

# Fusion Energy Sciences Perspective

**James W. Van Dam**  
Associate Director  
Office of Science  
Fusion Energy Sciences



U.S. DEPARTMENT OF  
**ENERGY**

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Office of Science

Fusion Energy Sciences Advisory Committee Meeting  
March 16, 2020



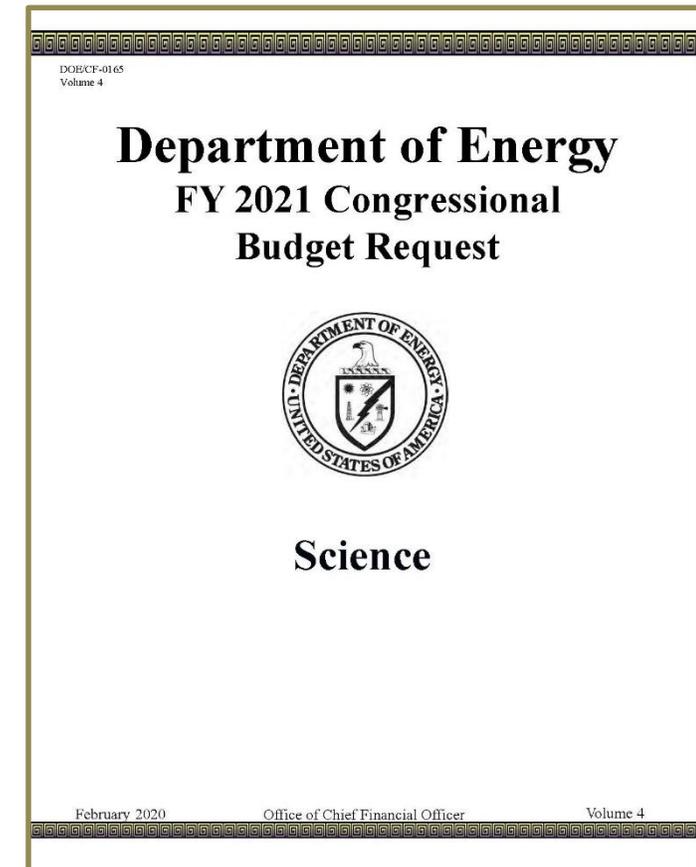
# ***1. Budget Updates***

# Robust FY 2019 and FY 2020 enacted budgets

## Enacted FES appropriations for FY 2019 (\$564M) and FY 2020 (\$671M) enable accelerated progress throughout the program:

- **U.S. Contributions to ITER:** Testing of the first superconducting central solenoid magnet module was completed. Cash contributions were allocated for FY 2019 and FY 2020. Fabrication of the remaining six modules and other U.S. in-kind hardware will continue in FY 2020.
- **DIII-D:** In FY 2019, DIII-D operated for 12 run weeks following completion of the Long Torus Opening. The world's first toroidally steerable, off-axis neutral beam injector was installed on schedule and successfully operated. In FY 2020, during 20-run-week operation, DIII-D research will utilize the new neutral beam and other heating and current drive systems to investigate steady-state plasma scenarios.
- **NSTX-U:** In FY 2019, the Recovery project successfully achieved SC approval of its baseline cost and schedule, and authorization of long-lead procurements. In FY 2020, Recovery is making strong progress, including completion of all final design reviews and fabrication/testing of at least four (of six) poloidal field replacement coils.
- **Materials Plasma Exposure eXperiment (MPEX):** This MIE project completed preliminary design and attained Critical Decision-1 approval in FY 2020. Engineering design activities will continue, with preparation for baseline approval and long-lead procurements.
- **Matter in Extreme Conditions (MEC):** The Petawatt Upgrade achieved approval of its Mission Need (CD-0) in FY 2019. Engineering design activities are continuing for the achievement of Critical Decision-1 approval .
- **Quantum Information Science:** FES made six awards with its first-ever solicitation in FY 2019 and issued another FOA in FY 2020.
- **International collaborations:** The portfolio was re-competed in FY 2019; ten multi-institutional awards were made for collaborative research on long and short pulse tokamak facilities in Asia and the EU. Stellarator research in Germany and Japan continued.
- **Private-public partnerships:** In FY 2019, FES established the Innovation Network for Fusion Energy (INFUSE) program and made twelve awards to six private companies. Another Request for Assistance was published in FY 2020, with expanded eligibility.
- **Artificial Intelligence & Machine Learning:** FES held a workshop in FY 2019, jointly with ASCR, to identify priority research opportunities. A follow-up solicitation has been issued in FY 2020 to competitively select awards in this area.

- The Administration's Budget Request to Congress for FY 2021 was released on February 10
- It marks the first step in an iterative process between the Executive and Legislative branches of the U.S. Government
- The Budget Request for FES is \$425,151,000, which is ~\$246M less than the FY 2020 enacted budget
- It includes \$107M for the U.S. Contributions to ITER project



[https://science.osti.gov/-/media/budget/pdf/sc-budget-request-to-congress/fy-2021/FY\\_2021\\_DOE-Congressional-Budget-justificatiom.pdf](https://science.osti.gov/-/media/budget/pdf/sc-budget-request-to-congress/fy-2021/FY_2021_DOE-Congressional-Budget-justificatiom.pdf)



## ***2. Programmatic Updates***



# Funding Opportunity Announcements & awards

Healthy budgets enabled multiple FOAs and awards across the program

***Getting the word out on FOAs and Awards***

<https://www.energy.gov/science/office-science>

Office of Science

**Department of Energy to Provide \$5 Million for Research on High Energy Density Plasmas**

JANUARY 17, 2020

Office of Science

**Department of Energy Announces Private-Public Awards to Advance Fusion Energy Technology**

OCTOBER 15, 2019

Department of Energy

**Department of Energy Announces \$50 Million for Fusion Energy R&D**

FEBRUARY 13, 2020

Office of Science

**Department of Energy Announces Early Career Research Program for FY 2020**

NOVEMBER 26, 2019

Department of Energy

**Department of Energy Announces \$30 Million for New Research on Fusion Energy**

MARCH 4, 2020

Office of Science

**Department of Energy Announces \$3 Million for Fusion Diagnostics**

MARCH 11, 2020



# Status of Funding Opportunity Announcements

FOA Title	Companion Lab Call	Status
Collaborative NSTX-U Diagnostics	No	Issued; pre-apps received
Collaborative Research on International and Domestic Spherical Tokamaks	No	Issued; pre-apps received
High-Energy-Density Laboratory Plasma Science	No	Issued; due 3/16 ( <b>now 4/6</b> )
Scientific Machine Learning and Artificial Intelligence for Fusion Energy Sciences	Yes	Issued; LOIs due on 3/30
Measurement Innovations for Magnetic Fusion Systems	Yes	Issued; LOIs due on 3/20
Opportunities in Frontier Plasma Science	Yes	Issued; LOIs due on 4/6
Quantum Information Science Research for Fusion Energy Sciences	Yes	Submitted
Theoretical Research in Magnetic Fusion Energy Science	No	Issued; LOIs due on 3/27
Early Career Research Program	Yes	Issued; due 3/16 ( <b>now 3/30</b> )
Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (ARPA-E / FES; led by ARPA-E)	N/A	Issued; Concept Papers due 3/27

Check <https://science.osti.gov/fes/Funding-Opportunities> for updates

## • Advanced Research Projects Agency–Energy

- A joint FES and ARPA-E funding opportunity has been announced focused on a range of enabling technologies required for commercially attractive fusion energy
- The program, called **Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts (GAMOW)**, will prioritize R&D particularly in:
  - All the required technologies and subsystems between the fusion plasma and the balance of plant
  - Cost-effective, high-efficiency, high-duty-cycle driver technologies; and
  - Important cross-cutting areas such as novel fusion materials and advanced and additive manufacturing
- GAMOW follows the ALPHA and BETHE solicitations focused on fusion energy that were issued by ARPA-E alone



ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)  
OFFICE OF SCIENCE- FUSION ENERGY SCIENCES (SC-FES)  
U.S. DEPARTMENT OF ENERGY

**GALVANIZING ADVANCES IN MARKET-ALIGNED FUSION FOR AN OVERABUNDANCE OF WATTS (GAMOW): ENABLING TECHNOLOGIES FOR COMMERCIALY ATTRACTIVE FUSION ENERGY**

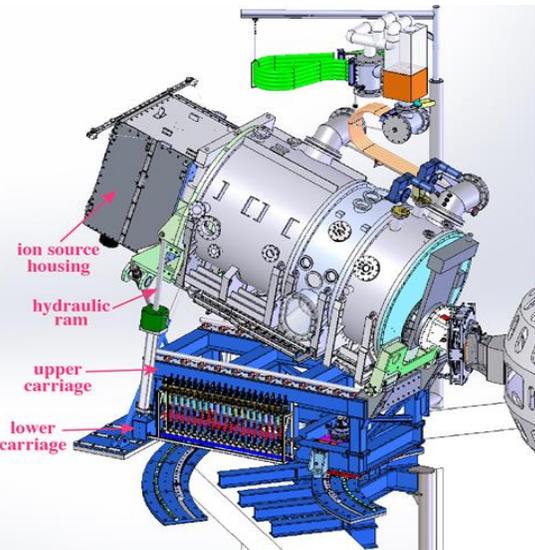
Announcement Type: Initial Announcement  
Funding Opportunity No. DE-FOA- 0002288  
CFDA Number 81.135

<b>Funding Opportunity Announcement (FOA) Issue Date:</b>	Thursday, February 13, 2020
<b>First Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a>:</b>	5 PM ET, Tuesday, March 17, 2020
<b>Submission Deadline for Concept Papers:</b>	9:30 AM ET, Friday, March 27, 2020
<b>Second Deadline for Questions to <a href="mailto:ARPA-E-CO@hq.doe.gov">ARPA-E-CO@hq.doe.gov</a>:</b>	5 PM ET, TBD
<b>Submission Deadline for Full Applications:</b>	9:30 AM ET, TBD
<b>Submission Deadline for Replies to Reviewer Comments:</b>	5 PM ET, TBD
<b>Expected Date for Selection Notifications:</b>	TBD
<b>Total Amount to Be Awarded</b>	Approximately \$30 Million, subject to the availability of appropriated funds.
<b>Anticipated Awards</b>	ARPA-E / SC-FES may issue one, multiple, or no awards under this FOA. Awards may vary between \$250,000 and \$7.5 million (federal share).

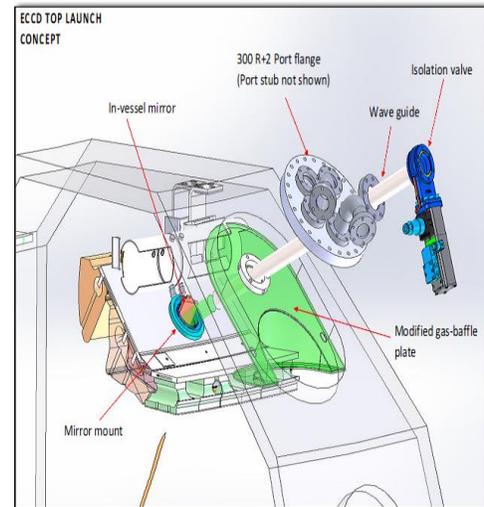
- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (<https://arpa-e-foa.energy.gov/Registration.aspx>). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at <http://arpa-e.energy.gov/faq>. For questions that have not already been answered, email [ARPA-E-CO@hq.doe.gov](mailto:ARPA-E-CO@hq.doe.gov) (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email [ExchangeHelp@hq.doe.gov](mailto:ExchangeHelp@hq.doe.gov) (with FOA name and number in subject line).

# DIII-D is pursuing several heating & current drive upgrades to develop AT scenarios at higher density



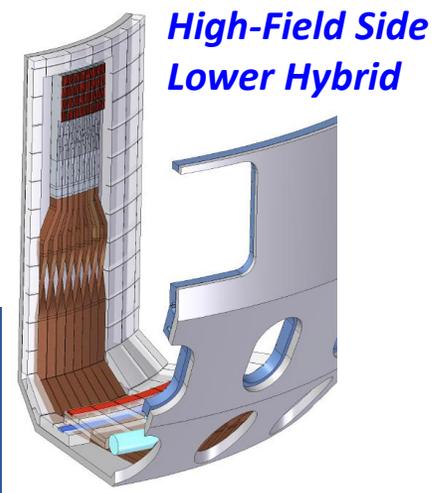
*Co/counter off-axis neutral beam*



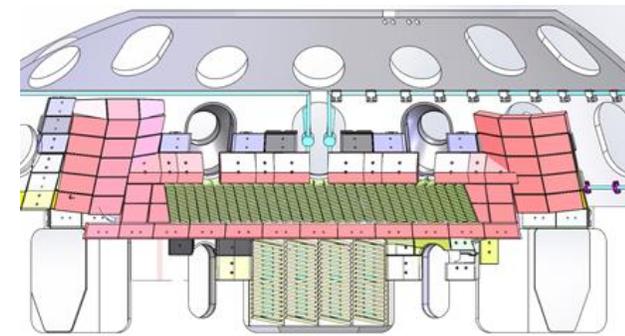
*Top launch ECCD*

Installed, commissioned, and demonstrated in 2019

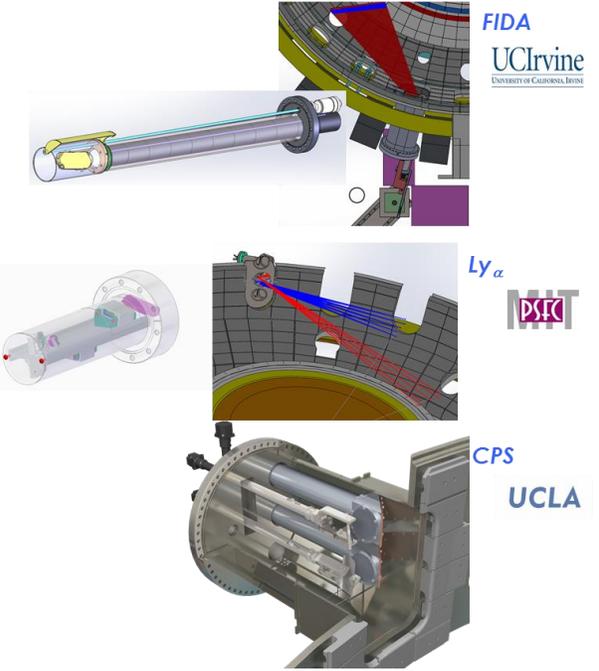
Diagnostics ready for exploitation in 2020



HFS-LH installation planned for FY 2021



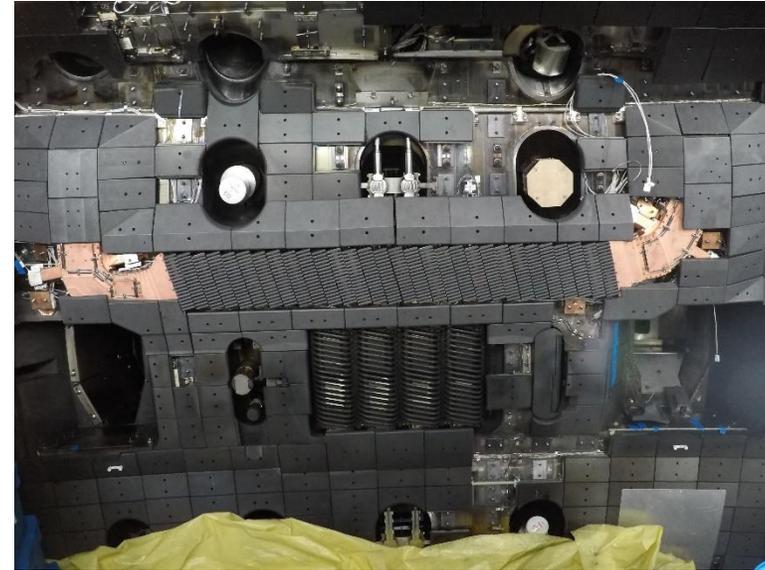
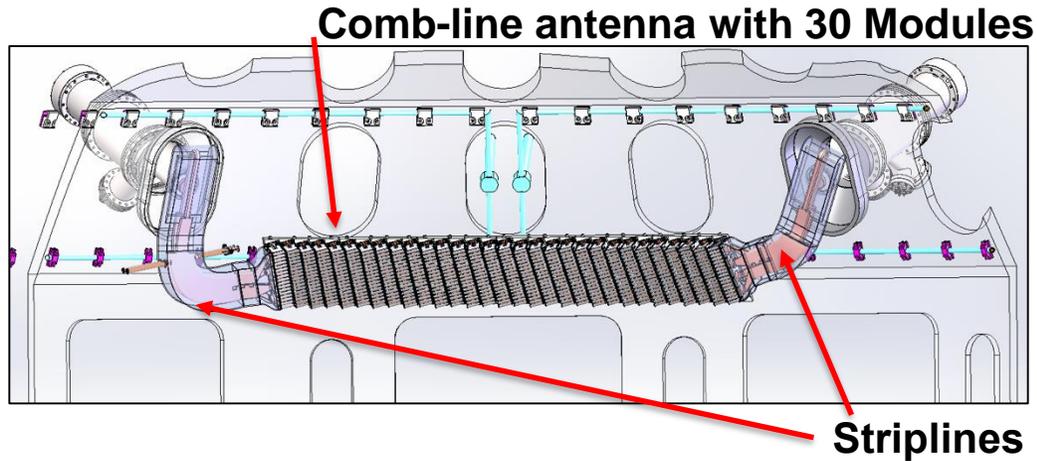
Novel helicon antenna installed in Feb. 2020



*New diagnostics*

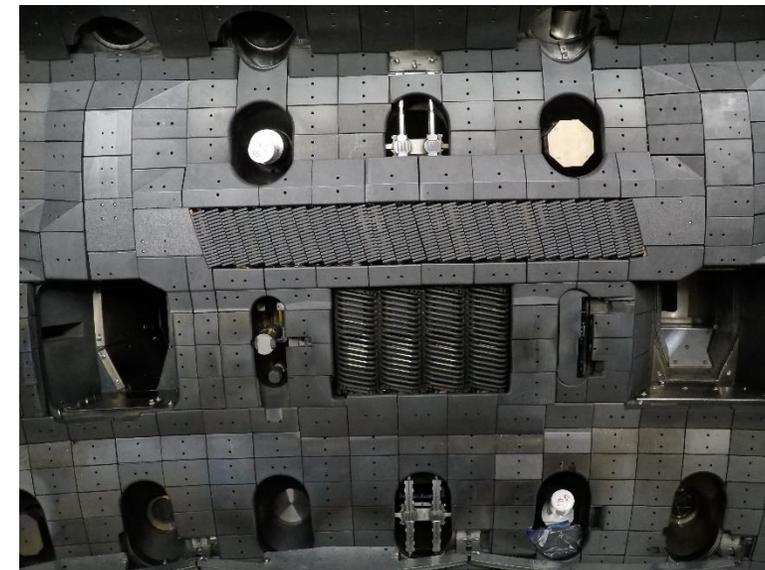


# Feb. 2020: Novel helicon antenna has been installed in DIII-D for efficient off-axis current drive



**Helicon antenna with striplines exposed**

- Antenna installed during 2020 vent period
- 1 MW klystron successfully tested
- 476 MHz modulated RF system
- RF diagnostics developed with DIII-D university collaborators (ORNL, UCLA, MIT)



**Full plasma-facing tile installation**



# ORNL shattered pellet injectors for disruption mitigation



## SPI on JET:

- SPI tested on world's largest tokamak (2019)
- International collaboration between ITER Organization, EUROfusion, USDOE Fusion Energy Sciences, US ITER Project Office, and ORNL, managed by UKAEA/Culham Centre for Fusion Energy

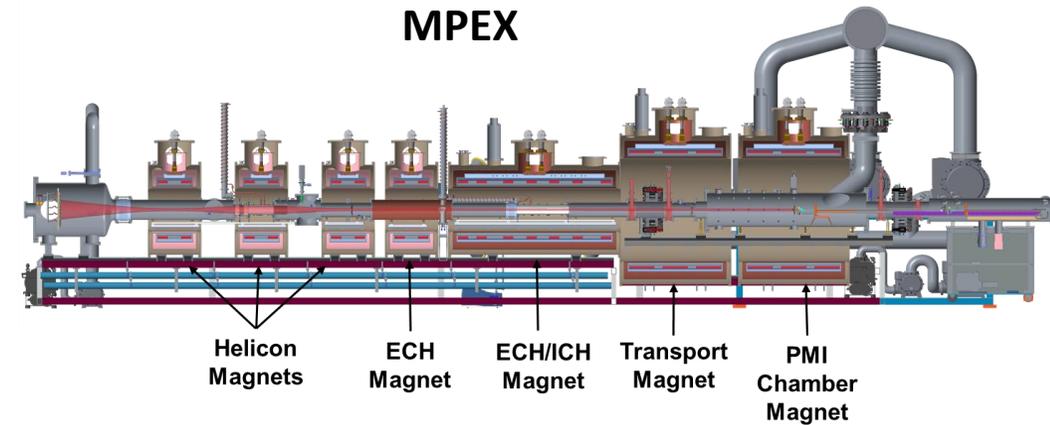


## SPI on KSTAR:

- SPI tested for first time in dual-injection configuration (exactly opposite locations)
- Cryogenic D-Ne pellets (28.5 mm X 50 mm)

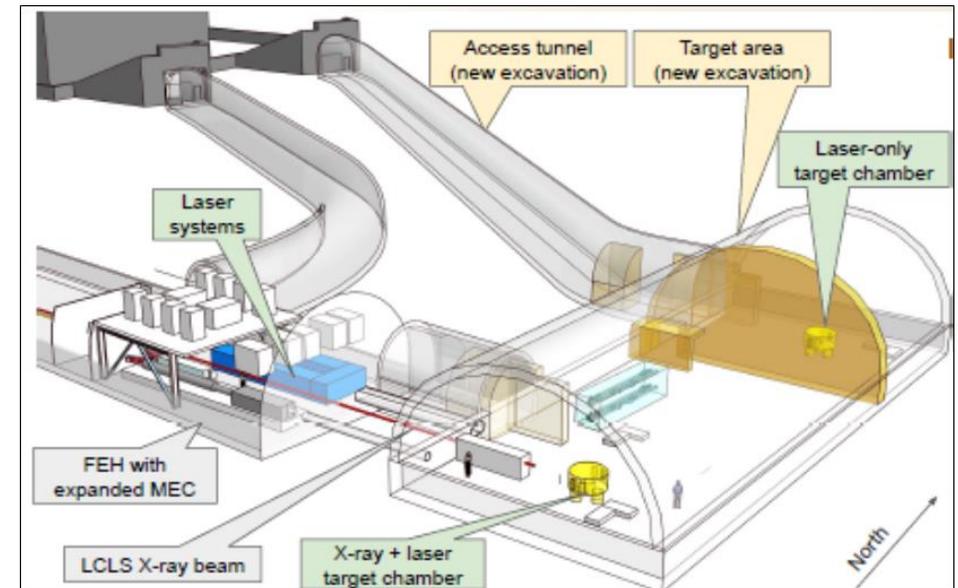
# Construction projects for new world-leading facilities

- **FES has initiated a new Major Item of Equipment project for a linear divertor simulator**
  - CD-1 Approval of Alternate Selection and Cost Range was obtained in January 2020
  - The Material Plasma Exposure eXperiment (MPEX) will address need for expanded materials science capabilities
  - MPEX will be capable of producing fusion reactor-relevant plasma conditions for materials & component-level exposures



- **FES is considering a Petawatt Laser Facility (PLF) project**
  - Mission Need (CD-0) approval obtained in FY 2019
  - Addresses a recommendation in the 2017 NAS report *Opportunities in Intense Ultrafast Lasers*
  - PLF will study properties of matter in extreme conditions of densities and temperatures, relativistic plasmas, planetary science and laboratory astrophysics, plasma photonics and nonlinear optics, and strong field quantum electrodynamics

## One Alternative: MEC Upgrade





# New Magnet Test Stand capability

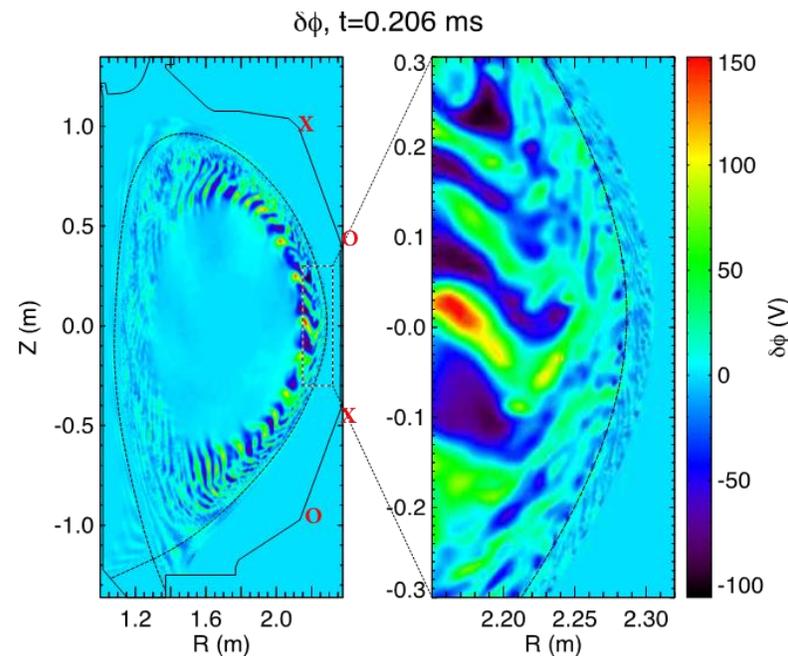
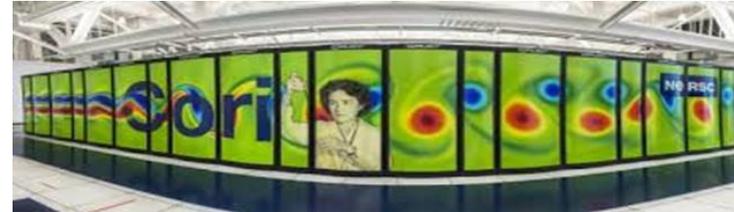
- **Magnet Test Stand** for high-critical-temperature superconductor cable and magnets
- Jointly funded by FES and High Energy Physics
- At Fermilab
- LBNL will be designing and fabricating a large superconducting dipole magnet (15 T) to be used in the Magnet Test Stand



*Right: Dr. James Siegrist (AD for HEP program)*

# FES high-performance computing efforts

- The nine multi-institutional projects in the FES SciDAC portfolio continue to make progress toward integration and Whole-Device Modeling
  - More details can be found at: [https://scidac.gov/partnerships/fusion\\_energy.html](https://scidac.gov/partnerships/fusion_energy.html)
- The PPPL-led WDMApp project in the SC Exascale Computing Project (ECP) portfolio is making good progress toward the coupling of edge and core tokamak regions using continuum and particle codes
- The JA-US collaboration on Exascale for fusion continues
- US scientists are prepared for the first Exascale computing systems ~2021 (Frontier at ORNL and Aurora at ANL)



FRONTIER Exascale Computer @ ORNL  
Coming in 2021



AURORA Exascale Computer @ ANL  
Coming in 2021

# NSF/DOE Partnership: Over \$7 million funded by DOE in 2019

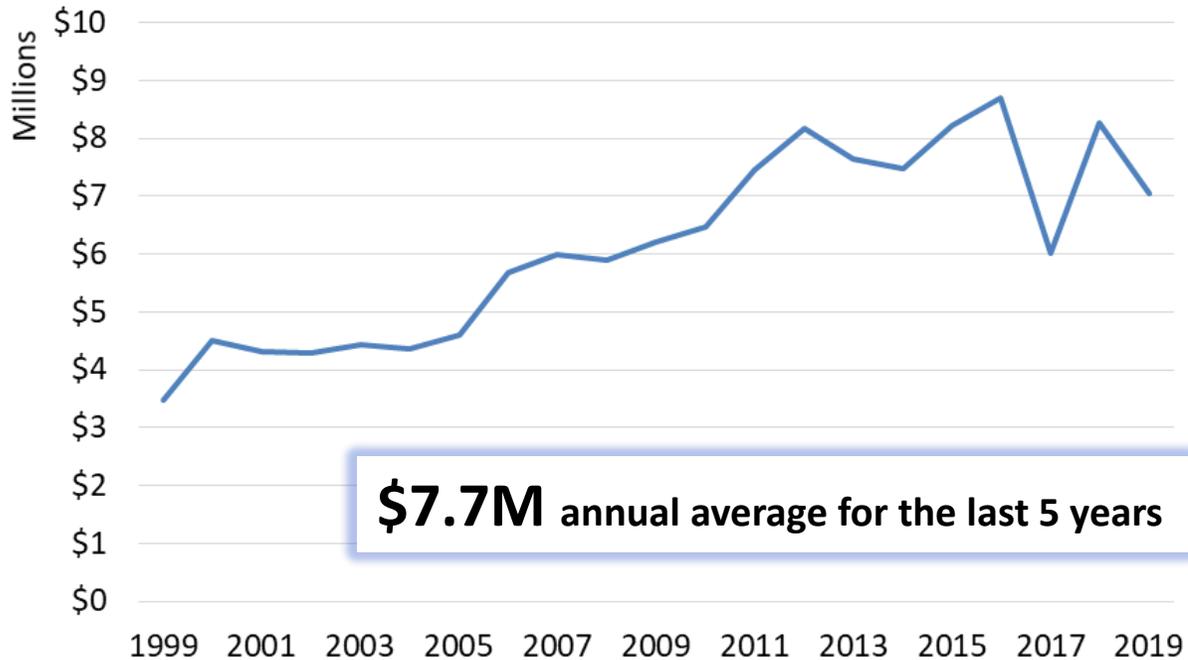
## NSF/DOE Partnership includes:

- ✓ General Plasma Science
- ✓ Exploratory Magnetized Plasmas
- ✓ and HEDLP

FY 2019 FES contribution

**\$7.0 M**

Annual FES Funding Profile for the Partnership



- FES provided \$7.0 million FY 2019 funds for the Partnership, supporting 11 new and 3 supplemental proposals in basic plasma, non-neutral/dusty plasma, HED plasma, and low-temperature plasma
- This includes \$2.7 million for Basic Plasma Science Facility's (BaPSF) continuing operation and collaborative research at UCLA





## Facilities

Colorado State University



**Advanced Beam Laboratory**

Contact:  
Jorge Rocca, [euvasers@colostate.edu](mailto:euvasers@colostate.edu)

[Website](#)

Lawrence Berkeley National Laboratory

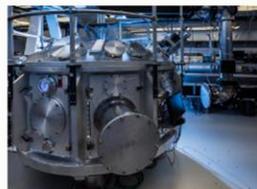


**Berkeley Lab Laser Accelerator (BELLA) Center**

Contact:  
Thomas Schenkel, [t\\_schenkel@lbl.gov](mailto:t_schenkel@lbl.gov)

[Website](#)

Lawrence Livermore National Laboratory



**Jupiter Laser Facility**

Contact:  
Robert Cauble, [cauble1@llnl.gov](mailto:cauble1@llnl.gov)

[Website](#)

Ohio State University



**Scarlet Laser Facility**

Contact:  
Douglass Schumacher, [schumacher.60@osu.edu](mailto:schumacher.60@osu.edu)

[Website](#)

SLAC National Accelerator Laboratory

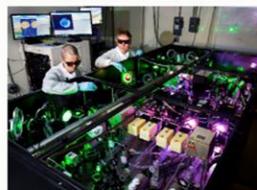


**Matter in Extreme Conditions**

Contact:  
Gilliss Dyer, [Gilliss@slac.stanford.edu](mailto:Gilliss@slac.stanford.edu)

[Website](#)

University of Michigan



**Center for Ultrafast Optical Science**

Contact:  
Karl Krushelnick, [kmr@umich.edu](mailto:kmr@umich.edu)

[Website](#)

University of Nebraska - Lincoln



University of Rochester



University of Texas - Austin

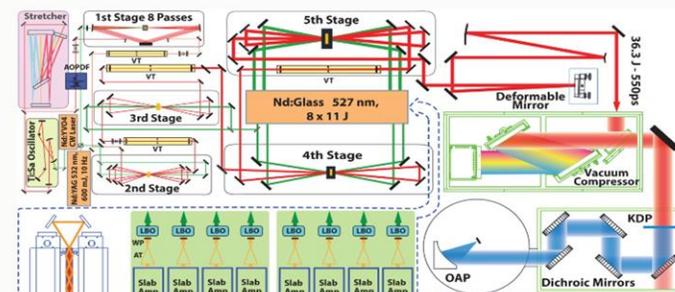


## Advanced Beam Laboratory

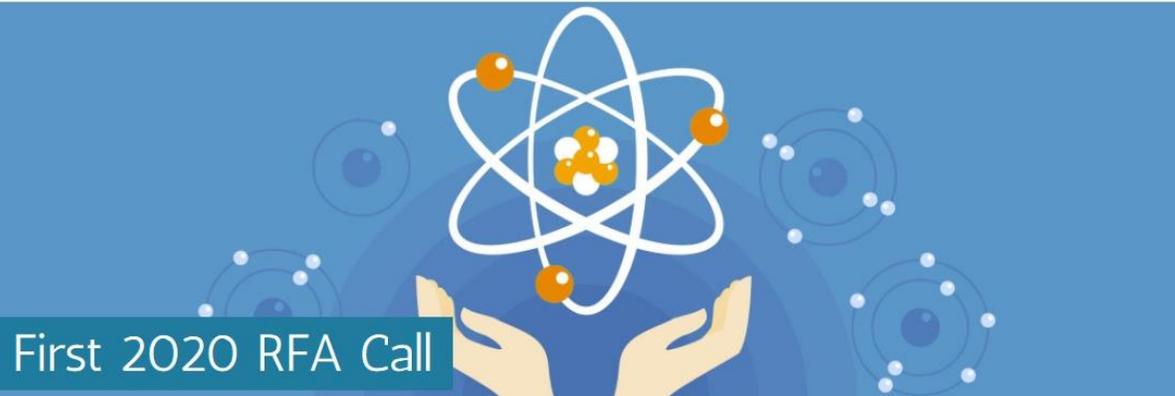
Colorado State University

Colorado State University Petawatt-Class Laser is an ultra-short pulse Ti:sapphire laser system that produces ultrahigh-contrast  $\lambda = 400$  nm femtosecond pulses of up to 10 J, obtained by frequency doubling 800 nm pulses of 30 fs duration. An intensity of  $6.5 \times 10^{21}$  W/cm<sup>2</sup> is obtained focusing the beam with an f/2 parabola. An f/1 parabola will be available after July 2019 that is expected to deliver intensities  $>1 \times 10^{22}$ . The beam/pulse parameters presently offered by the laser are summarized in the Laser Modes table.

A schematic diagram of the laser is shown in Figure 1. It consists of a conventional Ti:Sa front end that delivers  $\lambda = 800$  nm pulses into a chain of three high power Ti:Sa amplification stages pumped by Nd:YAG slab amplifiers. The 250 mJ output of this laser front end is further amplified in three multi-pass Ti:Sa amplifiers pumped by the frequency doubled output of eight compact flash lamp-pumped high energy Nd:glass slab amplifiers, developed at CSU. The slab geometry has long been recognized as a way to significantly reduce the limitations in repetition rate inherent to the more commonly used rod geometry. These pump laser allows Ti:sapphire system operation at a repetition rate of up to 3.3 Hz in burst mode. The beam propagates in a zig-zag path in the gain medium aided by total internal reflection in the polished wall of the slabs eliminating first-order thermal and stress-induced focusing, and also reducing stress-induced birefringence.



- **LaserNetUS website is managed by SLAC for the consortium**
  - It has information for users about facility capabilities and proposal submission process
- **Advanced Laser Light Source (Quebec) joined LaserNetUS**



First 2020 RFA Call

**First 2020 Request for Assistance Call was issued in February**

The first INFUSE workshop was held **November 22-23**, in Knoxville, TN

- Attendees included the Point-of-Contacts from the 10 participating labs (BNL, INL, LANL, LBNL, LLNL, ORNL, PNNL, PPPL, SNL, and SRNL); representatives from nine private fusion companies, ARPA-E, and the Fusion Industry Association; and DOE-FES staff



INFUSE workshop

- The **Innovation Network for Fusion Energy (INFUSE)** program for fusion R&D was announced in June, 2019
- INFUSE accepts research applications focused on innovation for fusion energy in enabling technologies, materials science, plasma diagnostics, modeling & simulation, and MFE experimental capabilities
- Awards are made to DOE national labs to help eligible private-sector companies overcome critical scientific and technological challenges in pursuing fusion energy
- In FY 2019, twelve awards were made to six private companies partnering with six DOE labs
- Awards are listed in: <https://infuse.ornl.gov/2019-infuse-awards-2/>
- In FY 2020, INFUSE expands eligibility to foreign companies whose participation is beneficial to the U.S., raises the funding level and duration of awards, and relaxes limits on number of proposals per topical area
- More information here: <https://infuse.ornl.gov/>



## ***3. ITER Updates***

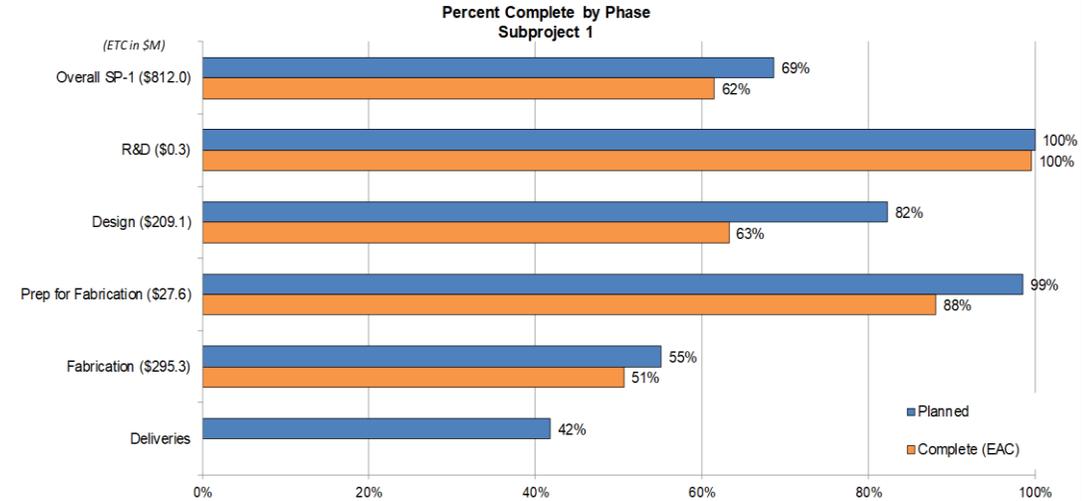
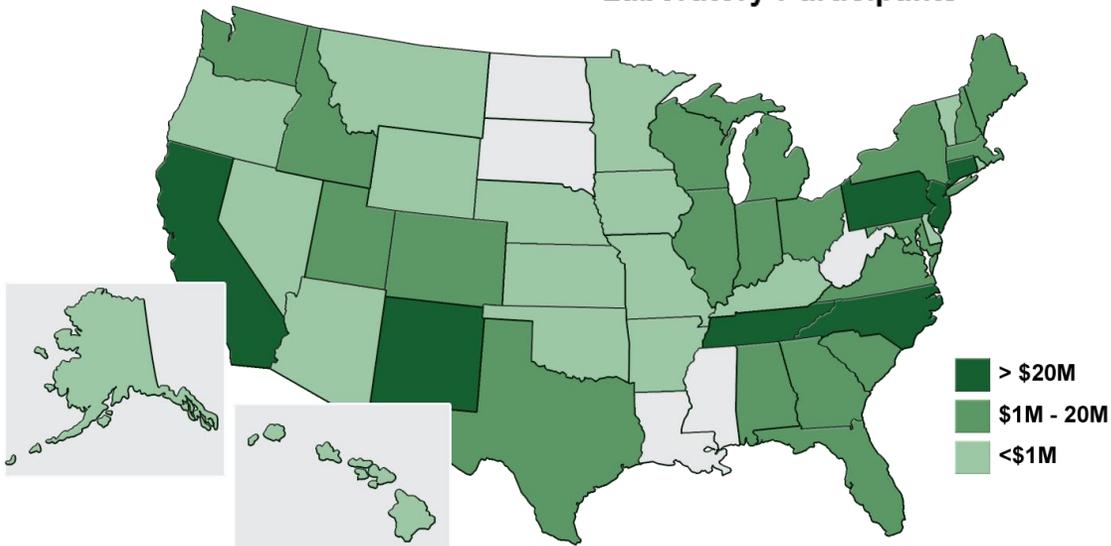
# Progress of U.S. ITER project: Subproject-1 (First Plasma) is 63% complete

**Hardware appropriations: ~ \$1.45 B  
(through FY 2019)**

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

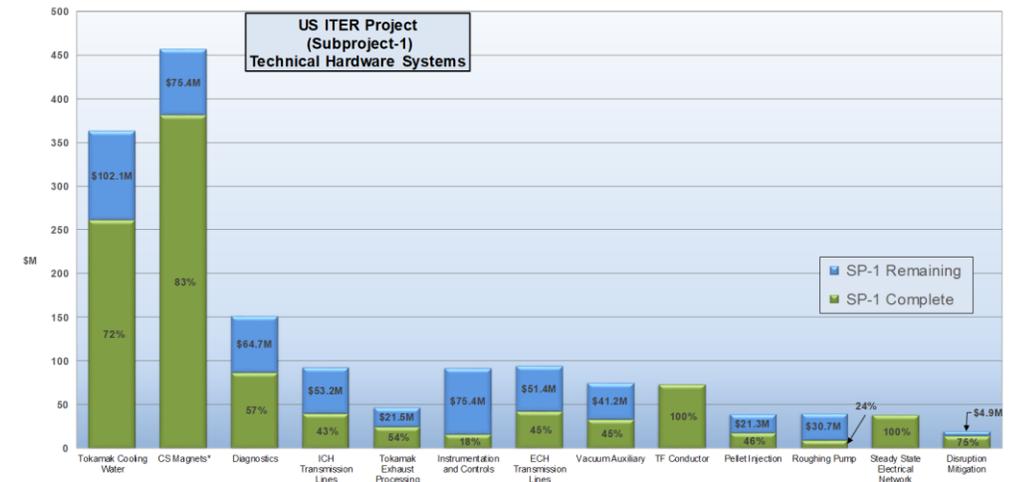
- 600+ contracts to U.S. industry, universities, and national laboratories in 44 states
- 500+ direct jobs, 1100+ indirect jobs per year

**Industry, University and National Laboratory Participants**



Does not include full impact of funding constraints.  
Data: December 2019

Variance in bars due to rounding



\*Includes CS Modules, Structures & Assembly Tooling  
Values do not include any impacts as a result of funding constraints  
Represents technical systems only. Project Management and Contingency not included

# New US ITER Project Director: Kathryn McCarthy

**Effective: March 2, 2020**

## **Recent Experience:**

### **Canadian Nuclear Laboratories**

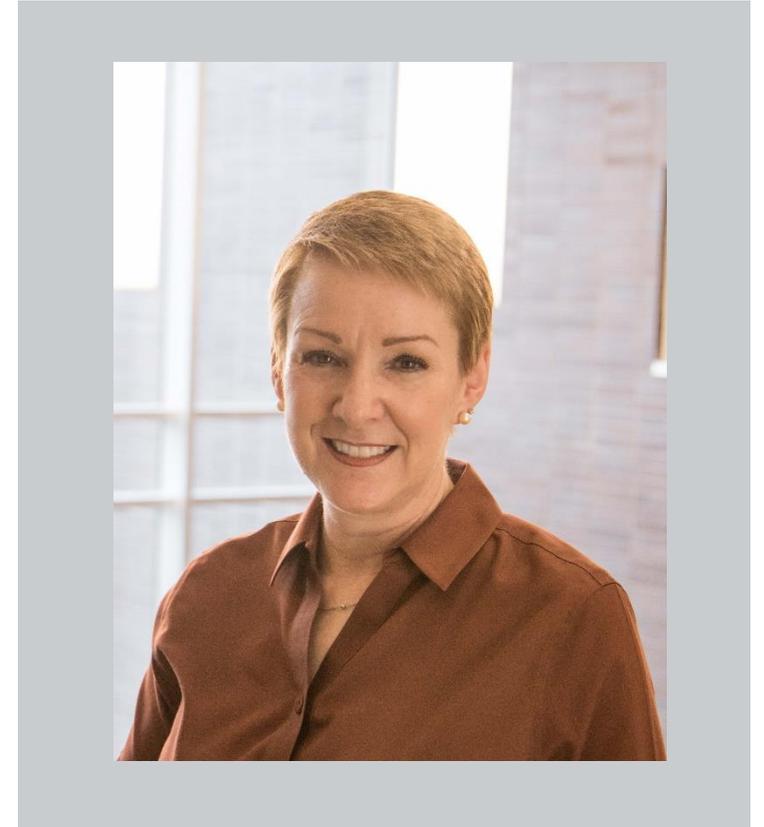
- Vice President for Science and Technology and Laboratory Director [oversaw staff of 650]

### **Idaho National Laboratory**

- Director of domestic programs in INL's Nuclear Science and Technology Directorate
- Director of the Light Water Reactor Sustainability Program Technical Integration Office
- National Technical Director for the Systems Analysis Campaign for DOE Nuclear Energy's Fuel Cycle R&D Program

## **Background:**

- Ph.D. in nuclear engineering (UCLA) with a major field of fusion engineering and minor fields of nuclear science and engineering and physics
- National Academy of Engineering inductee
- Awarded two American Nuclear Society presidential citations
- FESAC member 1999-2013
- US ITER technical advisory committee member 2010-2013

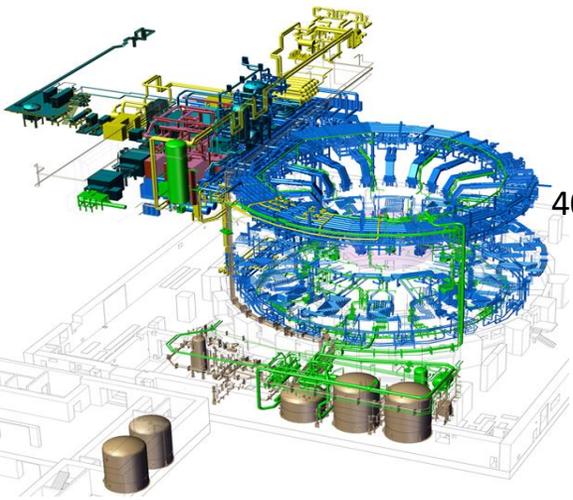


***Dr. Kathy McCarthy***



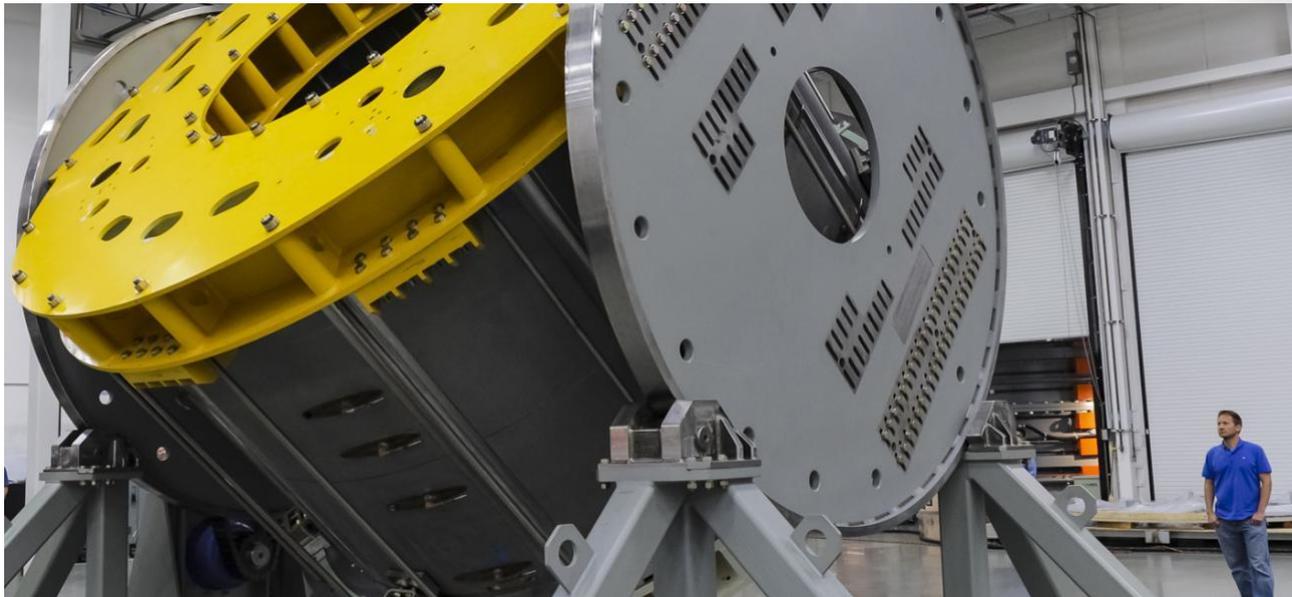
# Examples of U.S. hardware for ITER

## Tokamak Cooling Water System



40 km of piping in the Tokamak Cooling Water System and nearly all of it is manufactured in the U.S.

The Tokamak Cooling Water System will have total heat removal capacity = 1,000 MW (thermal)



## US tests first central solenoid module

The first production central solenoid module is currently being tested in the United States by contractor General Atomics. It will be delivered to the ITER site during FY 2020. Fabrication of each module requires multiple fabrication steps spread out over 24 months.

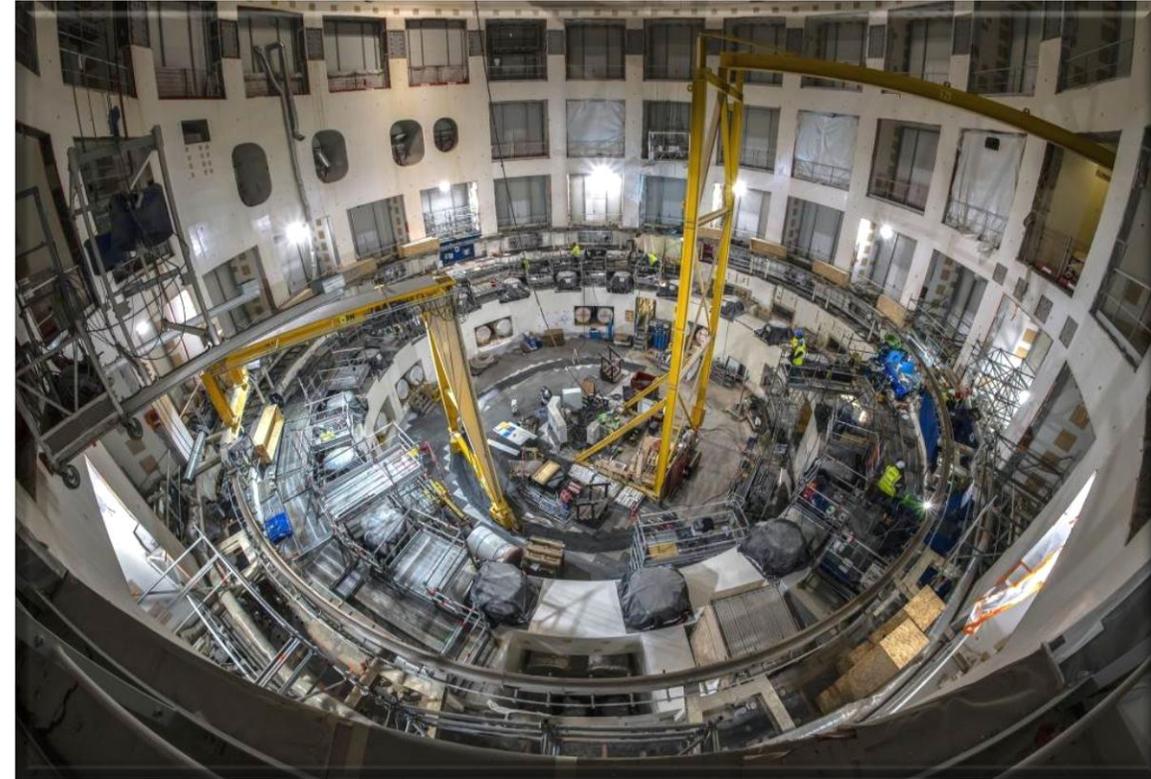
# ITER civil construction is nearly complete and assembly phase has begun



## Fully contained

The volume of the crane hall (right) is now fully framed out. When the interior partition wall is removed, the buildings will form one continuous assembly space.

26 FEBRUARY 2020



## Cryostat base: grand opening soon

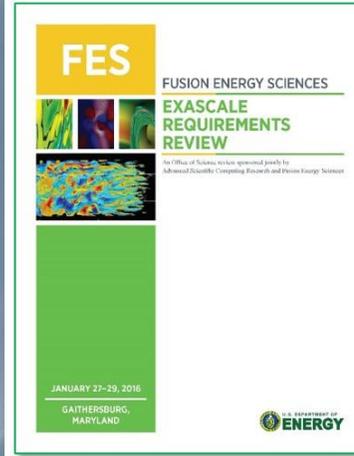
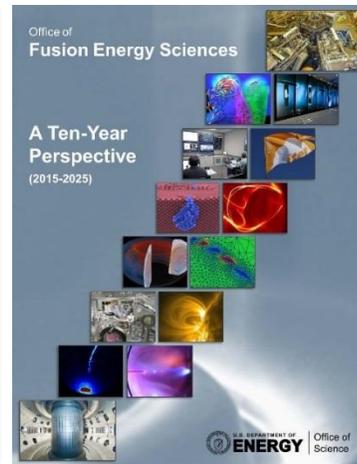
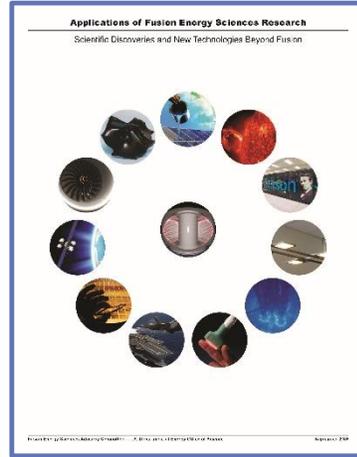
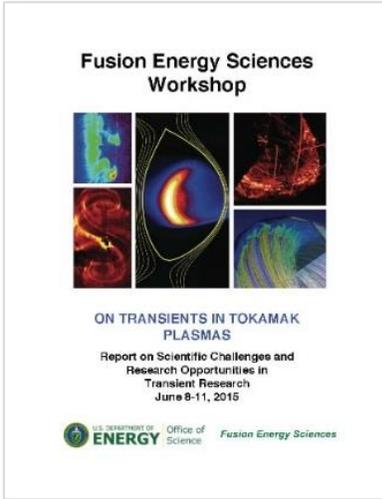
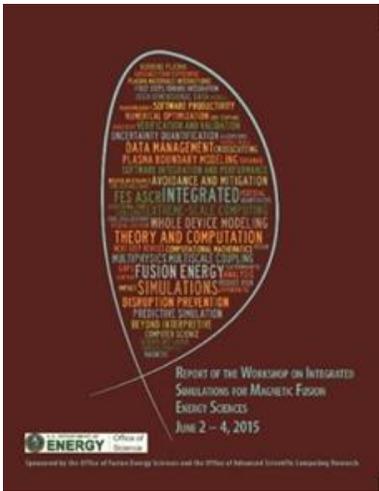
The huge cryostat base section will descend from above, supported by the overhead cranes as it is lowered 30 meters to the bottom of the pit.

13 FEBRUARY 2020



## ***4. Program Planning***

# FES strategic choices are informed by community and Advisory Committee input

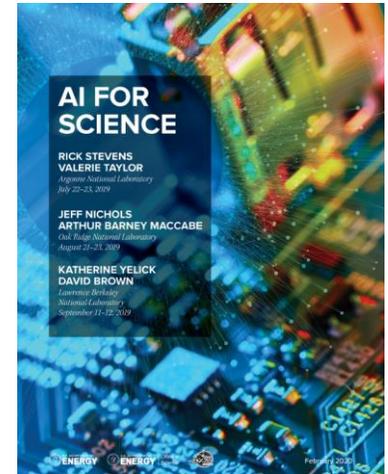
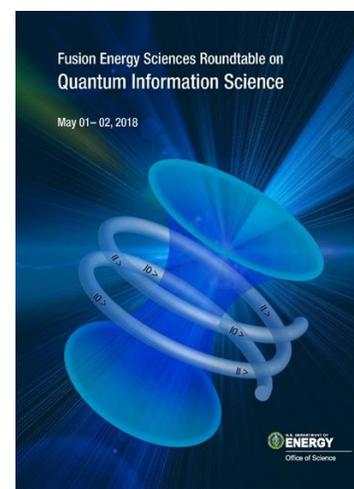
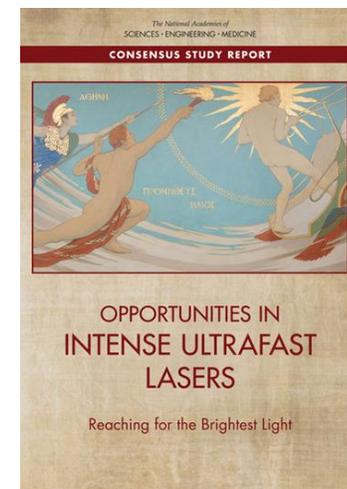
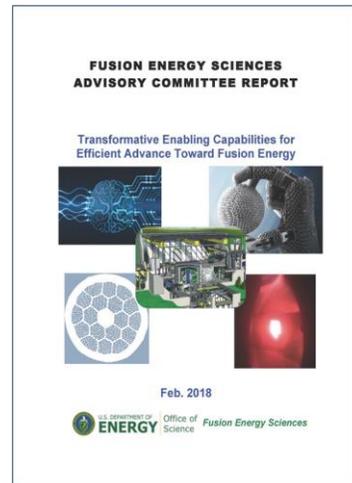
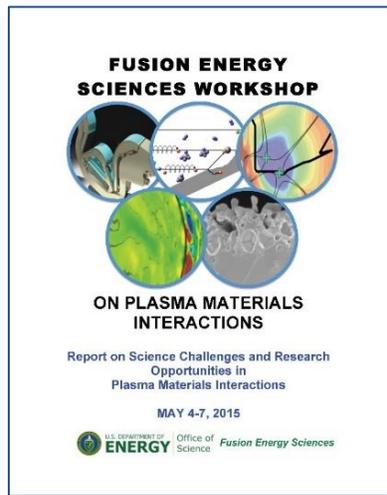


2015 Applications of Fusion Energy Sciences Research

2015 FES 10-year Perspective

2016 FES Exascale Requirements

2019 Report on Advancing Fusion with Machine Learning



2018 FESAC Transformative Enabling Capabilities

2017 FES NAS Report on Intense Ultrafast Lasers

2018 FES Roundtable on QIS

2020 Report on AI for Science (DOE Town Halls)

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

# CPP process concluded with a substantive report

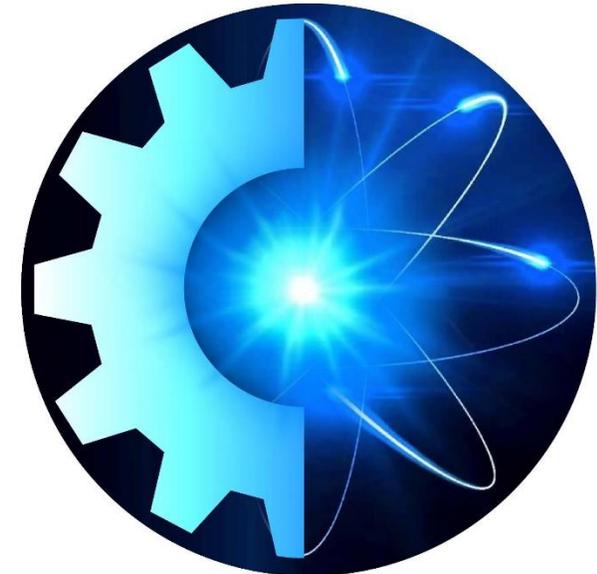
*Thank you!*

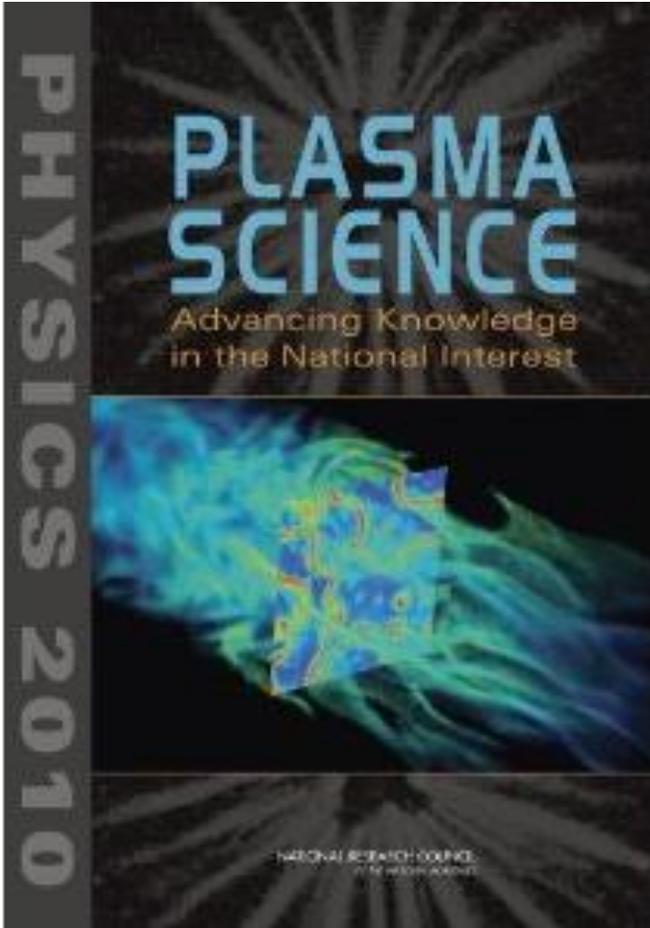


American Physical Society Division of Plasma Physics  
Community Planning Process  
January 13-17, 2020 • Houston, Texas

## A Community Plan for Fusion Energy and Discovery Plasma Sciences

Report of the 2019–2020 American Physical Society Division of  
Plasma Physics Community Planning Process





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

## Decadal Assessment of Plasma Science

**Chairs:** Prof. Mark Kushner & Prof. Gary Zank

- **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)
- **Current status:**
  - Draft report was sent to the reviewers in late February
  - Committee will address reviewer input under an accelerated schedule
  - Release of final report to federal sponsors is targeted for mid-April

- **Congress has expressed its interest on understanding the regulatory approach for Advanced Nuclear Reactors, including nuclear fusion reactors**
  - *Nuclear Energy Innovation and Modernization Act, S.512* (January 2018)
  - *Nuclear Energy Innovation Capabilities Act of 2017, S.97* (January 2018)
- **Early in 2019, FES along with ARPA-E formed an informal working group with the Nuclear Regulatory Commission to exchange information**
- **DOE and NRC senior management are aware of this activity and have been involved in planning future engagements**
- **The one-day DOE-NRC Public Forum on fusion regulation planned for this week will be rescheduled**





## *5. People*

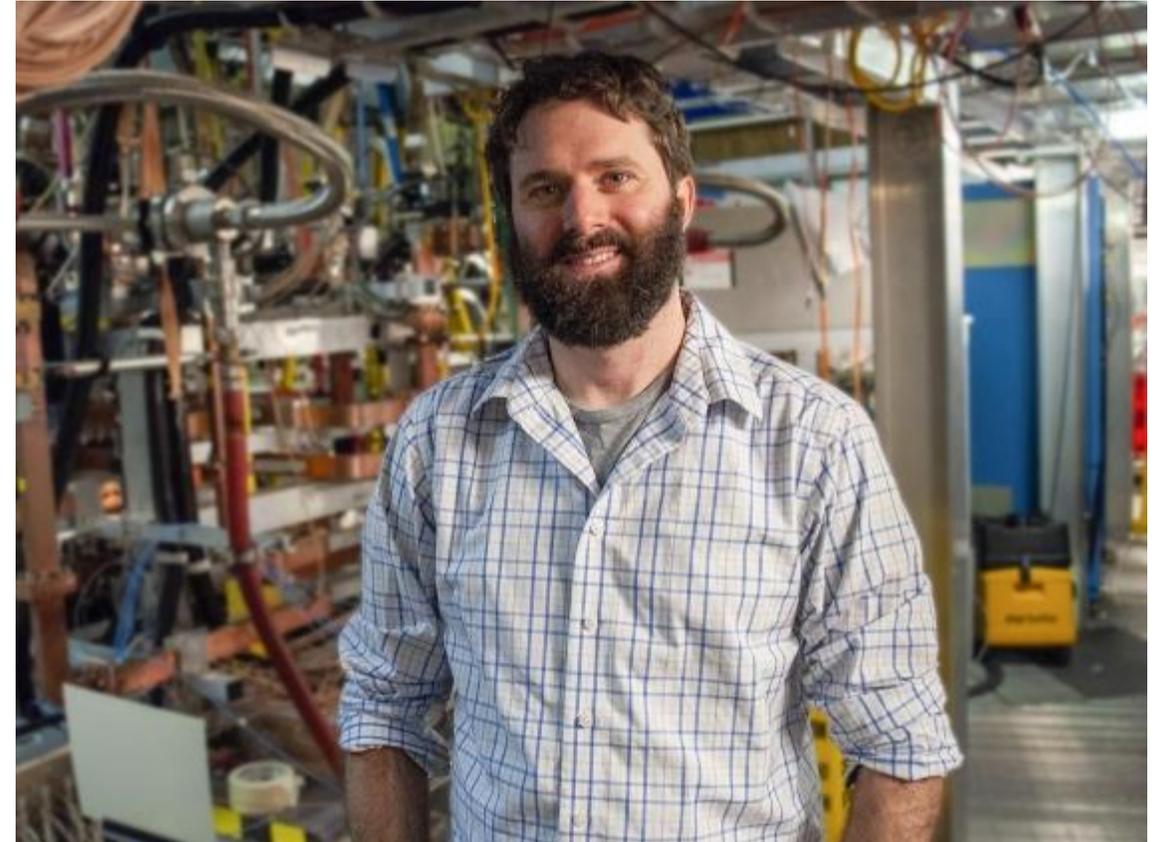


**Dan Brouillette** sworn in as the 15<sup>th</sup> Secretary of Energy, U.S. Department of Energy, on December 11, 2019

- Served as USDOE Deputy Secretary of Energy since August 2017
- Previous experience:
  - Senior Vice President and head of public policy for U.S. Automobile Association (USAA)
  - Vice President of Ford Motor Company
  - Chief of Staff to the U.S. House of Representatives Committee on Energy and Commerce



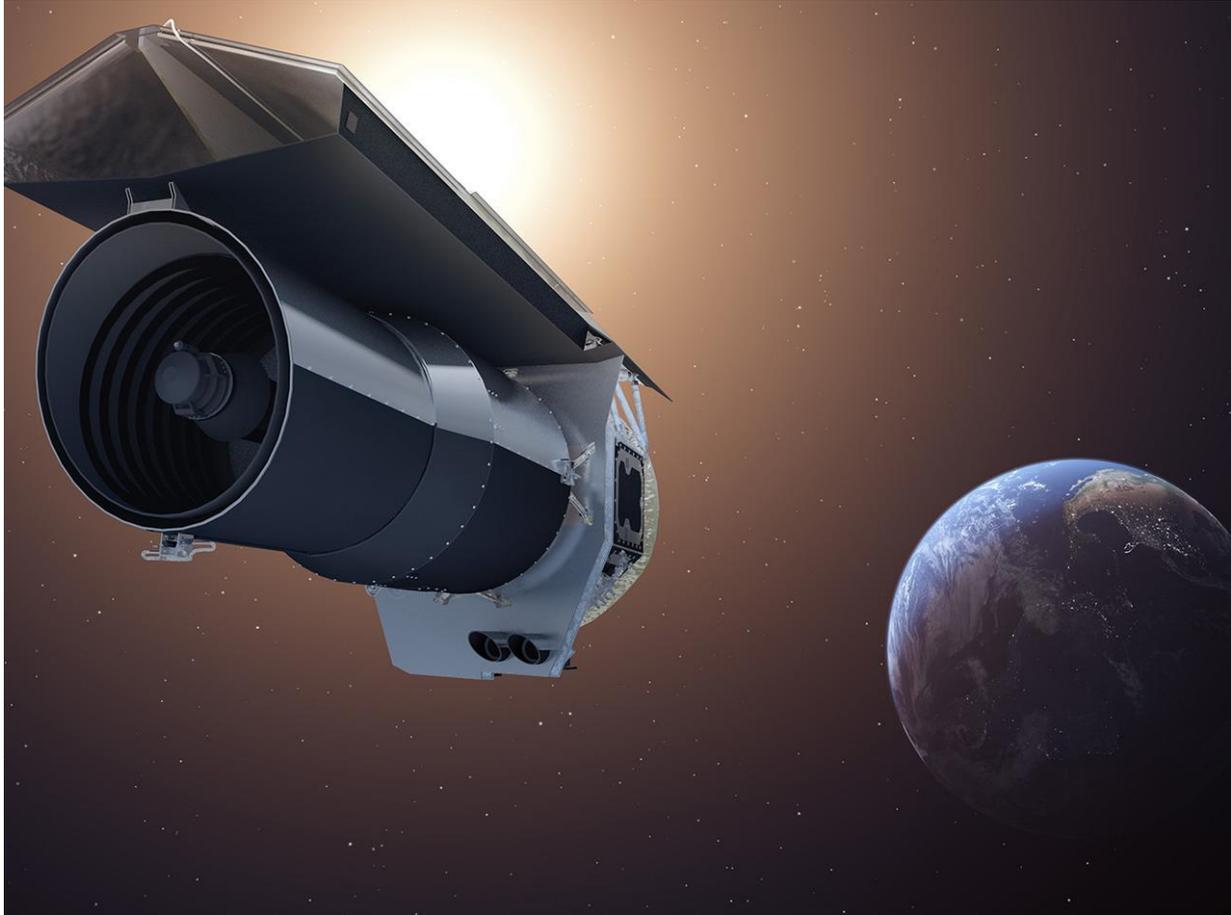
- Dr. Nathan Howard (MIT) received the 2019 Nuclear Fusion award for the paper “Multi-scale gyrokinetic simulation of tokamak plasmas: Enhanced heat loss due to cross-scale coupling of plasma turbulence” [Nuclear Fusion (2016)]
  - Co-authors were C. Holland, A. E. White, M. Greenwald, and J. Candy
- This paper presents novel gyrokinetic simulations that capture ion and electron-scale turbulence simultaneously.
  - The simulations reveal mechanisms explaining electron heat losses in the core of fusion plasmas.
  - The paper compared cutting-edge simulation results to experimental findings, providing convincing physical explanations for observed anomalous heat losses.
- The award will be presented at the IAEA Fusion Energy Conference, to be held in Nice, France in October 2020.



***Dr. Nathan Howard (PSFC/MIT)***



# Spitzer Space Telescope



- The infrared **Spitzer Space Telescope**, named after Prof. Lyman Spitzer, Jr. (founder of PPPL) and considered one of NASA's four "great observatories" (with Hubble Space Telescope, Chandra X-Ray Observatory, and Compton Gamma-Ray Observatory), was switched off on January 31 after 16 years of operation.