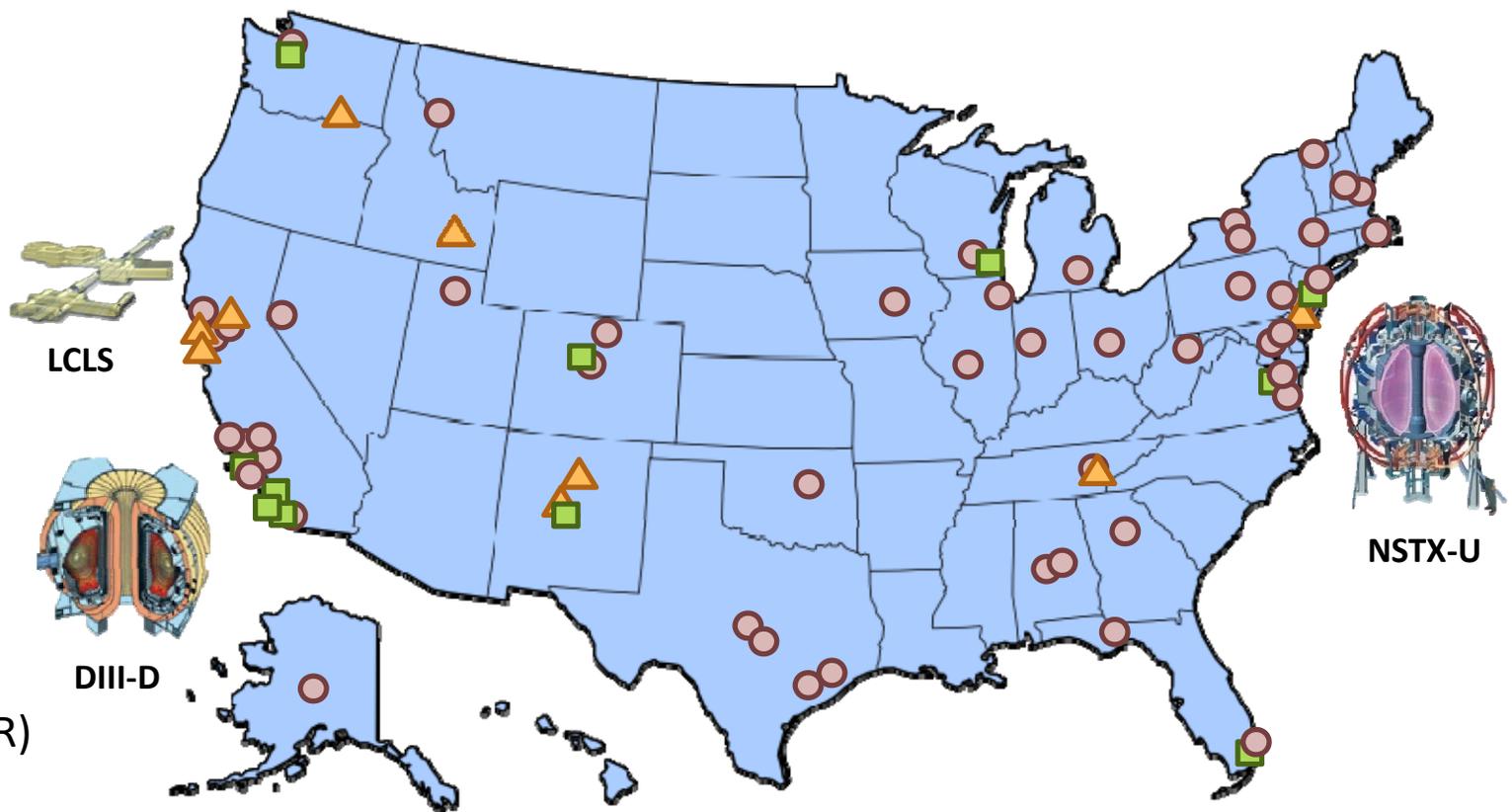
FES research is carried out at  
a diversity of US institutions



**42**  
universities

**12**  
industry

**9**  
laboratories





# Snapshot of Fusion Energy Sciences program

## High Energy Density Plasmas

Matter in Extreme Conditions Instrument (MEC) @ SLAC-LCLS

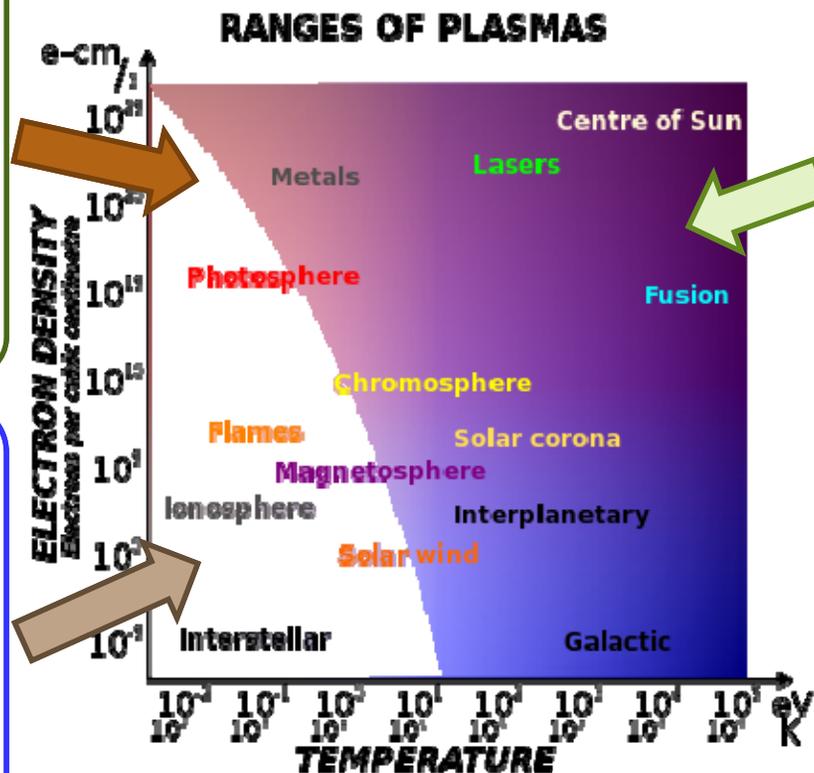


Joint Program with National Nuclear Security Administration



ITER Project (international partnership)

china eu india japan korea russia usa



## Mission of the Fusion Energy Sciences program

To expand the fundamental understanding of matter at very high temperatures and densities and build the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings.

## Magnetic Confinement Fusion

**Facilities**

- DIII-D Tokamak
- NSTX Upgrade
- Stellarator Research

**Measurement Innovation**

**Theory Simulation**

SciDAC

**International collaborations**

## Enabling R&D

Fusion Materials Science

Enabling Technology

Systems Studies

Small Business Innovation Research

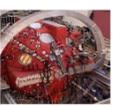
## General Plasma Science



NSF/DOE Partnership in Basic Plasma Science



Plasma Science User Facilities



Lab Basic Plasma Science



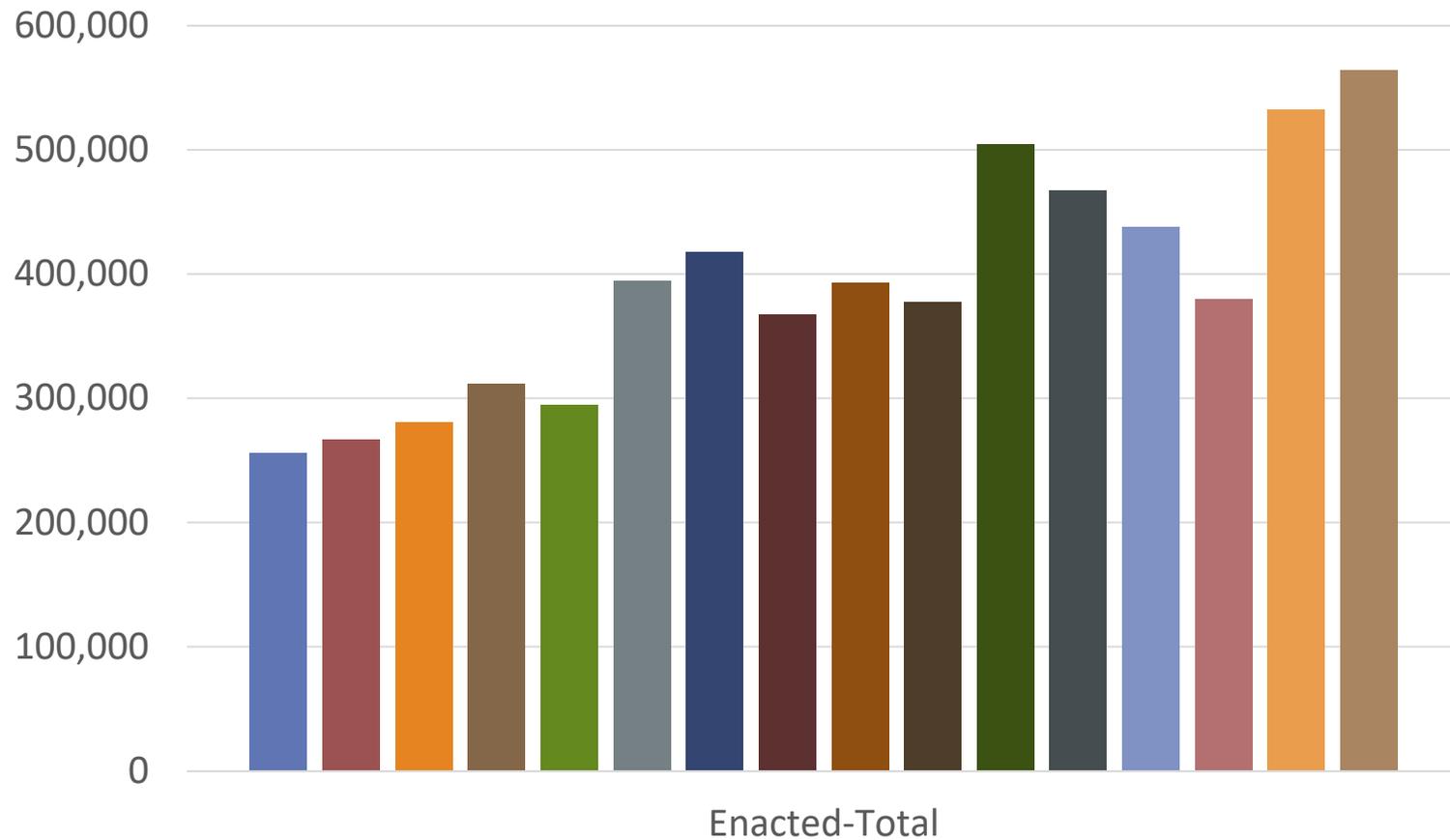
Max-Planck / Princeton Center for Plasma Physics



Low Temperature Plasma Science Center



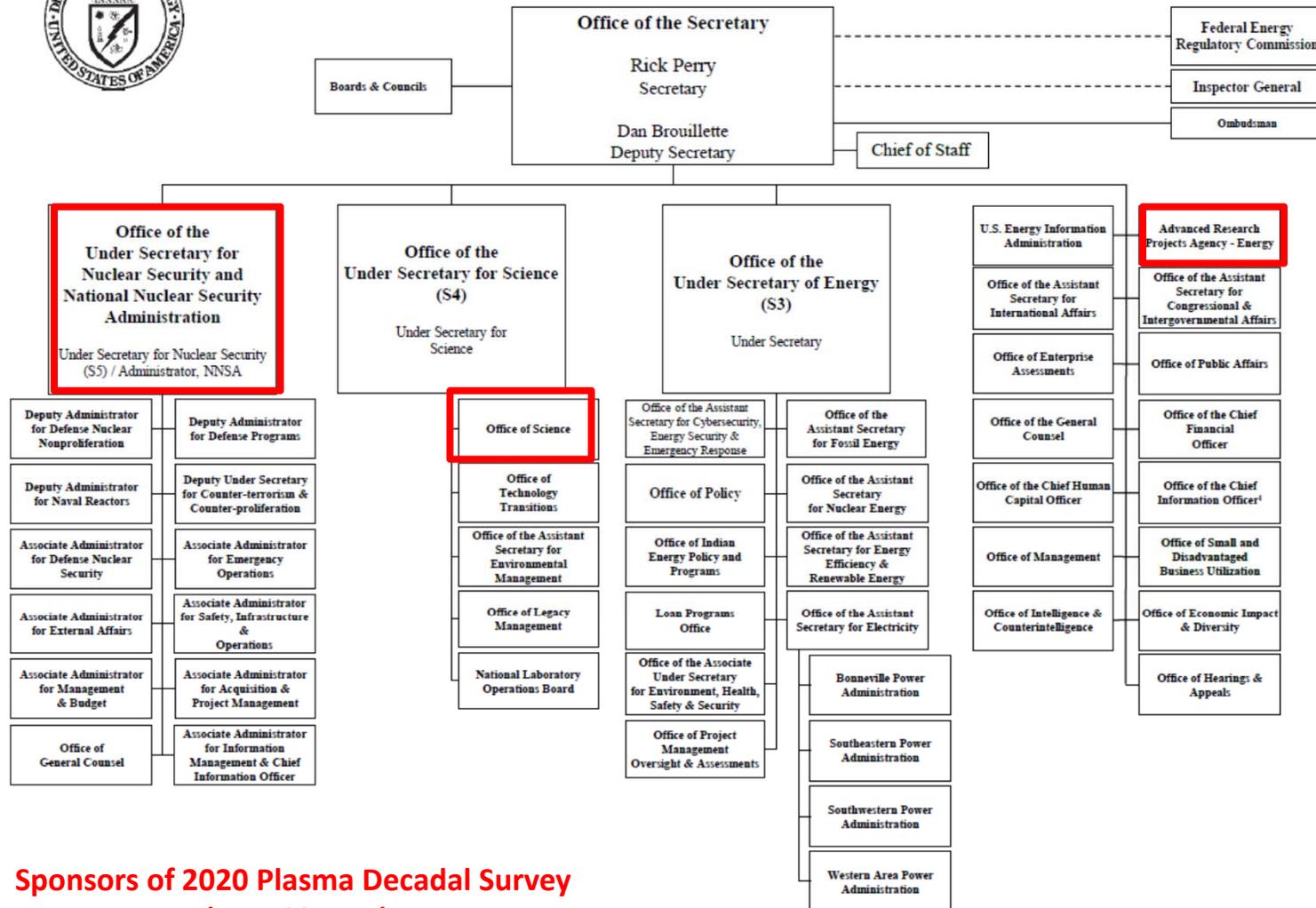
## Total FES funding FY 2004-2019



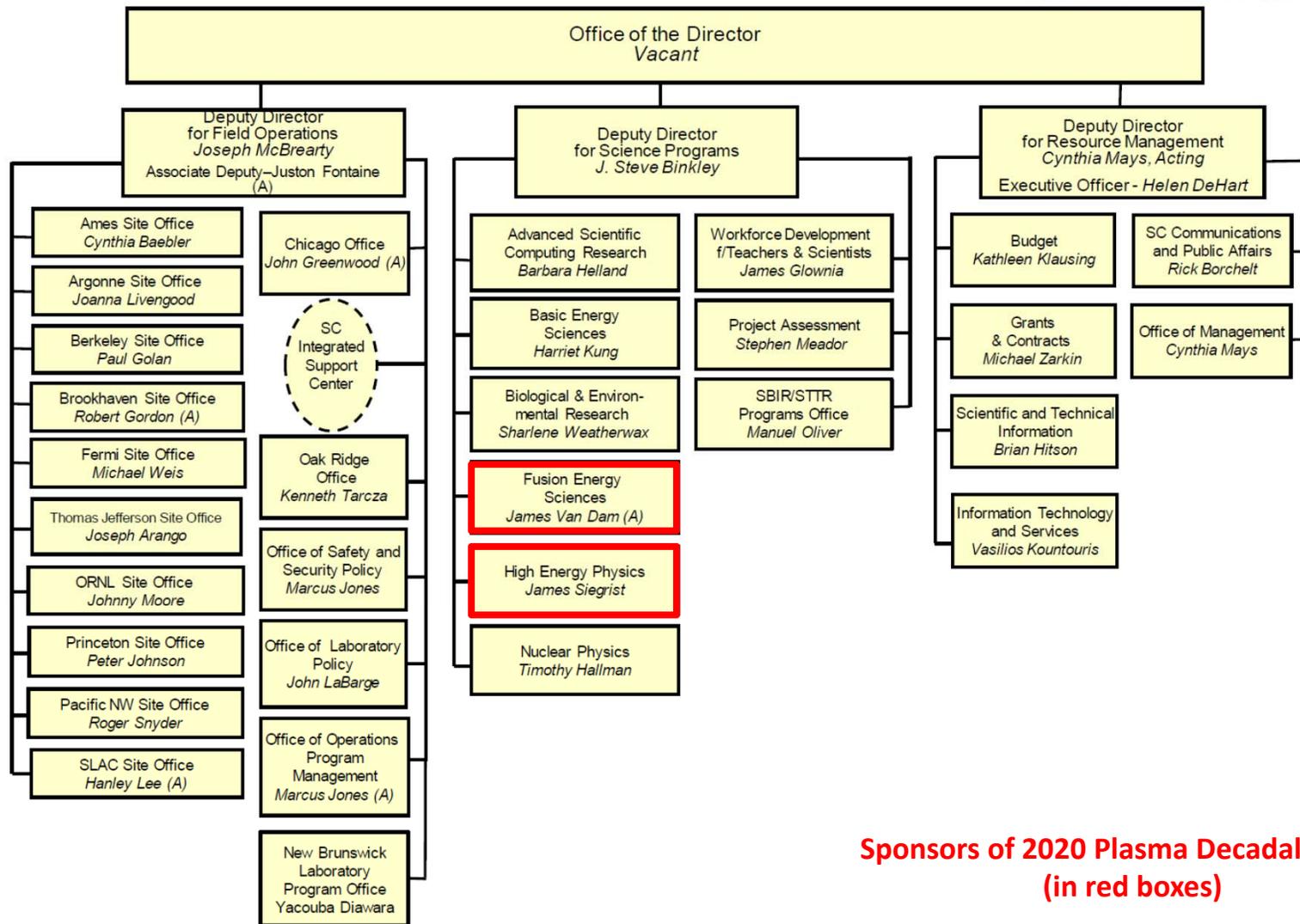
2004 2005 2006 2007 2008 2009 2010 2011  
2012 2013 2014 2015 2016 2017 2018 2019



## DEPARTMENT OF ENERGY



Sponsors of 2020 Plasma Decadal Survey  
(in red boxes)



Sponsors of 2020 Plasma Decadal Survey (in red boxes)



**FES participates in coordinated initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science**

- **Within SC:**

- **ASCR:** Joint support of SciDAC high-performance computing research projects
- **BES:** Operate the Matter in Extreme Conditions (MEC) instrument at LCLS (SLAC)
- **BES:** Use HFIR (ORNL) for materials irradiation research
- **HEP:** Support for BELLA facility (LBNL)

- **Within DOE:**

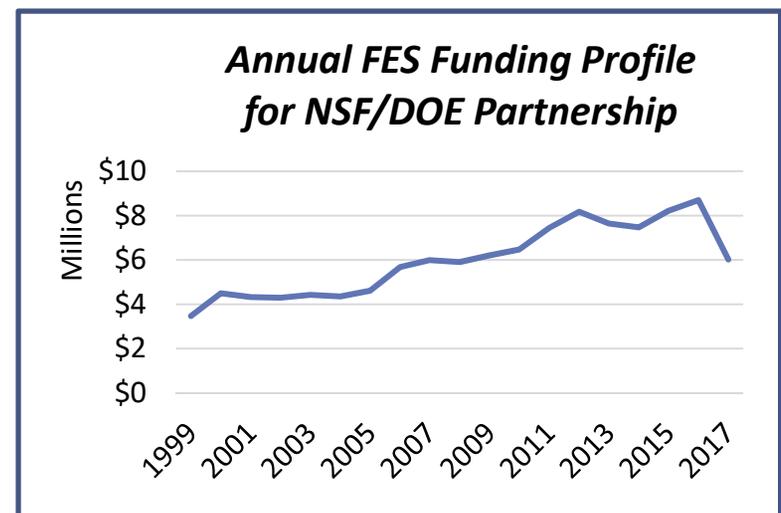
- **NNSA:** Joint program in high energy density laboratory plasma science
- **NNSA:** Support for Jupiter Laser Facility

- **Outside DOE:**

- **National Science Foundation:** Joint Partnership in support of discovery-driven plasma science research in partnership with NSF



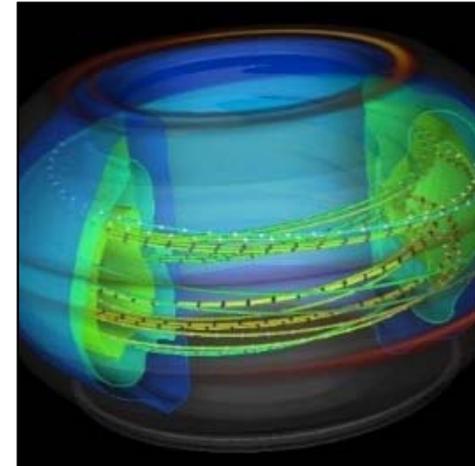
*January 2017 workshop celebrated 20-year anniversary of NSF-DOE Partnership*





# FES partnership with ASCR in high-performance computing is critical to scientific progress

- **The current FES SciDAC-4 portfolio** consists of nine multi-institutional and interdisciplinary partnerships, with seven jointly supported by FES and ASCR
  - 11 universities, 8 DOE national laboratories, and 5 private industry institutions (including small businesses) in 13 states
- FES SciDAC research activities accelerate progress toward whole-device modeling
- The SciDAC portfolio strengthens U.S. domestic fusion program, advances U.S. world leadership and competitiveness in fusion simulations, and addresses research opportunities identified in recent community workshops



**High-Fidelity Whole-Device Modeling of Magnetically Confined Fusion Plasma**  
(led by PPPL)



**27-petaflops Titan supercomputer (ORNL)**

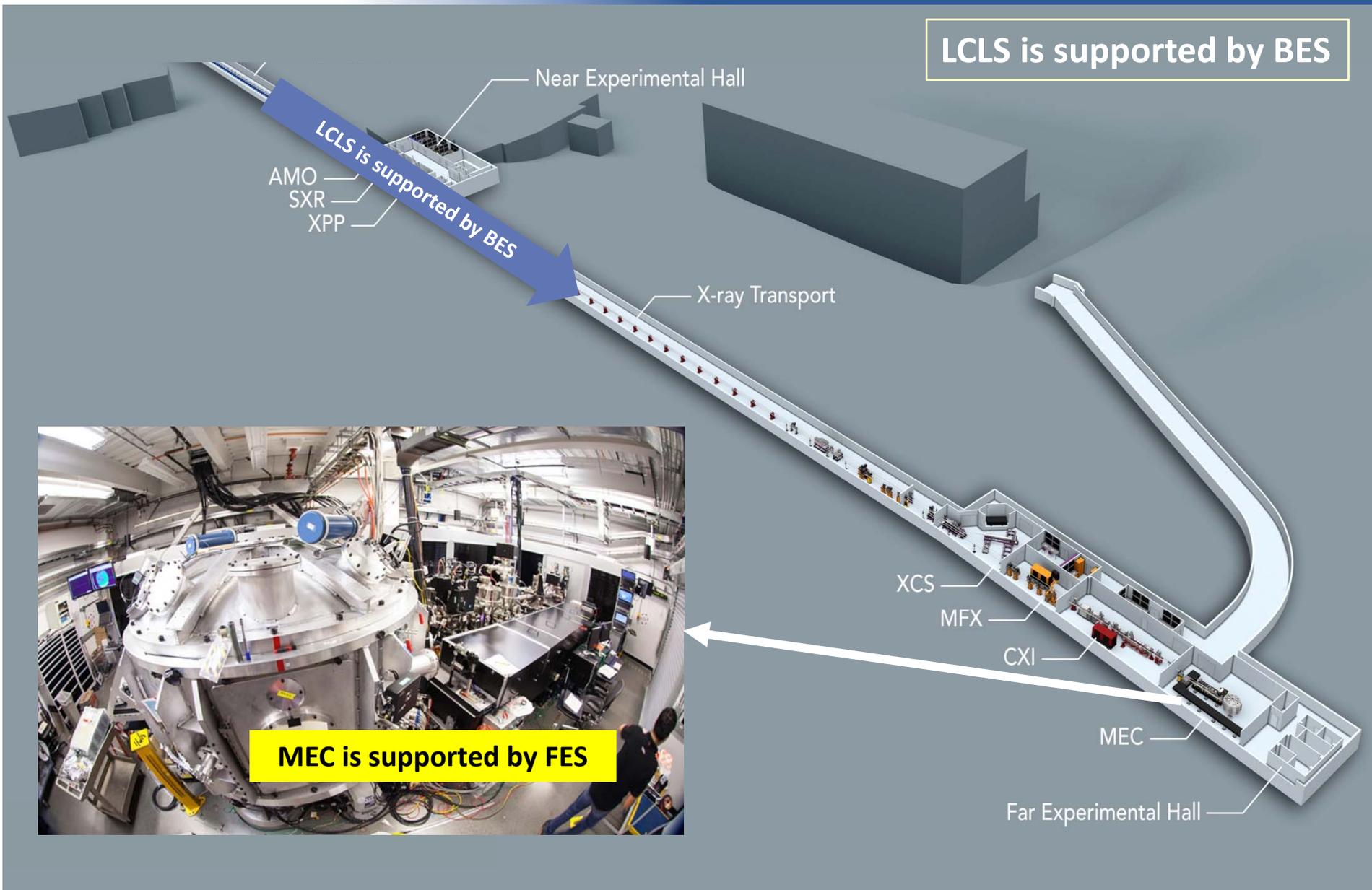
- **The upcoming Exascale era** will enable transformative advances in predictive power for fusion systems, based on fundamental science and high-performance computing
- Two fusion-relevant multi-institutional efforts are part of the DOE Exascale Computing Project (ECP) Universities participate through subcontracts with DOE Labs



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# FES is leveraging other DOE investments (LCLS) to conduct world class HED research





- **US-Japan PHENIX program**
  - Conduct joint experiments on High Flux Isotope Reactor (HFIR) at ORNL to study irradiation response of JA and US structural and special purpose materials and evaluate their performance for use in future fusion reactors



*HFIR for material irradiation*

HFIR is supported by BES

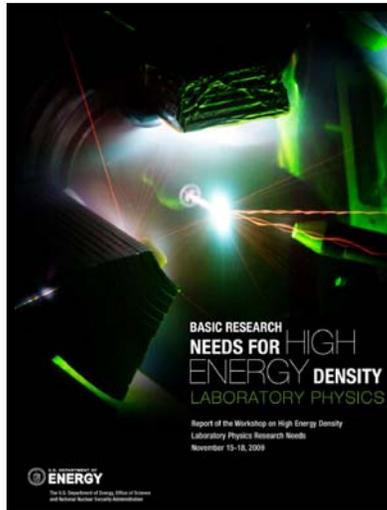


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# SC-NNSA Joint Program in High Energy Density Laboratory Plasmas

ReNeW Report (2009)

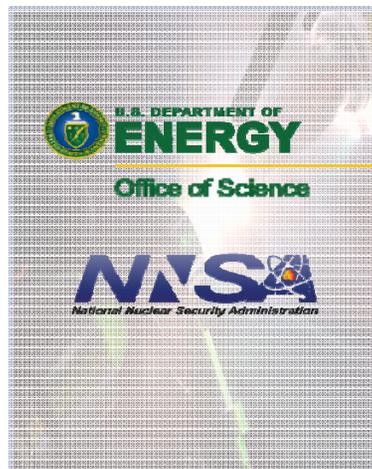


## Main Topics:

1. High energy density (HED) hydrodynamics
2. Nonlinear optics of plasmas
3. Relativistic HED plasma and intense beam physics
4. Magnetized HED plasma physics
5. Radiation-dominated dynamics and material properties
6. Warm dense matter

## Additional cross-cutting topics:

1. *Computing*
2. *Diagnostics*
3. *Research infrastructure*
4. *High-Z multiply ionized HED atomic physics.*



## Joint Program Funding Opportunity Announcement

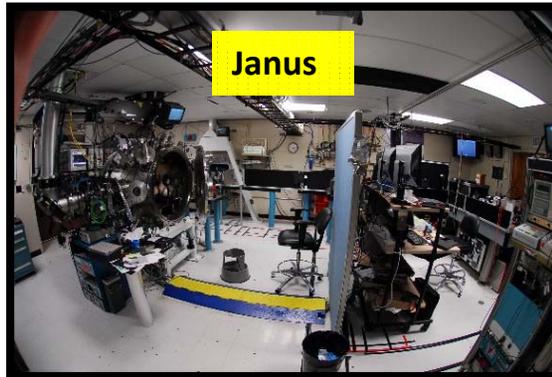
(DE-FOA-0001801)

FY 2018



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# High Energy Density Laboratory Plasma: leveraging opportunities at NNSA

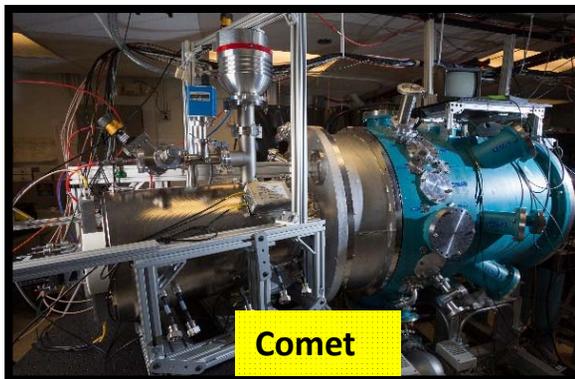


Janus

**Jupiter Laser Facility (suite) refurbishment and upgrade in partnership with LLNL**



Titan



Comet



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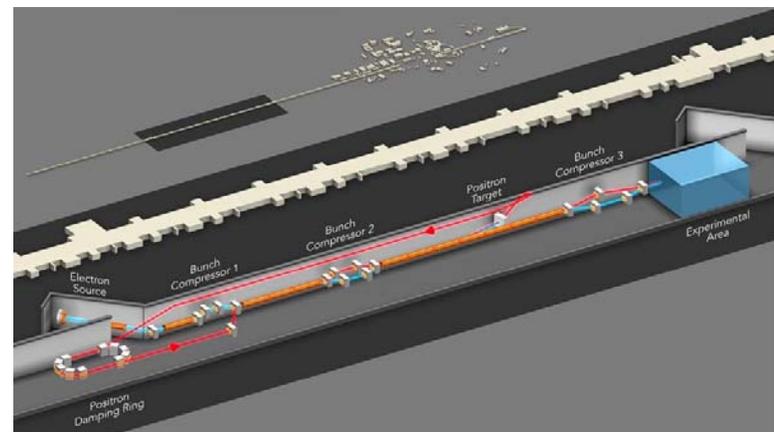
**Where in your agency do plasmas appear and are supported outside of your program?**



- **FES:** Primarily in Fusion Energy Sciences program office
- **HEP:** Wake-field plasma acceleration research in High Energy Physics program office
  - BELLA laser program (LBNL)
  - FACET program (SLAC)
- **ASCR:** FES investigators are leading an Exascale Computing Project application for the Advanced Scientific Computing Research program office
- **BES:** FES investigators have also on occasion received grants from Basic Energy Sciences program office



**BELLA upgrade:** Short focal length, high Intensity beam line with double plasma mirror for dedicated HEDLP science



**FACET-II upgrade:** Accelerate positrons



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# FES Burning Plasma Science: Foundations

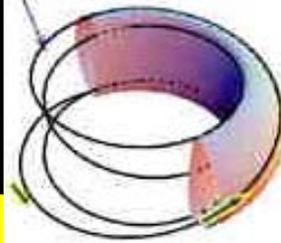
## Advanced Tokamak



**DIII-D**

General Atomics

Magnetic Field Line



## Spherical Tokamak



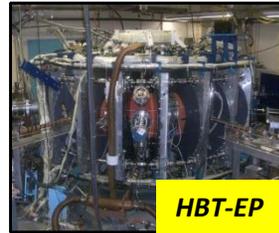
**NSTX-U**

PPPL

Magnetic Surface



## Small-Scale Tokamak



**HBT-EP**

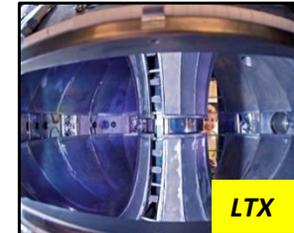
Columbia U.

## Small-Scale Spherical Tokamak



**Pegasus**

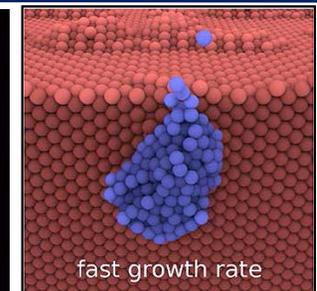
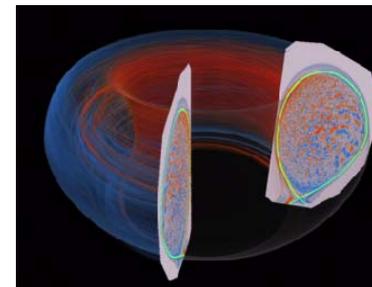
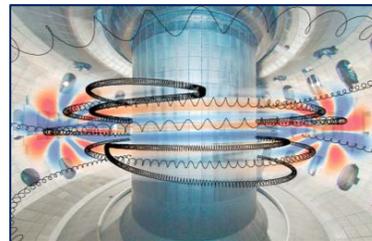
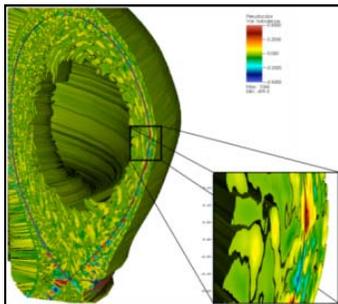
U. Wisconsin



**LTX**

PPPL

## Theory & Simulation





## Burning Plasma Science: Long Pulse



**EAST**

China



**KSTAR**

South Korea

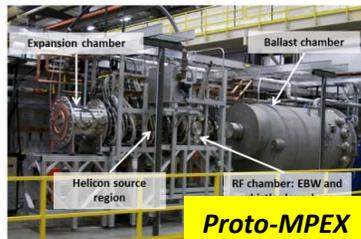
Long Pulse Tokamak



**W7-X**

Germany

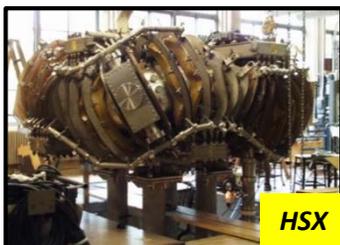
Superconducting Stellarator Research



**Proto-MPEX**

ORNL

Materials Research & Fusion Nuclear Science



**HSX**

U. Wisconsin

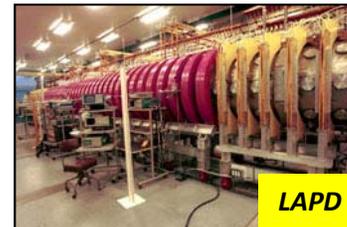
Compact Stellarator Research



**CTH**

Auburn U.

## Discovery Plasma Science



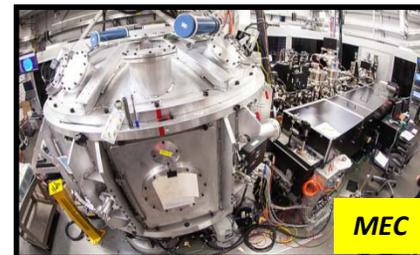
**LAPD**

UCLA



**MRX**

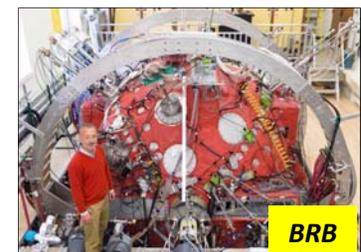
PPPL



**MEC**

SLAC

- General Plasma Science
- High Energy Density Laboratory Plasma
- Exploratory Magnetized Plasma
- Measurement Innovation



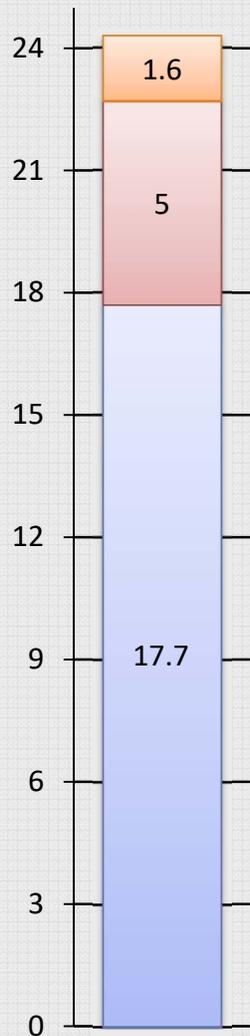
**BRB**

U. Wisconsin



# Overview of the FES General Plasma Science Portfolio

FY17 Spending  
\$24.3 M



**20**  
Universities

**4**  
Laboratories

**4**  
Industry & other

**55**  
PIs & CoPIs

**44**  
Postdocs & Scientists

**63**  
Grad Students

**10**  
Undergrads

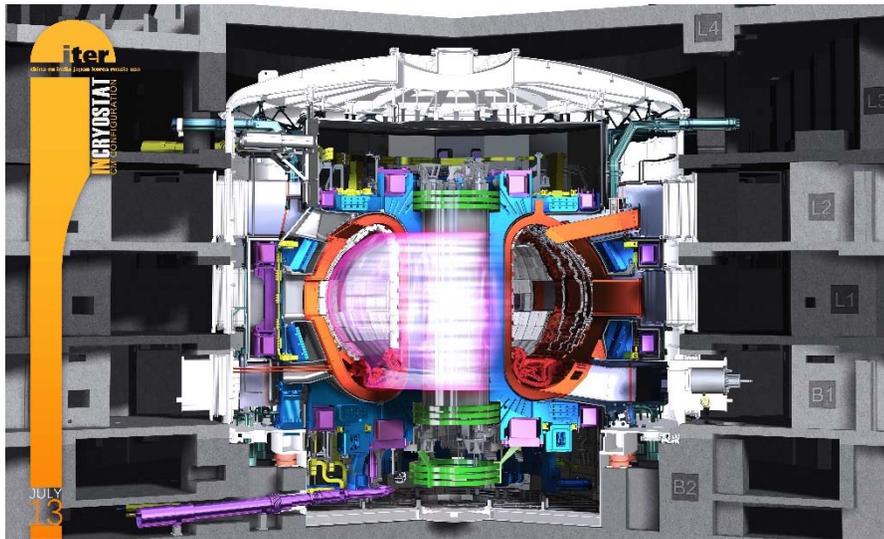


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# The US is a 1/11<sup>th</sup> partner in ITER, the world's major step forward in fusion research

*ITER will demonstrate the scientific and technical feasibility of fusion energy*

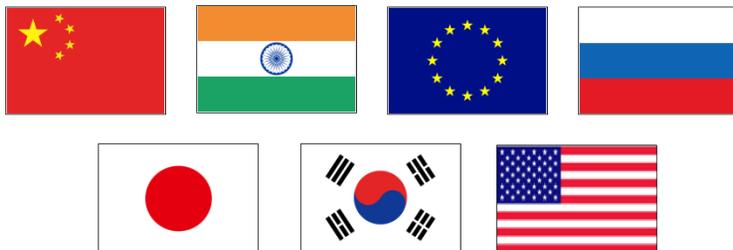


**ITER is the essential next step in development of fusion energy science**

- **As of today:** 16 MW, 1 sec, gain < 1
- **With ITER:** 500 MW, > 400 sec, gain  $\geq 10$  (and ITER Phase-II to achieve 3000 seconds, gain = 5)
- Uncharted science, leveraging US intellectual investments
- Major contributions from US industry

**The world's biggest fusion energy research project ("burning plasma")**

- 15 MA plasma current, 5.3 T magnetic field, 6.2 m major radius, 2.0 m plasma minor radius, 840 m<sup>3</sup> plasma volume, superconducting magnets

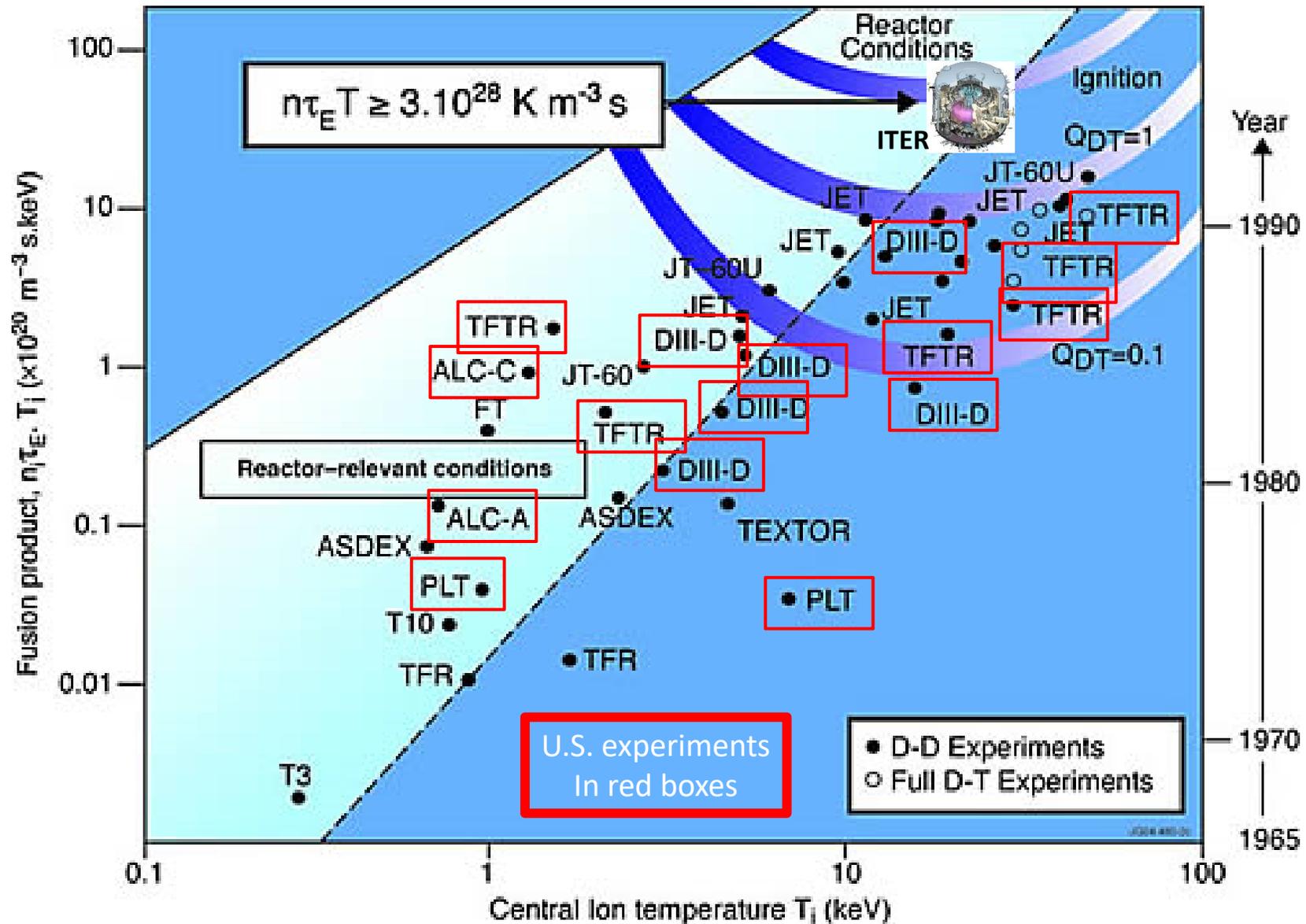


**An international collaboration**

- 7 Member partners, representing 50% of world's population
- EU the host Member, with site in France



# Due to strong scientific progress, the fusion energy regime is within striking distance

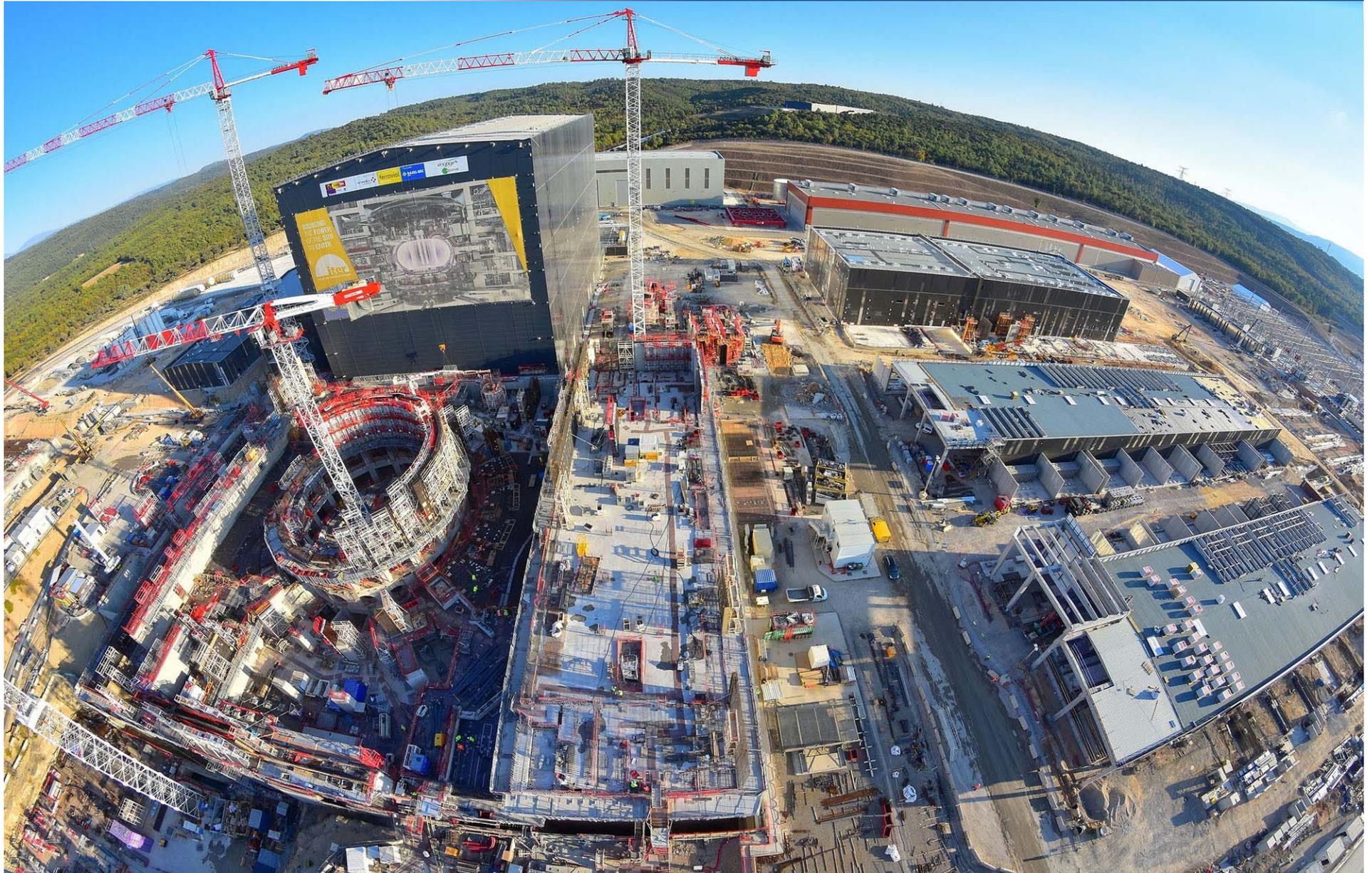




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# ITER Organization announced 50% completion to First Plasma in December 2017



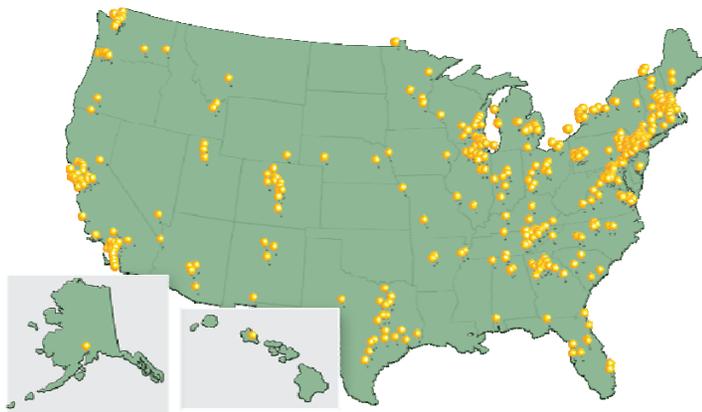


## >80% of fabrication awards for U.S. ITER project remain in the U.S.

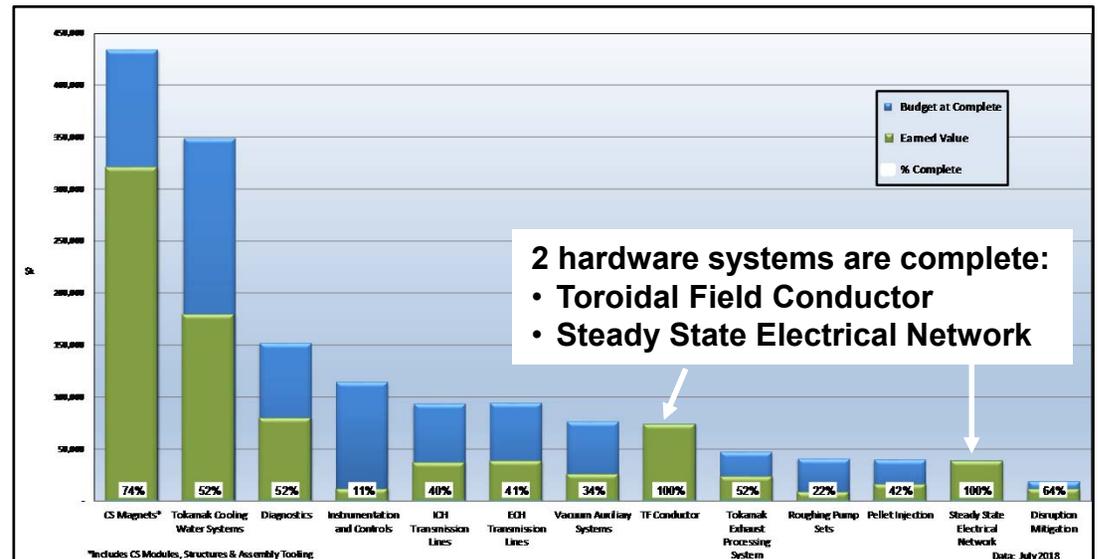
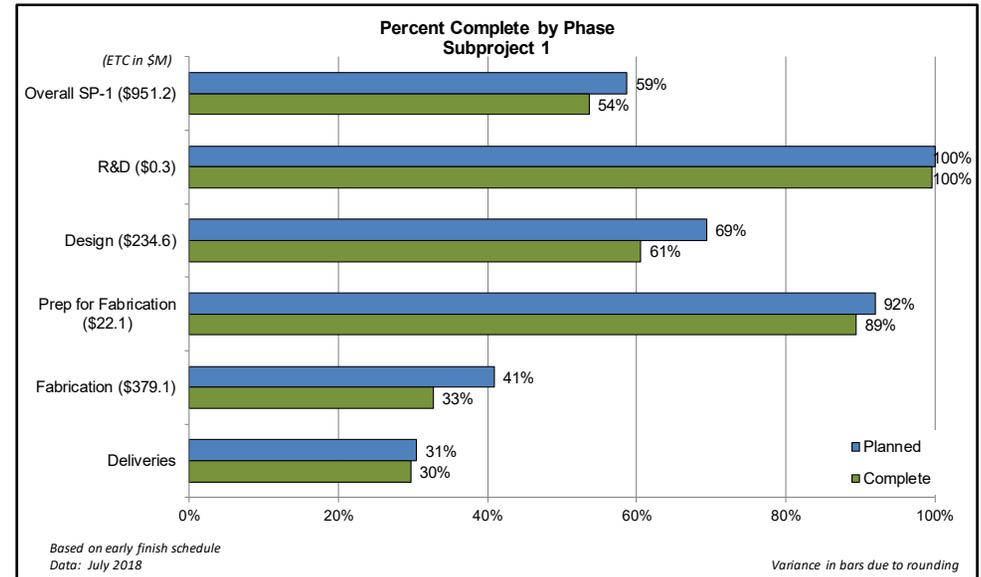
- 600+ contracts to U.S. industry, universities, and national laboratories in 44 states
- 500+ direct jobs, 1100+ indirect jobs per year

**US ITER Subproject-1 (First Plasma) is 54% complete**

### Industry, University and National Laboratory Participants

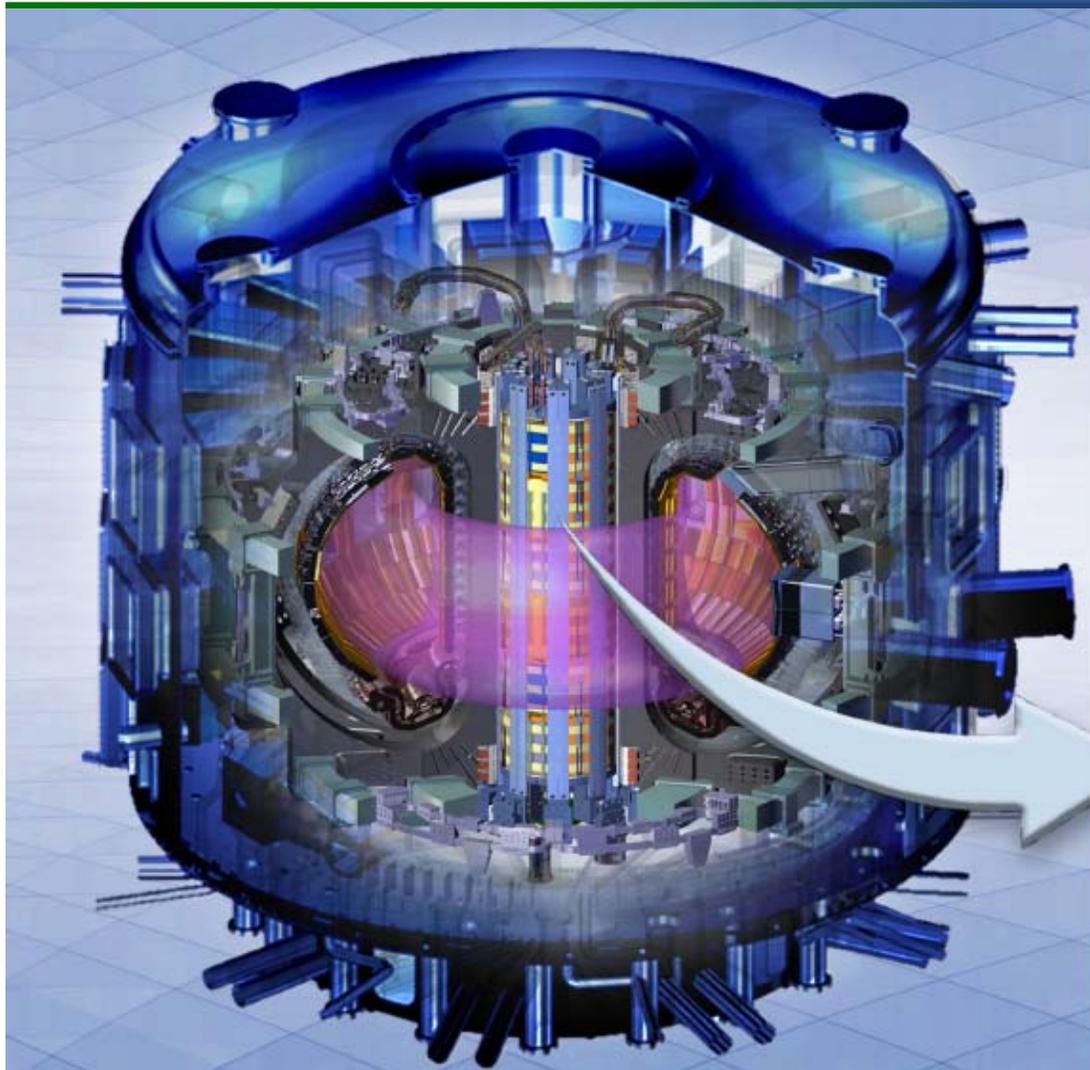


**Total Awards: ~\$1B (as of June 2018)**

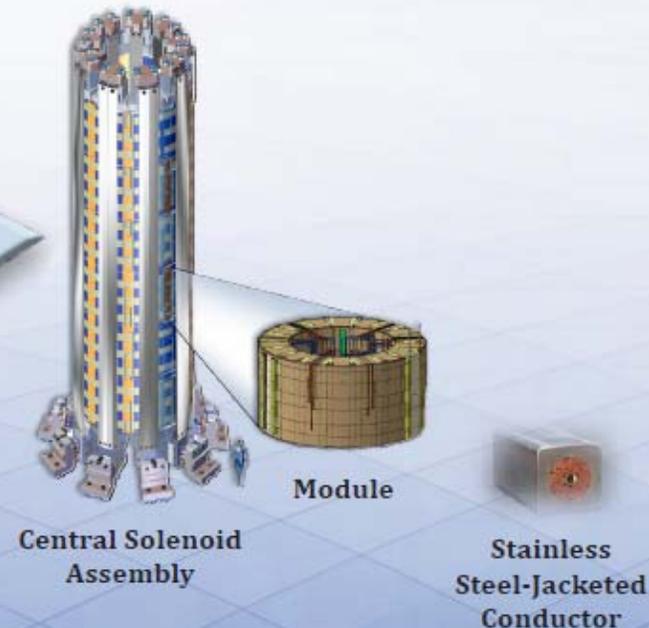




# ITER central solenoid will drive 15 MA of electrical current to heat plasma for 400 sec



- **Central solenoid assembly**
  - 6 modules, 1,000 ton
  - Height: 59 feet (17.7 meters) – 5 stories!
  - Diameter: 14.1 feet (4.3 meters)
  - Peak field strength: 13.1 Tesla
  - Stored energy capacity: 5.5 gigajoules
- **Each CS module**
  - 250,000 lbs (110-tonne)
  - Height: 7 feet (2.1 meters)
  - Diameter 14 feet (4.1 meters)
  - 3.6 miles (5.8 km) of steel-jacketed conductor
  - Conductor wound into 40 layers



ITER Central Solenoid will be world's largest superconducting electromagnet (millimeter precision)



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## **What is the role (perception? importance?) of plasmas at your agency as a whole?**

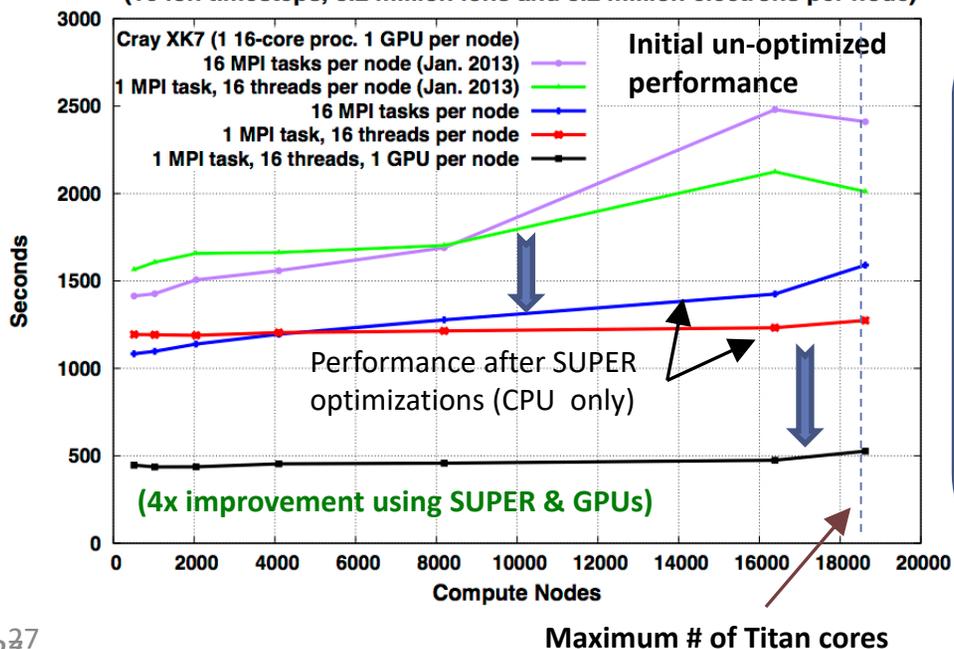
- **Strategic planning: Identifying and updating research opportunities**

# SciDAC program beneficially combines natural science and computer science

From the early days of the MFECC (predecessor to NERSC) to today's Leadership Computing Facilities, HPC has played a significant role in fusion research -- *essential component of the strategy to develop predictive capability*



**XGC1 Performance: Weak Particle Scaling on DIII-D grid**  
(10 ion timesteps, 3.2 million ions and 3.2 million electrons per node)



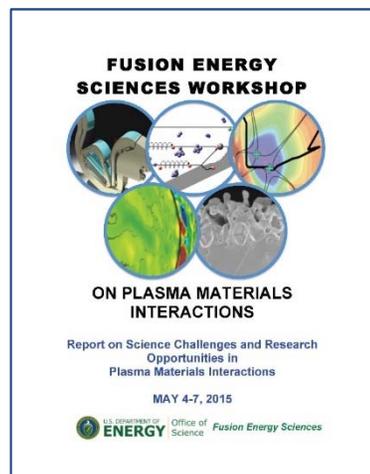
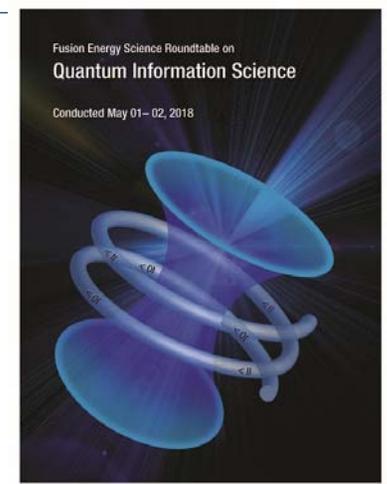
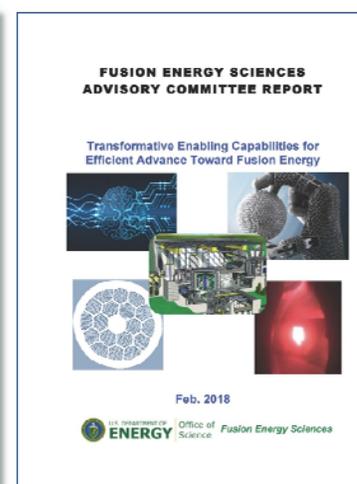
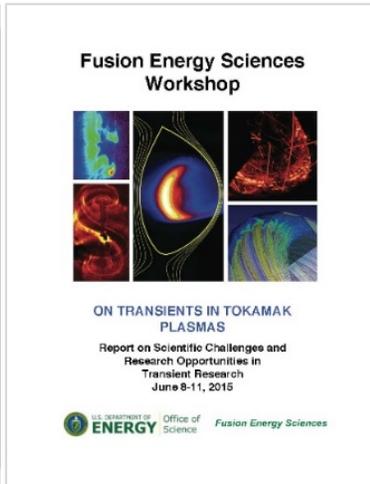
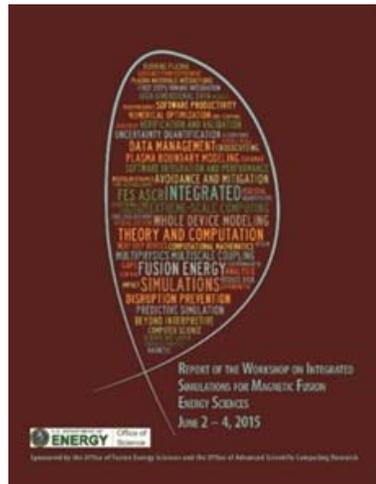
Partnerships between fusion scientists and computational scientists, under SciDAC, have accelerated the rate of scientific discovery in fusion plasma science by improving the performance of fusion codes on Leadership Computing Facilities and addressing challenging data management and visualization issues associated with high-performance computing.



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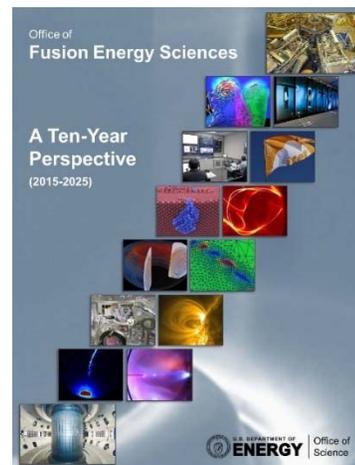
# Strategic choices are informed by community and Advisory Committee input



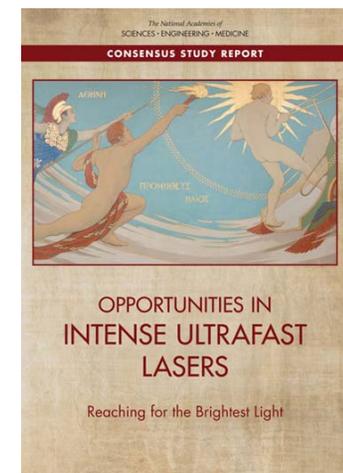
2016 FES Exascale Requirements

2018 FESAC Transformative Enabling Capabilities

2018 FES Roundtable on QIS



2015 FES 10-year Perspective



2017 FES NAS Report on Intense Ultrafast Lasers

2015 Community Workshops: Integrated Simulations, Transients, Plasma Materials Interactions, & Plasma Science Frontiers



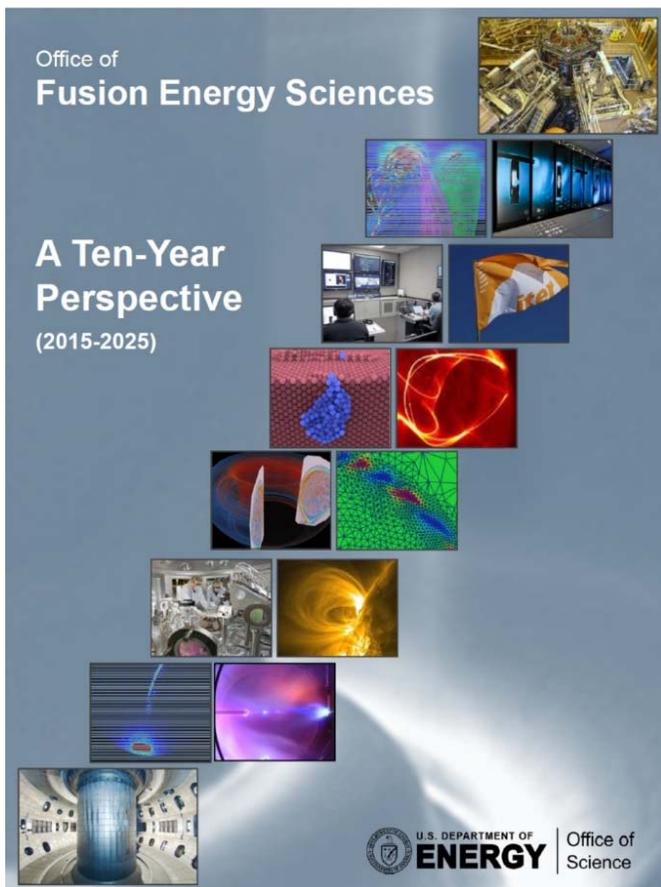
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## FES priorities are guided by its strategic Ten-Year Perspective

### Several critically important areas for the U.S. fusion energy sciences enterprise over the next decade

- **Massively parallel computing** with the goal of validated whole-fusion-device modeling
- **Materials science** for greatly improved plasma confinement and heat exhaust
- **Transient events**, predicted and controlled, for confidence in machine designs and operation with stable plasmas
- **Discovery in plasma science** to address frontier science issues of the visible universe and help attract a new generation of plasma/fusion scientists
- **FES user facilities** kept world-leading through operations support and regular upgrades
- **Leveraging resources** among agencies and institutions and strengthening partnerships with international research facilities



(Submitted to Congress in Dec 2015)



## 2016 FESAC report on “Non-Fusion-Energy Applications”



**National Security:** The Electromagnetic Aircraft Launch System, a spinoff from FES development of precision control of sequencing mag - nets, is now replacing the Navy’s steam catapults on air - craft carriers. USS Gerald Ford was the first carrier to use the Electromagnetic Aircraft Launch System. Electromagnetic Aircraft Launch Systems. *Photo courtesy of General Atomics.*



**Transportation:** Safer, more efficient jet engines have been created by spray coating their turbine blades with a ceramic powder that was injected into a flowing plasma jet. Plasma spray-coating improves jet engine turbine blade efficiency and safety. *Photo courtesy of JETPOWER.*



**Basic Materials Science:** FES researchers have created dusty plasmas to generate nucleation ‘factories’ for the production of nanoparticles and nanocrystals developed for efficient solar cells and fuel cells. DOE Basic Energy Sciences Energy Frontier Research Centers. *Photo courtesy of Los Alamos National Lab with the University of Minnesota.*



**Medical/Health:** Atmospheric and non-neutral plasma physics as well as FES technology spinoffs have enabled a wide range of new medical procedures ranging from plasma surgery to non-invasive imaging to cancer therapy. Plasma tissue welding. *Photo courtesy of Ion Med Ltd.*

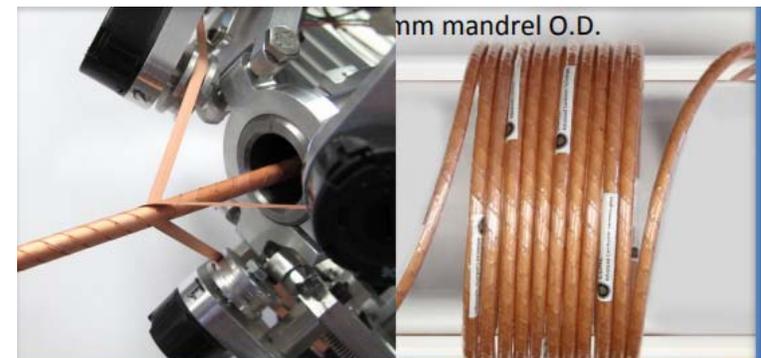
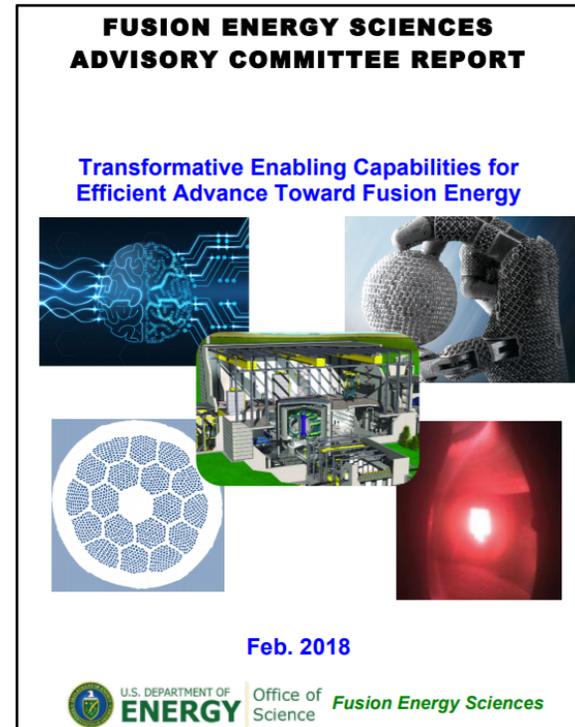
The final edited version is available online:

([https://science.energy.gov/~media/fes/fesac/pdf/2015/2101507/FINAL\\_FES\\_NonFusionAppReport\\_090215.pdf](https://science.energy.gov/~media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf))

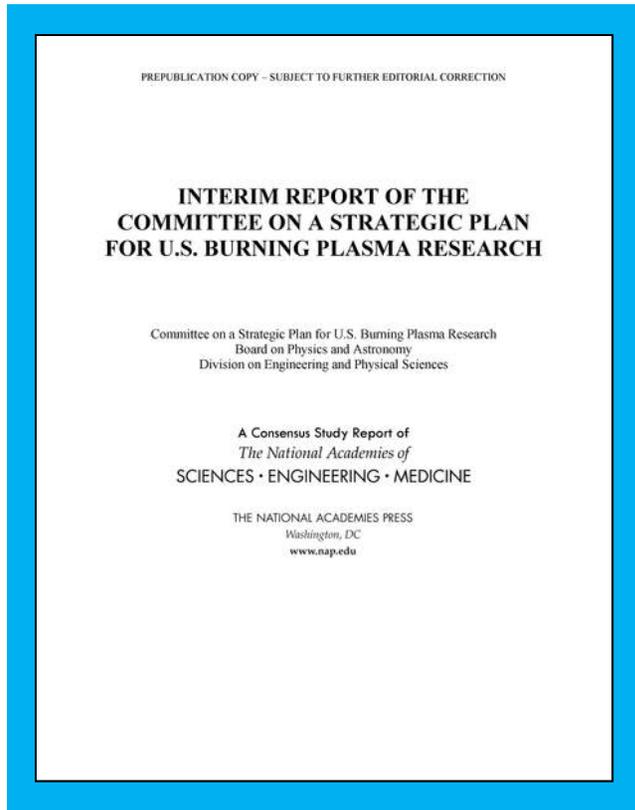


# 2018 FESAC report on “Transformative Enabling Capabilities toward Fusion Energy”

- FESAC was charged to identify the most promising transformative enabling capabilities (TECs) for the U.S. to pursue that could promote efficient advance towards fusion energy, building on burning plasma science and technology
- The FESAC report identified the following four first-tier (most promising) TECs:
  - Advanced algorithms
  - High critical-temperature superconductors
  - Advanced materials and manufacturing
  - Novel technologies in tritium fuel-cycle control
- Also one second-tier (promising) TEC:
  - Fast-flowing liquid-metal plasma-facing components
- FES and HEP have a high-temperature superconductor (HTS) collaborative research program



D. van der Laan, Advanced Conductor Technologies LLC



## US fusion community organized two workshops to provide input to the NAS panel

- Madison, WI—July 2017
- Austin, TX—December 2017

## Interim report (Dec 21, 2017) stated:

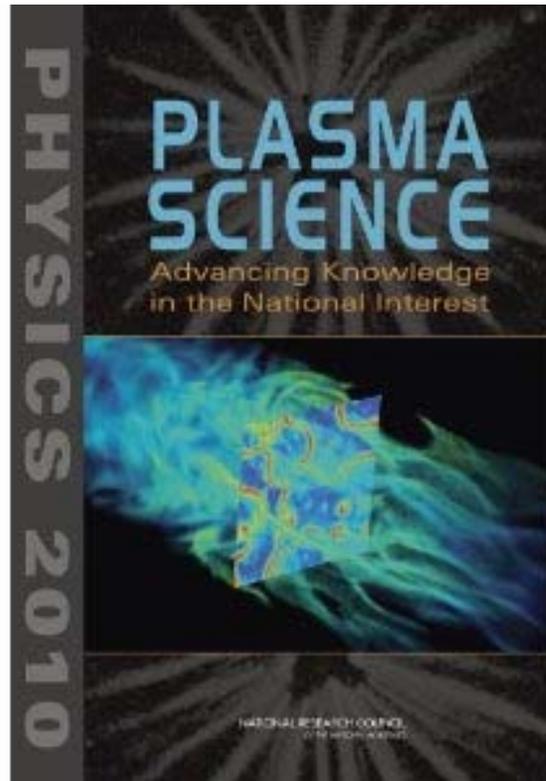
- Burning plasma research is essential to the development of magnetic fusion energy
- The U.S. has contributed leading advances in burning plasma science
- ITER is the only existing project to create burning plasma at reactor scale
- The U.S. should develop a national strategic plan leading to a fusion demonstration device

## Full report is expected by the end of 2018

- Charge question #4: *“In two separate scenarios in which, after 2018, (1) the United States is a partner in ITER, and (2) the United States is not a partner in ITER, provide guidance on a long-term strategic plan for a national program of burning plasma science and technology research which includes supporting capabilities and which may include participation in international activities, given the U.S. strategic interest in realizing economical fusion energy in the long term.”*



## Previous Decadal Survey



*2010 Plasma Decadal Survey*  
(Chair: Steve Cowley)

- **Has been launched**
  - Co-chairs: Mark Kushner (U. Michigan) & Gary Zank (U. Alabama-Huntsville)
  - First public meeting: Wash DC, Oct 15, 2018
- **Charge and Statement of Task**
  - Objective: conduct a study of the past progress and future promise of plasma science and technology and provide recommendations to balance the objectives of the field in a sustainable and healthy manner over the long term
- **Multiple federal sponsors**
  - DOE (FES, HEP, NNSA, ARPA-E)
  - NSF
  - DOD (AFOSR, ONR)
- **To be performed over 24 months**



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**You are at the nexus of plasmas inside the beltway hearing from both sides (the agencies and the researchers). In that role, what are your perspectives on the research issues that are dominating those discussions?**



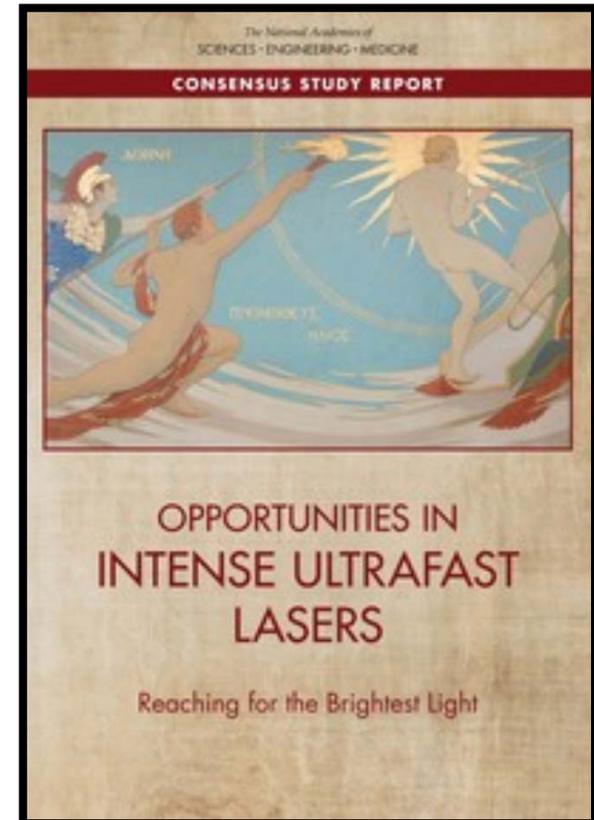
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# Opportunities in Intense Ultrafast Lasers Reaching for the Brightest Light

## Recommendation 1:

**The Department of Energy should create a broad national network, including universities, industry, and government laboratories**, in coordination with the Office of Science and Technology Policy, the research arms of the Department of Defense, National Science Foundation, and other federal research organizations, as the ***cornerstone of a national strategy to support science, applications, and technology of intense and ultrafast lasers***



The committee concluded that high-intensity lasers enable a significant and important body of science, which has a large and talented technical community already, but it is ***fragmented across different disciplines.***



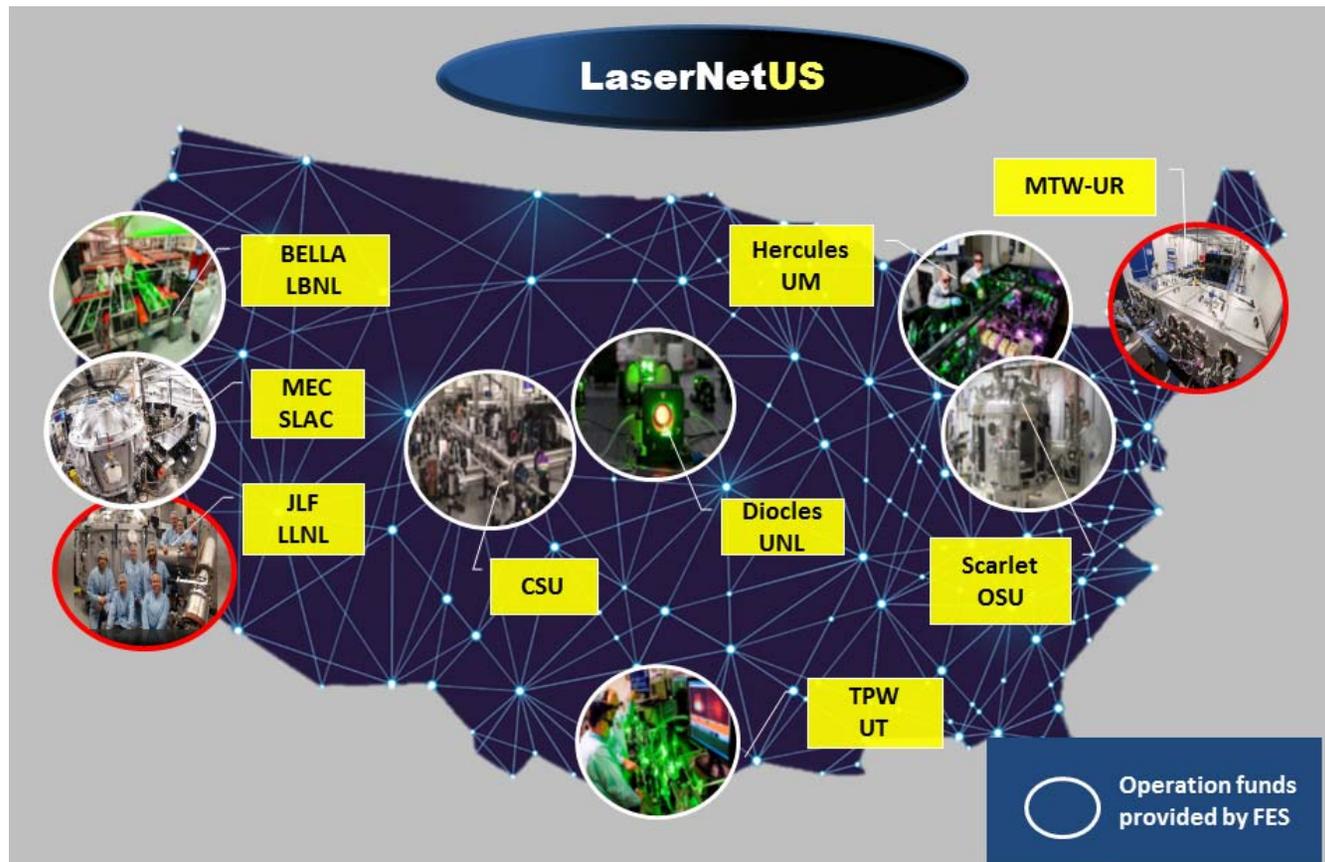
# World distribution of petawatt lasers



NAS report “... significant concentration in Europe. ....The United States is notably behind”



# FES recently launched LaserNetUS



- LaserNetUS is a new FES initiative funded at \$3.5M per year
- Nine mid-scale facilities (3 Nat. Labs and 6 Universities)
- Addresses the recent National Academy recommendation for a Network to coordinate high intensity laser research in the US



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**What are the perceptions, roles and opportunities for plasmas to be more impactful among the Federal agencies?**

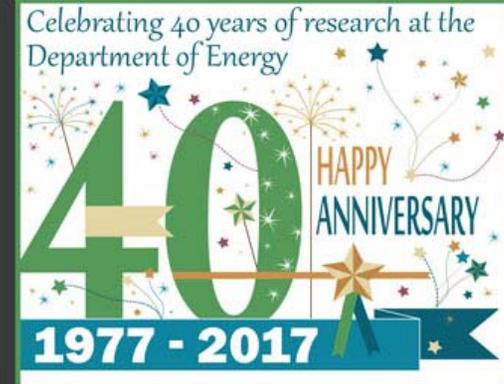
**How can the contributions of plasmas be better recognized and be better supported overall?**



# DOE 40<sup>th</sup> Anniversary

## THE OFFICE OF SCIENCE PRESENTS: Research milestones over the past 40 years

# 1977 - 2017



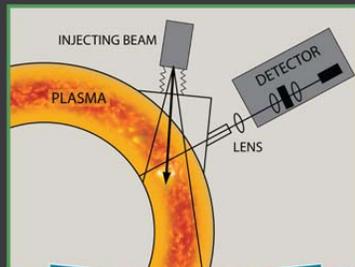
THE OFFICE OF SCIENCE PRESENTS:  
RESEARCH MILESTONES OVER THE PAST  
FORTY YEARS



DOE 40<sup>th</sup> Anniversary

Office of Science • RESEARCH MILESTONE • **1978**

N.J. Fisch, PRL 41(13), 873 (1978)  
Confining a tokamak plasma with rf-driven currents



DOE 40<sup>th</sup> Anniversary

Office of Science • RESEARCH MILESTONE • **1989**

F.M. Levinton et al., PRL 63, 2060 (1989)  
Magnetic field pitch-angle measurements in the PBX-M tokamak using the motional Stark effect



DOE 40<sup>th</sup> Anniversary

Office of Science • RESEARCH MILESTONE • **1990**

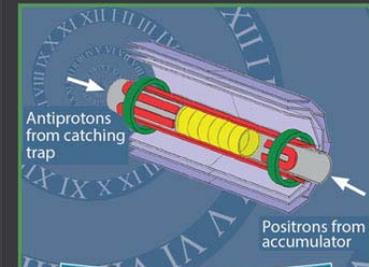
R.J. Groebner et al., PRL 64, 3015 (1990)  
Role of edge electric field and poloidal rotation in the L-H transition



DOE 40<sup>th</sup> Anniversary

Office of Science • RESEARCH MILESTONE • **1994**

J.D. Strachan et al., PRL 72, 3526 (1994)  
Fusion power production from TFTR plasmas fueled with deuterium and tritium



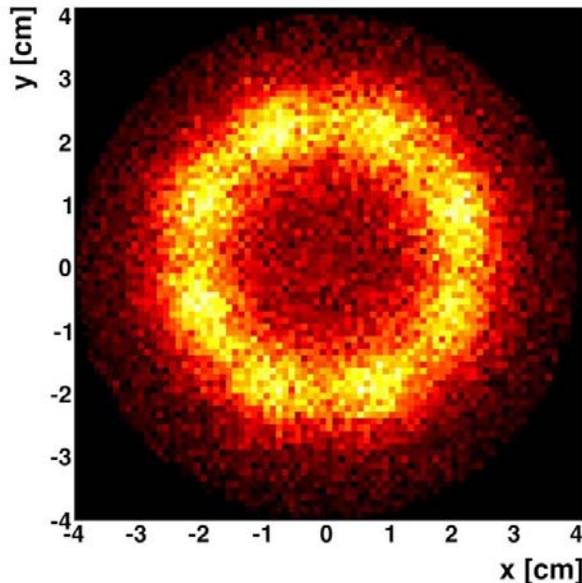
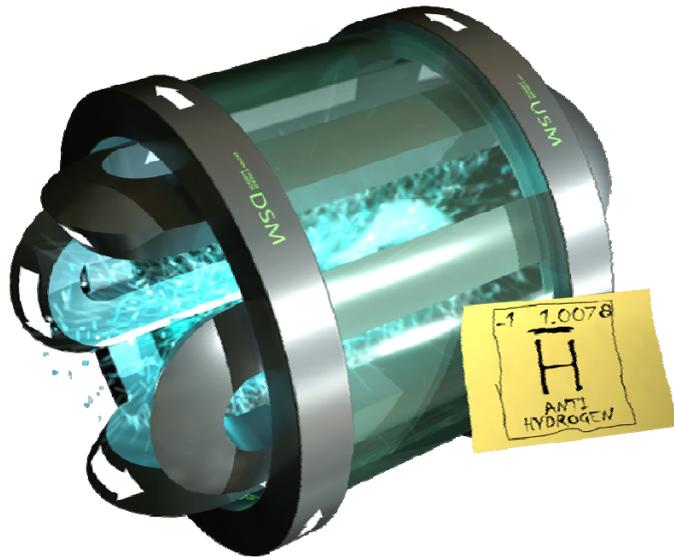
DOE 40<sup>th</sup> Anniversary

Office of Science • RESEARCH MILESTONE • **2010**

G.B. Andresen et al., Nature 468, 673 (2010)  
Trapped antihydrogen



# Advances in non-neutral plasma physics enable world-leading antimatter research



- The laws of physics predict equal amounts of matter and antimatter in the primordial universe—so why is there so little antimatter left in the present Universe?
- The Antihydrogen Laser Physics Apparatus (ALPHA) project, located at the European Organization for Nuclear Research (CERN), has been at the forefront of antimatter research. A U.S. research team led by the University of California, Berkeley has been participating in ALPHA.
- Enabled by plasma physics research, trapped antihydrogen atoms in ALPHA, made from non-neutral antiproton and positron plasmas, open the door for advanced measurements that can test critical antimatter properties and shed new light on this mystery.

## Recent advances:

- In 2010, scientists trapped 38 antihydrogen atoms for the first time.
- In 2017, scientists were able to greatly improve the trapping rate of antihydrogen atoms and make the first measurements of antihydrogen spectrum.



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**What was the impact of the Plasma 2010 report at your agency? In hindsight, what was missing from that report?**



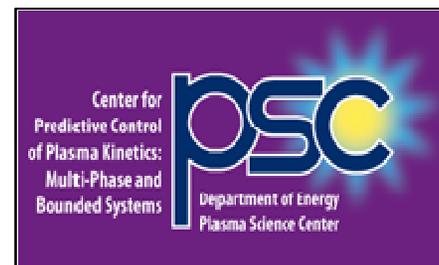
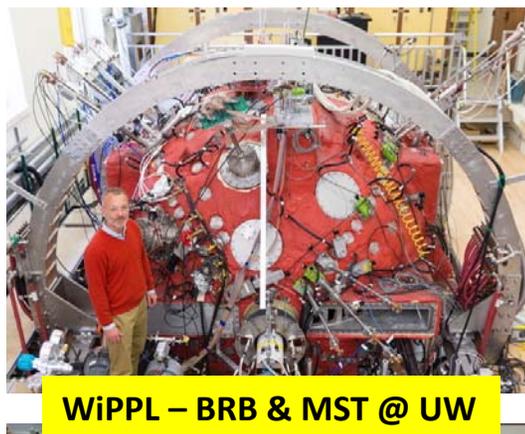
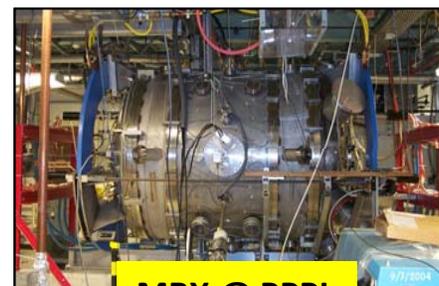
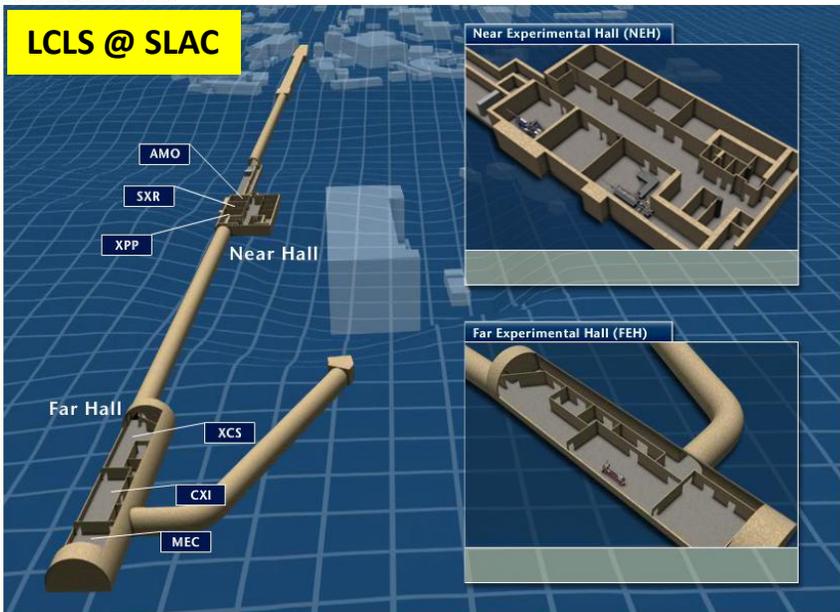
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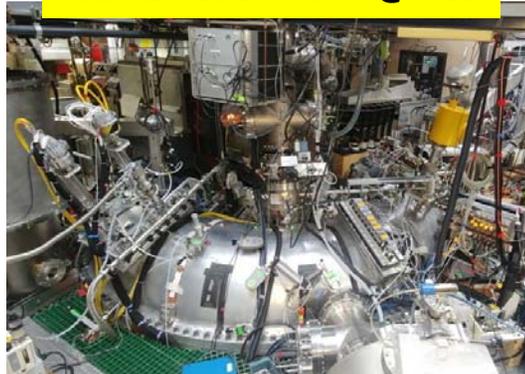
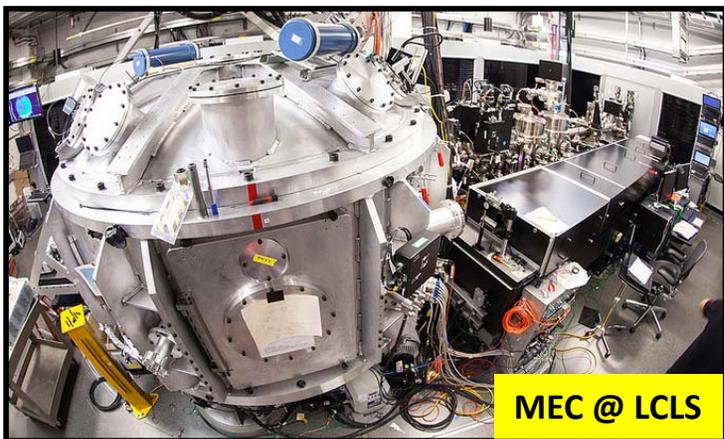
# FES supports a broad program to advance the frontiers of plasma science

## INSTRUMENT MAP

A suite of X-ray instruments for exploiting the unique scientific capability of the LCLS will be built at SLAC. Four instruments will be designed and built by the LUSI group. Each instrument will have unique capabilities, creating a diverse experimental landscape of probing ultrafast dynamics.



**Low Temperature Plasma Science Center**

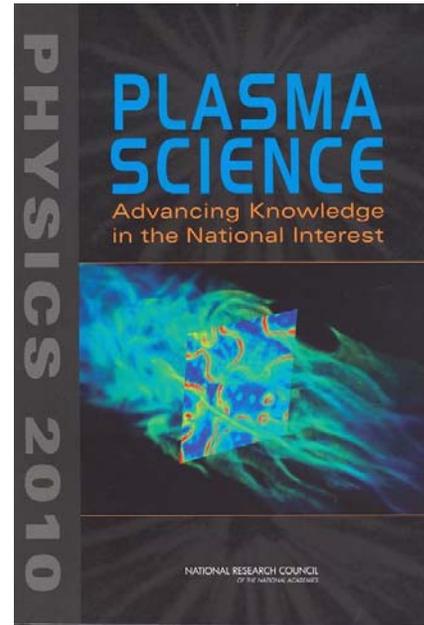
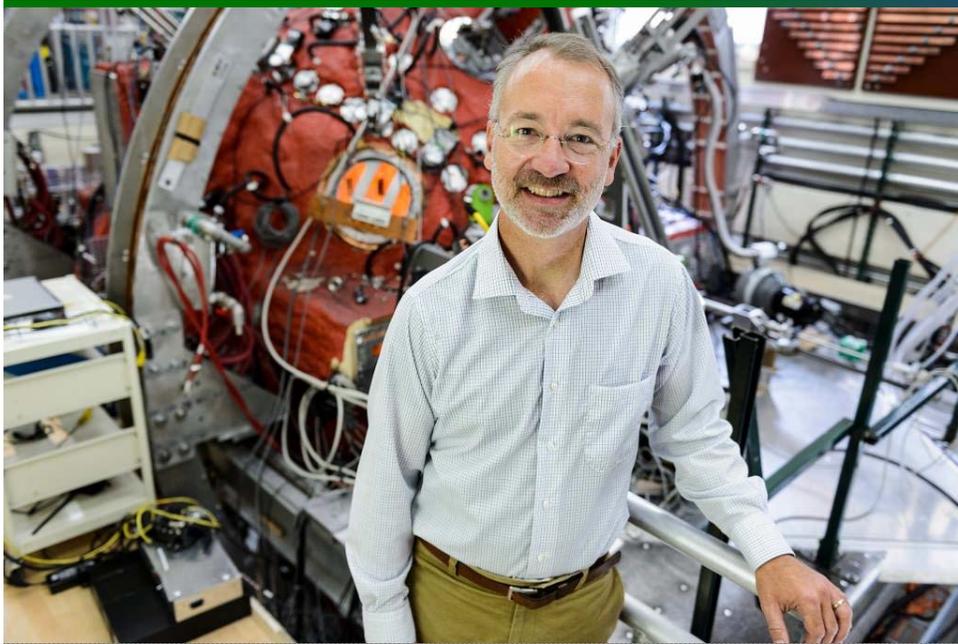




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# A new intermediate-scale facility for basic plasma science of magnetic field reconnection



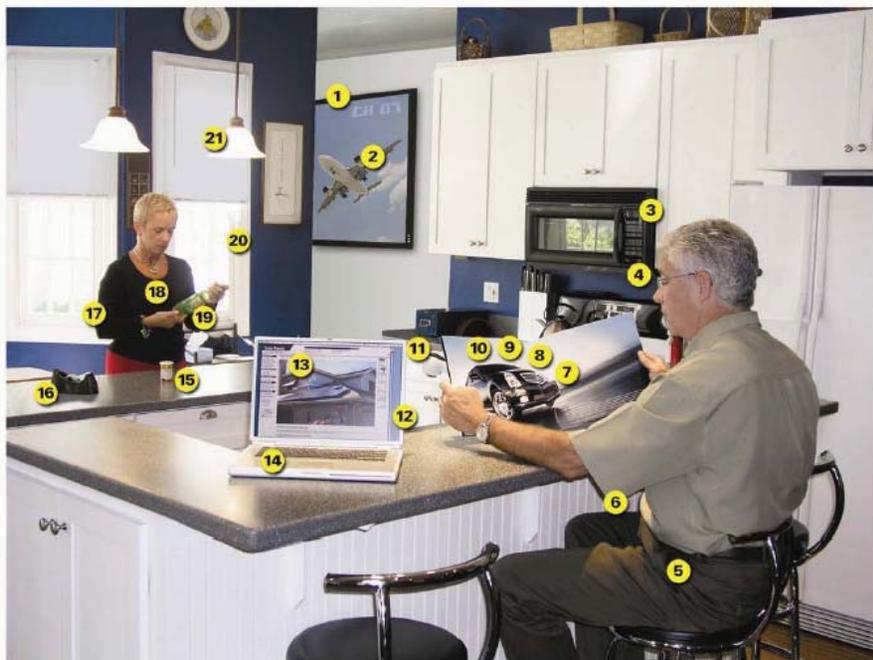
In FY 2017, the DOE Office of Fusion Energy Sciences awarded \$12.5 million funding over five years to the University of Wisconsin–Madison to develop an intermediate-scale, integrated, collaborative plasma science user facility that will expand the frontiers of plasma astrophysics. Two existing experiments, the Big Red Plasma Ball and the Madison Symmetric Torus, are combined into the new Wisconsin Plasma Physics Laboratory (WiPP). The new project will join the expertise of more than two dozen UW–Madison scientists and technicians with outside plasma scientists, who will gain access to the facility and establish new collaborations.

“Several areas of basic plasma science would benefit from new intermediate-scale facilities.” (2010 NAS Plasma Decadal Study)

“There is a need for creation and exploration of new regimes in the laboratory.” (2016 PSF Workshop Report)



# Low-temperature plasma science



01—Plasma TV

02—Plasma-coated jet turbine blades

03—Plasma-manufactured LEDs in panel

04—Diamondlike plasma CVD  
eyeglass coating

05—Plasma ion-implanted artificial hip

06—Plasma laser-cut cloth

07—Plasma HID headlamps

08—Plasma-produced H<sub>2</sub> in fuel cell

09—Plasma-aided combustion

10—Plasma muffer

11—Plasma ozone water purification

12—Plasma-deposited LCD screen

13—Plasma-deposited silicon for  
solar cells

14—Plasma-processed microelectronics

15—Plasma-sterilization in  
pharmaceutical production

16—Plasma-treated polymers

17—Plasma-treated textiles

18—Plasma-treated heart stent

19—Plasma-deposited diffusion barriers  
for containers

20—Plasma-sputtered window glazing

21—Compact fluorescent plasma lamp

The multi-institutional **Center for Predictive Control of Plasma Kinetics: Multi-phase and Bounded Systems** is funded by FES. The Center is enabling fundamental research on low-temperature plasmas — ionized gases with vast potential for practical technological advancements. In particular, the Center will investigate techniques to customize the distributions of charged particles (electrons and ions) in these plasmas. A vast array of modern technologies, including renewable energy sources, lighting, **microelectronics**, and medicine, would not exist in the absence of low-temperature plasmas. The fundamental research that is being conducted at the Center could lead to more efficient solar cells, finer-featured microchips and new medical tools that cut and heal tissues with plasma-activated chemistry.

University of Michigan

**From the *Plasma 2010 Decadal Study of the National Academies*:** “To fully realize the opportunities in plasma research, a unified approach is required. Therefore, the Department of Energy’s Office of Science should reorient its research programs to incorporate magnetic and inertial fusion energy sciences, basic plasma science, non-mission-driven high-energy density plasma science, and low-temperature plasma science and engineering.”



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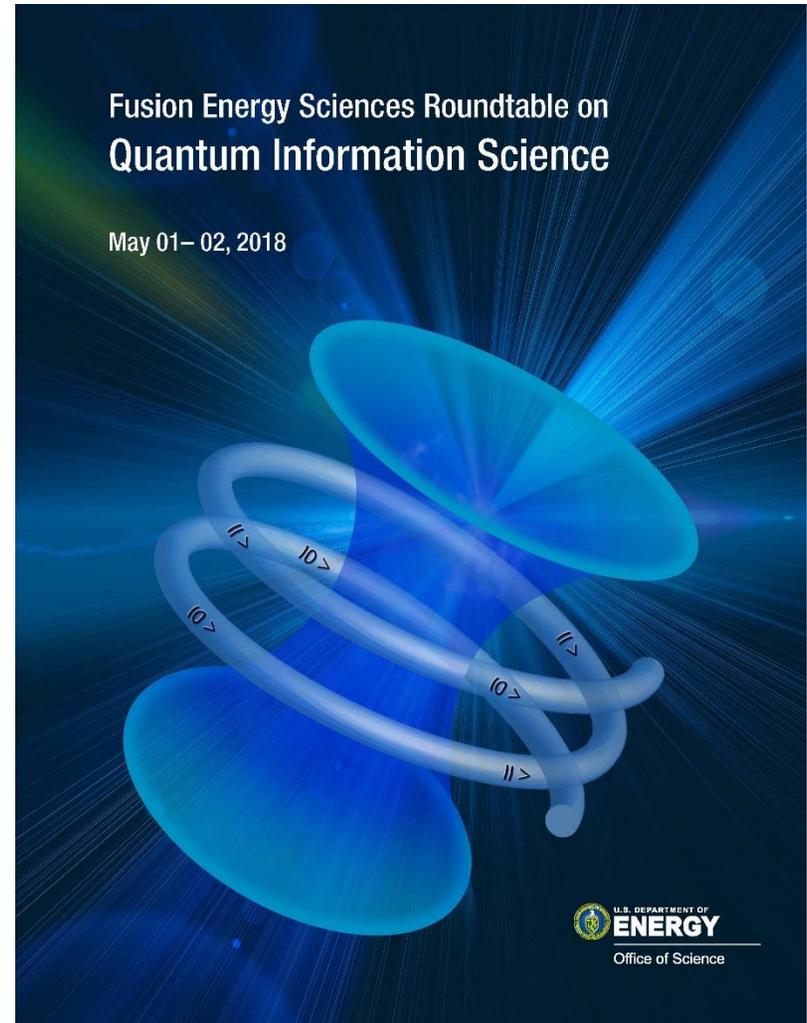
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**If the 2020 report was being written only by your agency, what topics, areas, themes would you like to see emphasized?**



- **Strengthened core program**
  - DIII-D research/ops; NSTX-U recovery; ITER
  - Theory & simulation
  - U.S. research on overseas facilities
  - Fusion materials & nuclear science
  - General plasma science; high energy density plasmas
- **New/accelerated thrusts**
  - Quantum information science
  - Machine learning (AI)
  - Partnerships with private-sector fusion companies
  - Laser facility upgrades to remain world leading
  - World-class materials testing capability
  - High- $T_c$  superconductor research
  - Low-temperature plasmas for microelectronics
  - Fusion prototypic neutron source

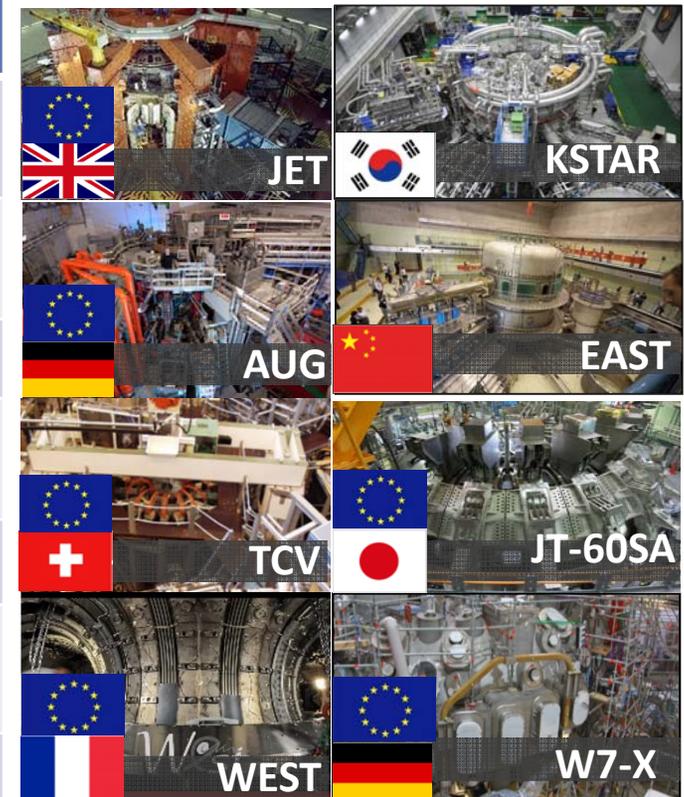
- **QIS**—which includes quantum science and instrumentation for next-generation computing, information, and other fields—has been identified as an important cross-cutting topic with potential impact across all SC program offices
- In 2018, FES explored its role in QIS, joining the other SC programs
- FES Roundtable meeting was held May 1-2:
  - To identify fundamental science supported by FES that could advance QIS development
  - Explore QIS applications that could have a transformative impact on FES mission areas, including fusion and discovery plasma science
- The recent Roundtable report described priority research opportunities



## International collaborative research

Multi-institutional teams of U.S. scientists and students are leveraging U.S. capabilities to lead research overseas on unique facilities

Facility	Research Area	Institutions
EAST KSTAR	Control of long pulse tokamak scenarios	GA, Lehigh, LLNL, MIT, ORNL, PPPL, UCLA, & U Texas-Austin
EAST	Control of plasma-material interactions	PPPL, JHU, LANL, MIT, ORNL, U Tennessee, & UIUC
KSTAR	Disruption physics	Columbia, MIT, PPPL
W7-X	3D, steady-state stellarators	PPPL, ORNL, Auburn, LANL, MIT, Wisconsin, Xantho Tech.
JT-60SA	Energetic ion physics	GA, UC-Irvine
JET, AUG TCV	Research in support of burning plasma physics	ORNL, PPPL, GA, MIT, UCSD, Wisconsin, U Texas-Austin
WEST	Plasma-facing components and diagnostics testbed	ORNL, MIT



*International Collaboration in FES  
Research (FESAC report 2012)*



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# U.S. remote control rooms enhance utilization of international & domestic research facilities



**MIT**

**PPPL**

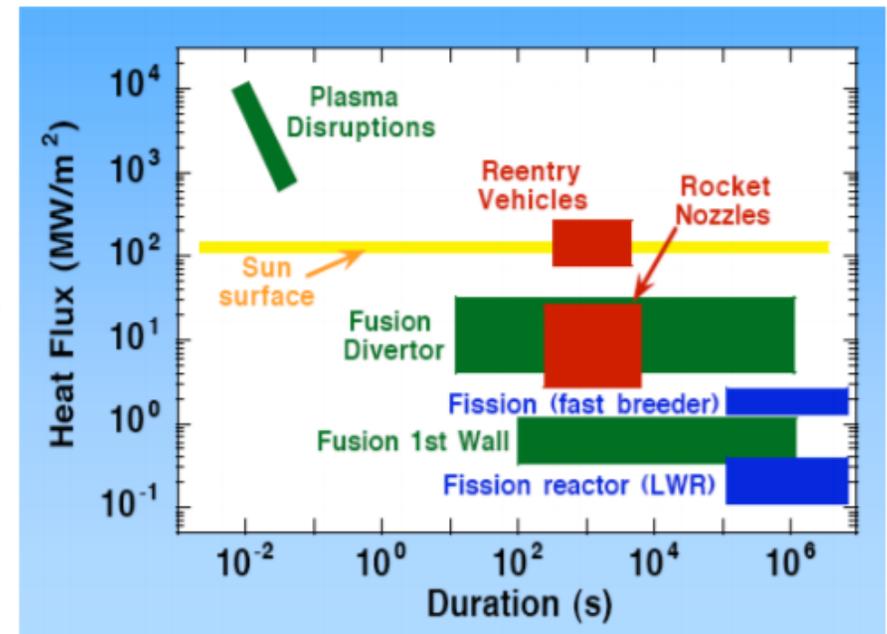
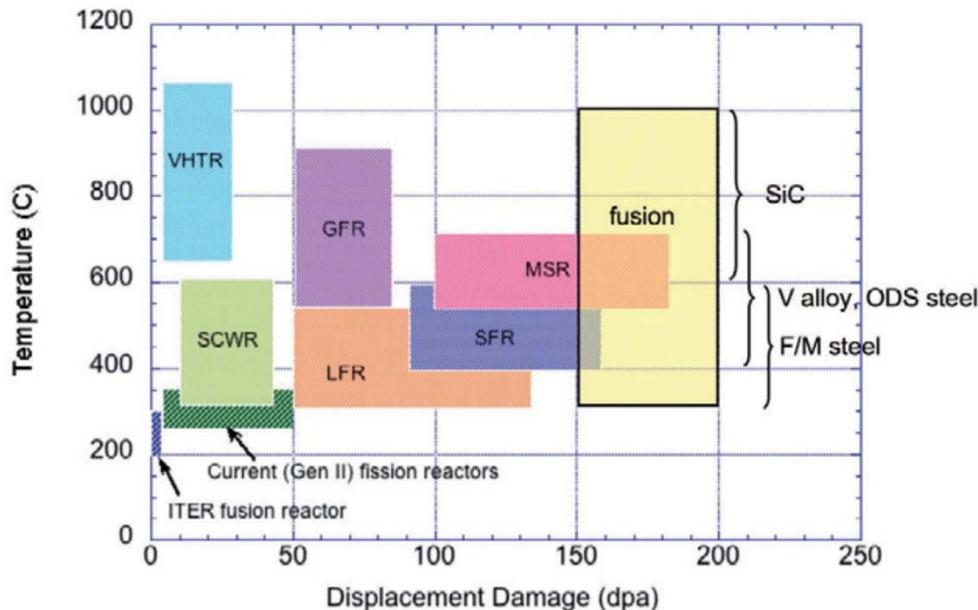
**GA**

- U.S. teams at **GA** completed a week of experiments in FY 2017 during EAST third shift and can lead experiments at KSTAR
- **PPPL** and collaborators can lead experiments on KSTAR & connect to W7-X, DIII-D
- Remote control room at **MIT** is being designed, with assembly to commence in Spring FY 2018



# Significant scientific and technical challenges for fusion materials

- Fusion reactors present a uniquely hostile environment that includes combinations of high temperatures, reactive chemicals, large time-dependent thermal-mechanical stresses, and intense damaging radiation (especially 14 MeV neutrons)
- Developing materials and components that not only survive the extreme fusion environment but also meet objectives for performance, safety, and environmental attractiveness is an unprecedented challenge

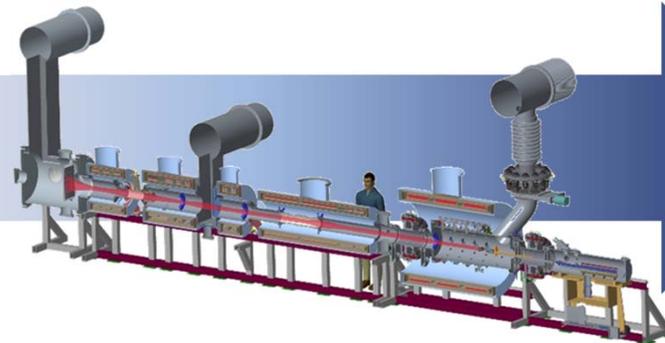


*Materials Science and Technology Research Opportunities Now and in the ITER Era (FESAC report, 2012)*

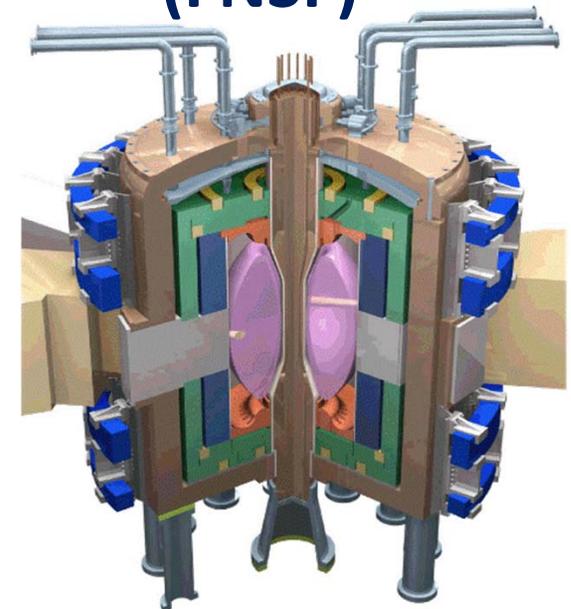


## Plasma Material Interactions

Currently addressing with the MPEX MIE Project at ORNL

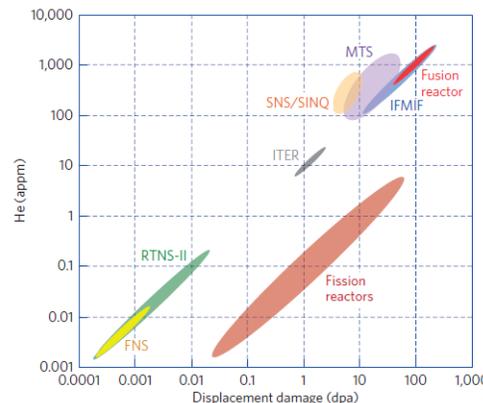


## Fusion Nuclear Science Facility (FNSF)



## Nuclear Degradation of Materials

Unresolved need for a fusion neutron source (most likely: accelerator based source)



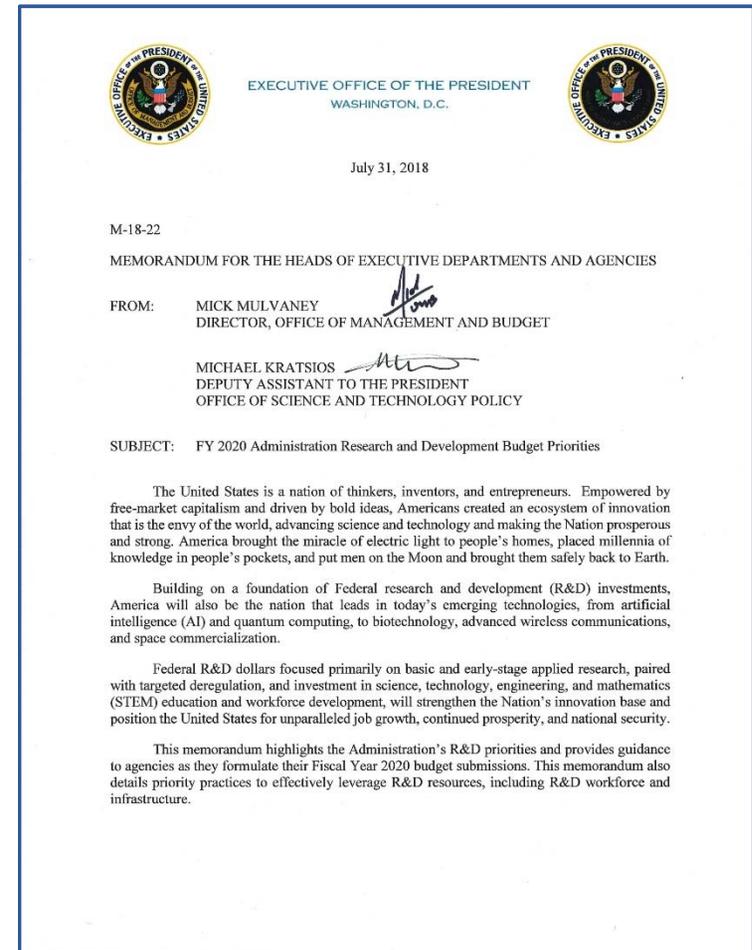
**Fusion neutron source:** allows material sample exposure to high dose neutron irradiations

**FNSF:** Fully integrated next-step facility with fusion neutron flux & plasma exposure



# FES program addresses several Administration R&D priorities and practices

- **American Leadership in emerging technologies:** FES investments in transformational technologies such as machine learning, quantum information science (QIS), microelectronics, and high-performance computing will accelerate progress in several mission areas
- **American Energy Dominance:** Research in fusion could contribute to American energy dominance by making available to the American people a robust base-load electricity clean energy technology that relies on widely available and virtually inexhaustible fuel sources
- **Managing and Modernizing R&D Infrastructure:** Investments in our major fusion facilities and smaller-scale experiments will maintain and modernize our research infrastructure for continuing to conduct world-leading research
- **Maximizing Agency Coordination :** Established partnerships within DOE (ASCR, BES, NNSA) and outside (NSF) maximize leverage and increase the cost effectiveness of FES research activities
- **Partnering with Industry:** Public-private collaborations will leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology).
- **Technology Transfer:** Research on high-temperature superconductors, additive manufacturing, low-temperature plasmas, and high-energy-density plasmas lead to connections with and spinoffs for U.S. industry.
- **Workforce Training & Education:** The unique scientific challenges and rigor of fusion and plasma physics research contribute to the development of a well-trained STEM-focused workforce, which will contribute to maintaining and advancing U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security



July 31, 2018 OMB memo on the FY 2020 Administration R&D priorities

**Links for more information:**

<http://science.energy.gov/fes/>

<https://burningplasma.org>

**Contact:**

[james.vandam@science.doe.gov](mailto:james.vandam@science.doe.gov)



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