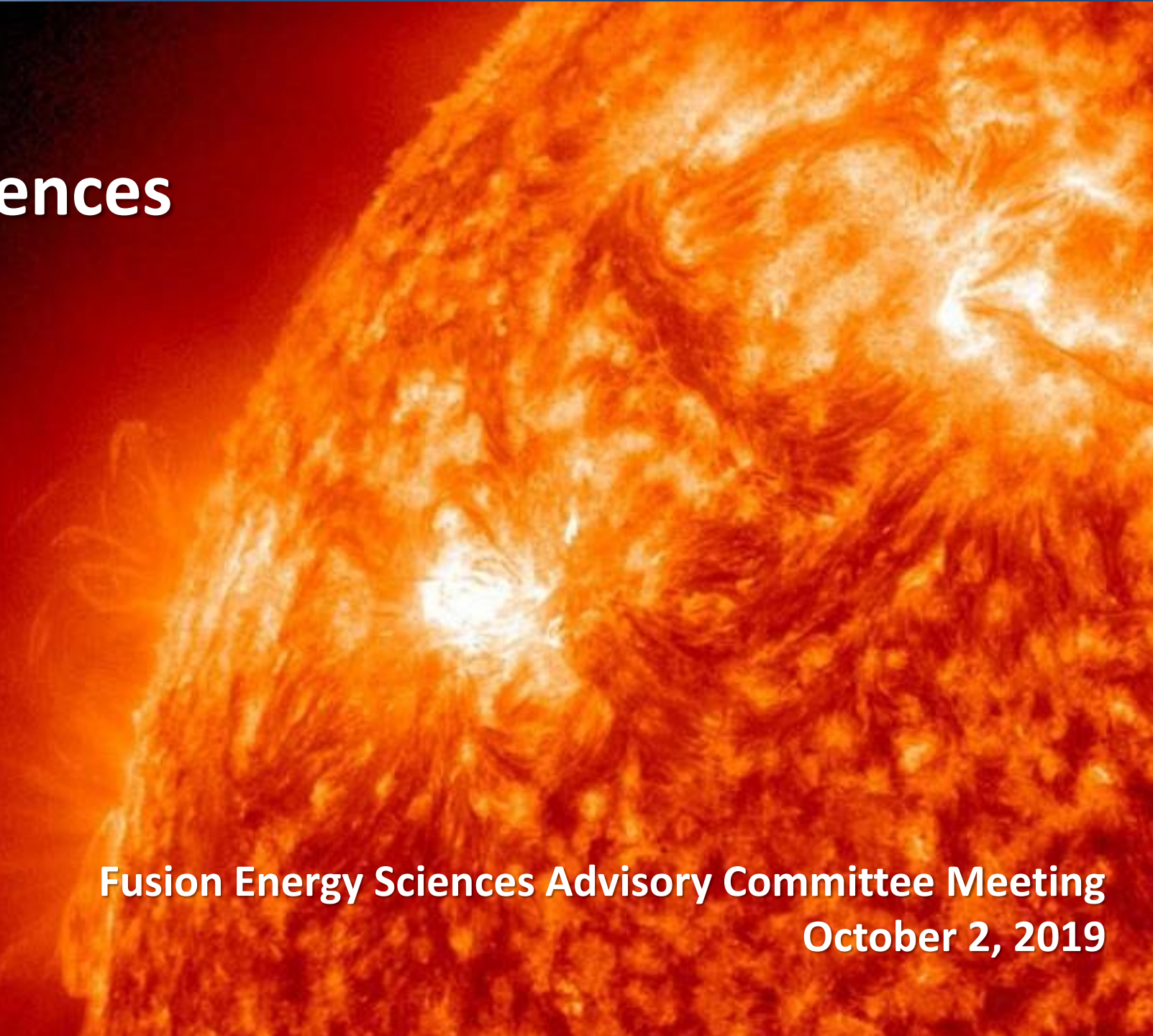
Fusion Energy Sciences Perspective

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

U.S. DEPARTMENT OF ENERGY
Office of Science



Fusion Energy Sciences Advisory Committee Meeting
October 2, 2019

1. Budget Updates

The FY 2019 FES budget enabled a number of accomplishments

- **U.S. Contributions to ITER project**: Completed testing of the first superconducting central solenoid magnet module. Cash contribution was made in FY 2019.
- **DIII-D:** Successfully completed 12 run weeks in FY 2019. The world's first toroidally steerable, off-axis neutral beam injector was installed on schedule and successfully operated. In FY 2020, DIII-D research will utilize the new neutral beam and other heating/current drive systems to investigate steady-state plasma scenarios.
- **NSTX-U Recovery project**: Successfully achieved SC approval of its baseline cost and schedule, and authorization of long-lead procurements.
- **Materials Plasma Exposure eXperiment (MPEX) MIE project**: Completed conceptual design. The project plans to complete preliminary design and attain Critical Decision-1 approval in FY 2020.
- **Matter in Extreme Conditions (MEC) Petawatt Upgrade**: Achieved approval of its Mission Need (CD-0).
- **Quantum Information Science (QIS):** FES made awards in connection with its first-ever solicitation in QIS.
- **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. Also, U.S. scientists are designing and building a high-speed pellet fueling system for the W7-X stellarator.
- **Innovation Network for Fusion Energy** (**INFUSE**): FES established this to support private-public partnerships. The initial awards were selected in September.
- **Machine Learning:** FES held a workshop, jointly with ASCR, to identify priority research opportunities in AI/ML.

U.S. DEPARTMENT OF ENERGY
Office of Science

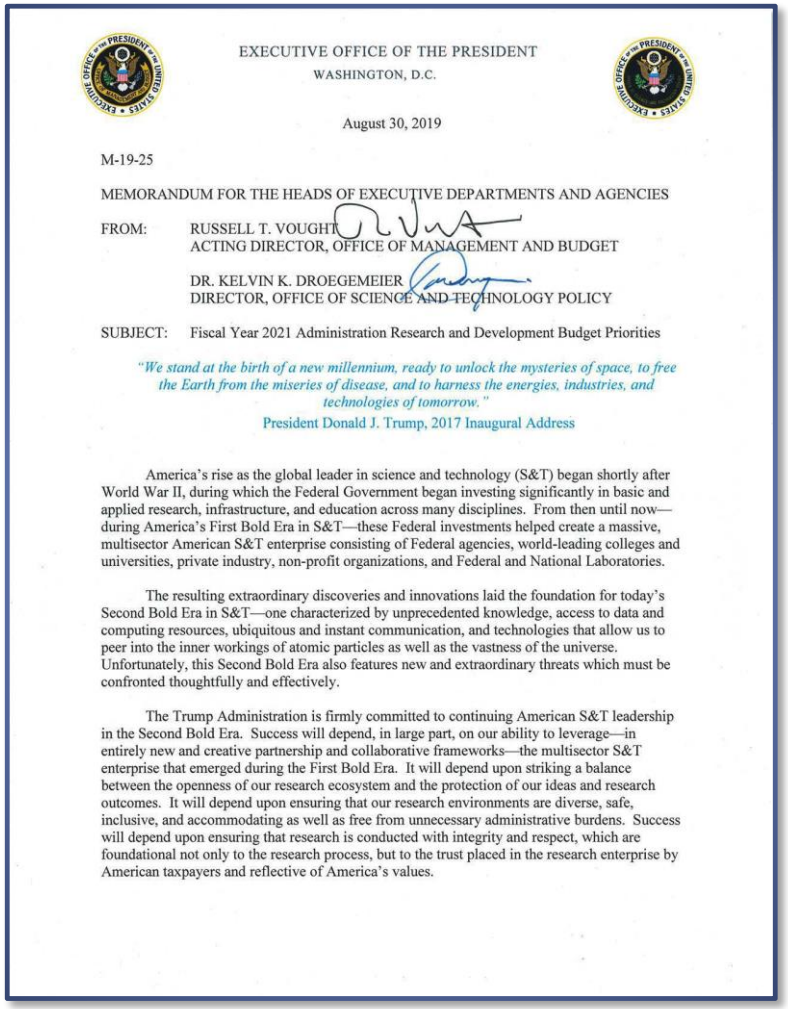
Highlights from the House and Senate marks for FY 2020 budget

- **From the House Energy and Water Development mark [May 2019]**
  - The Committee recommends **$688,000,000** for Fusion Energy Sciences
  - Within available funds, the recommendation provides **$20,000,000** for High Energy Density Laboratory Plasmas, including activities for LaserNetUS
  - Within available funds, the recommendation includes **$4,000,000** for a Fusion Public-Private Partnership Program
  - The recommendation includes **$21,000,000** for MPEX
  - The Committee recommends **$230,000,000** for the U.S. contribution to the ITER project
- **From the Senate Energy and Water Development mark [September 2019]**
  - The Committee recommends **$570,000,000** for Fusion Energy Sciences
  - The Committee recommends **$180,000,000** for the domestic, in-kind contributions and related support activities of the ITER project
  - Encourages supporting optimal facility operations levels for DIII-D
  - Recommends **$30,000,000** for the Material Plasma Exposure eXperiment
  - Supports the Matter in Extreme Conditions Petawatt Upgrade project and recommends **$14,400,000** in construction funding and **$1,400,000** in other project costs funding.
  - The Committee recommends **$20,000,000** for LaserNetUS
  - Provides up to **$20,000,000** over the budget request for the continuation of the INFUSE program
  - Directs the Department to create a Fusion **Public-Private Partnership Cost Share Program** that advances multiple fusion advanced reactor technologies and recommends up to **$20,000,000** for this new program
- **FY 2020 will begin with a seven-week Continuing Resolution, to November 21, 2019.**

U.S. DEPARTMENT OF ENERGY
Office of Science

FES FY 2021 Budget Request addresses Administration R&D priorities and practices

- **American Leadership in Industries of the Future:**
  - FES investments in transformational technologies such as artificial intelligence / machine learning, quantum information science (QIS), data science, microelectronics, advanced manufacturing, and high-performance computing will accelerate progress in several mission areas
- **American Energy & Environmental Leadership**:
  - Early-stage 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.
  - Investments in our major fusion facilities and smaller-scale experiments will maintain and modernize our research infrastructure for continuing to conduct world-leading research
- **Build & Leverage a Diverse, Highly Skilled American Workforce:**
  - 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
- **Create and Support Research Environments that Reflect American Values:**
  - FES-supported research is guided by the principles of Integrity and scientific rigor, diversity and inclusiveness, and emphasis on safety and protection of American research assets
- **Support Transformative Research of High Risk and Potentially High Reward**:
  - 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
- **Build, Strengthen, and Expand Strategic Multisector Partnerships:**
  - Established partnerships within DOE (ASCR, BES, HEP, ARPA-E, NNSA) and outside (NSF) maximize leverage and increase the cost effectiveness of FES research activities
  - Private-public partnerships through the INFUSE program leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology)



EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C.

August 30, 2019

M-19-25

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: RUSSELL T. VOUGHT
ACTING DIRECTOR, OFFICE OF MANAGEMENT AND BUDGET

DR. KELVIN K. DROEGEMEIER
DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUBJECT: Fiscal Year 2021 Administration Research and Development Budget Priorities

"We stand at the birth of a new millennium, ready to unlock the mysteries of space, to free the Earth from the miseries of disease, and to harness the energies, industries, and technologies of tomorrow."
President Donald J. Trump, 2017 Inaugural Address

America's rise as the global leader in science and technology (S&T) began shortly after World War II, during which the Federal Government began investing significantly in basic and applied research, infrastructure, and education across many disciplines. From then until now—during America's First Bold Era in S&T—these Federal investments helped create a massive, multisector American S&T enterprise consisting of Federal agencies, world-leading colleges and universities, private industry, non-profit organizations, and Federal and National Laboratories.

The resulting extraordinary discoveries and innovations laid the foundation for today's Second Bold Era in S&T—one characterized by unprecedented knowledge, access to data and computing resources, ubiquitous and instant communication, and technologies that allow us to peer into the inner workings of atomic particles as well as the vastness of the universe. Unfortunately, this Second Bold Era also features new and extraordinary threats which must be confronted thoughtfully and effectively.

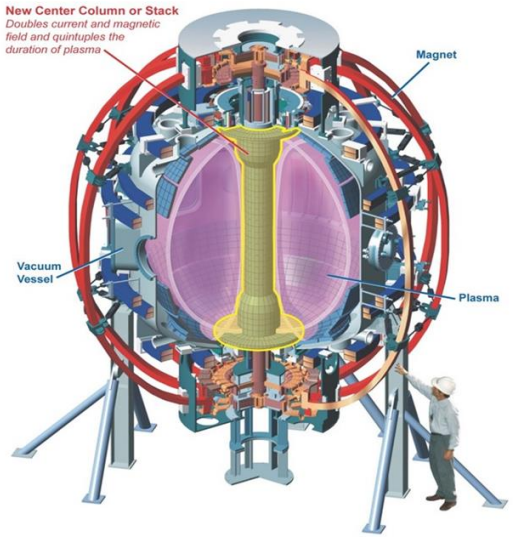
The Trump Administration is firmly committed to continuing American S&T leadership in the Second Bold Era. Success will depend, in large part, on our ability to leverage—in entirely new and creative partnership and collaborative frameworks—the multisector S&T enterprise that emerged during the First Bold Era. It will depend upon striking a balance between the openness of our research ecosystem and the protection of our ideas and research outcomes. It will depend upon ensuring that our research environments are diverse, safe, inclusive, and accommodating as well as free from unnecessary administrative burdens. Success will depend upon ensuring that research is conducted with integrity and respect, which are foundational not only to the research process, but to the trust placed in the research enterprise by American taxpayers and reflective of America's values.

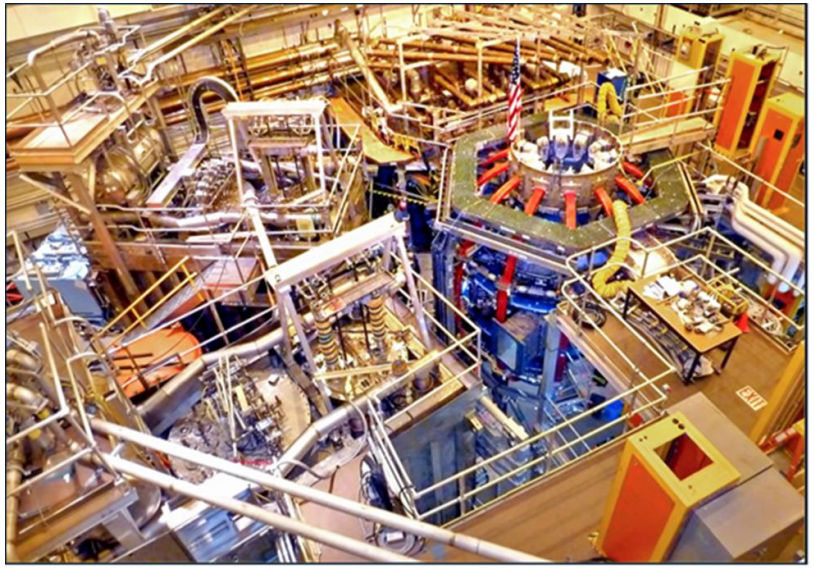
OMB/OSTP memo on the FY 2021 Administration R&D priorities (30 August 2019)

2. Programmatic Updates

National Spherical Torus Experiment-Upgrade (NSTX-U)

- **An Independent Project Review was held August 27-29 to baseline the NSTX-U Recovery Project**
  - Review panel noted that the project is quite mature, given the overall completion of ~50% (with over 70% design complete), and concluded it is ready to begin major construction
  - The baseline cost of the NSTX-U Recovery project is $199.4M, with a completion date (CDE-4) of July 2022 (and early finish in FY 2021)
- **An ESAAB-equivalent meeting was held on September 30**
  - CDE-2/3A received final approval to begin construction
- **Prior-authorized early construction activities have been underway**
  - Clean room winding lines to fabricate poloidal field coils are complete
  - Procurement of all graphite material for PFC replacement is complete





The NSTX-U Test Cell

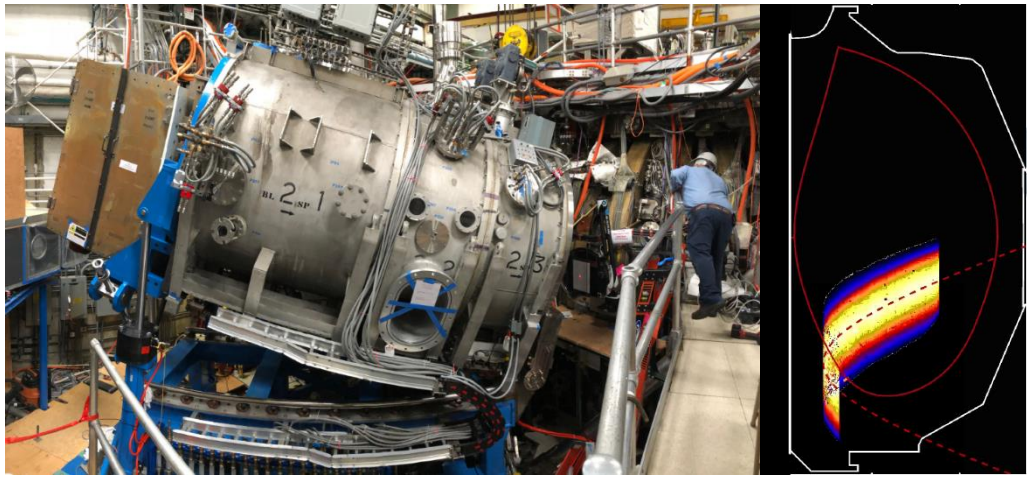
DIII-D: Facility operations & research

FY 2019 Highlights and Achievements

- Completed Long Torus Opening activities during 12-month vent period, including installation of toroidally steerable, off-axis neutral beam injector
- Completed 12-week experimental science campaign
- Demonstrated top-launch electron cyclotron current drive system
- Fabricated helicon antenna modules
- Designed high-field-side lower hybrid system

FY 2020 Plans

- 20-week experimental campaign
  - Study steady-state scenarios with two off-axis NBI
  - One-week hydrogen campaign
  - 1-2 week Frontier Science Campaign
- Install helicon antenna
- Fabricate prototype for mid-plane 3D field coil



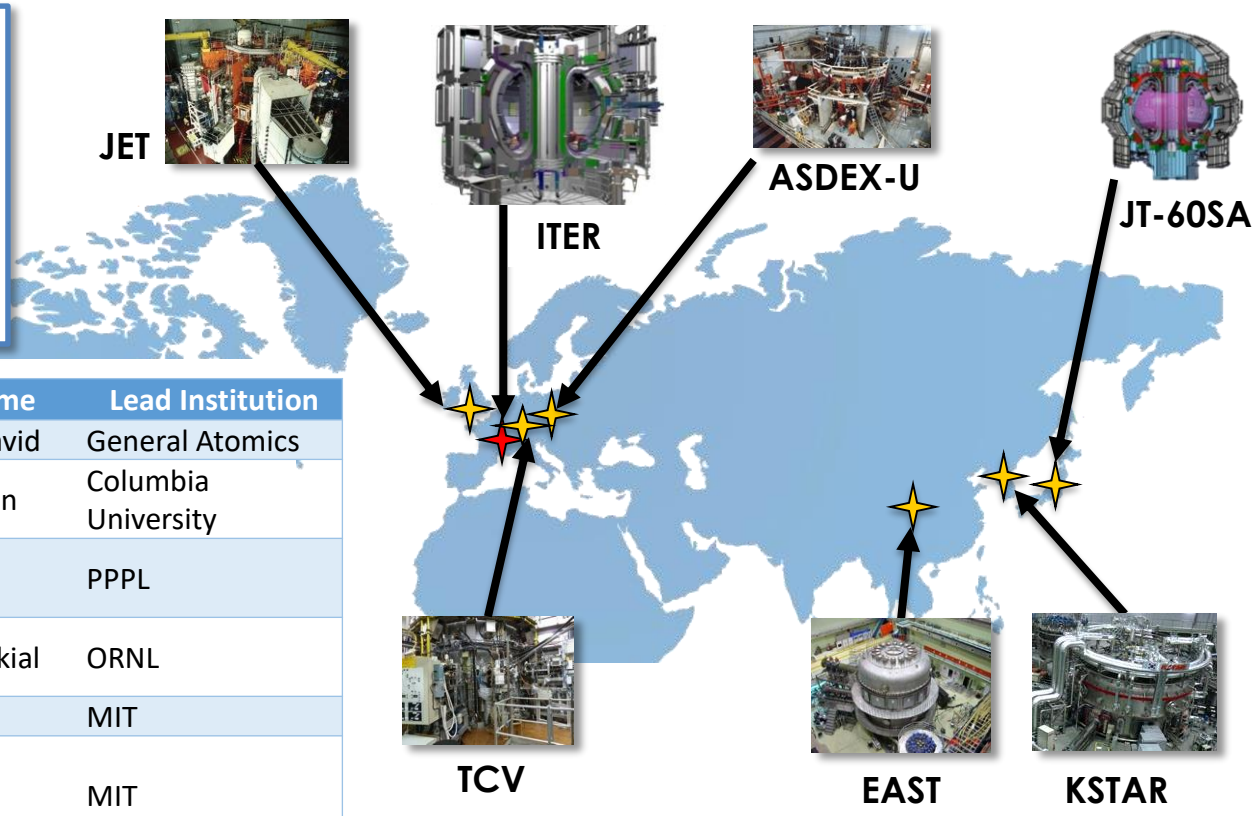
Off-axis neutral beam and imaging from beam-into-gas commissioning

Helicon antenna modules and 1 MW klystron from SLAC

Burning Plasma Long Pulse: Tokamak

Competitive solicitation was conducted in FY 2019 involving activities on both long- and short-pulse tokamaks

- Interdisciplinary teams from multiple U.S. institutions are supported for collaborative research aimed at advancing the scientific and technology basis for sustained long-pulse burning plasma operation



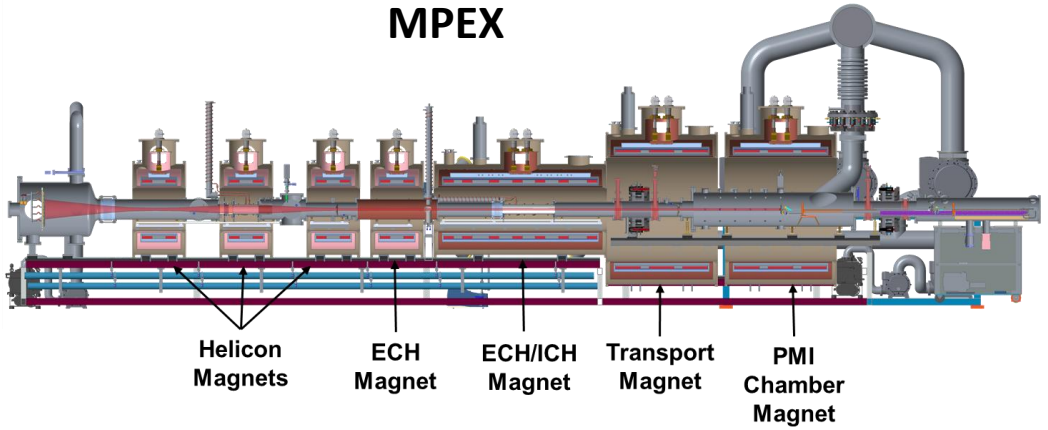
Collaborative Proposal Title	Facility	Lead PI Name	Lead Institution
Long Pulse High Performance Scenarios and Control in EAST	EAST	Humphreys, David	General Atomics
Disruption Prediction and Avoidance in High Beta Long Pulse KSTAR Plasmas – Real Time Expansion	KSTAR	Sabbagh, Steven	Columbia University
Physics Basis, Optimization, and Control for Integrated 3D Edge Long-Pulse Tokamak Scenarios	KSTAR, AUG, COMPASS	Park, Jong-Kyu	PPPL
Evaluation of Tungsten as the Main Plasma-Facing Material in a Long-pulsed Tokamak	WEST	Unterberg, Ezekial	ORNL
Boundary, SOL, and Divertor Physics Studies on TCV	TCV	Marmar, Earl	MIT
Turbulent Transport Studies at ASDEX Upgrade Enabled by Correlation Electron Cyclotron Emission and nT-phase Diagnostic	AUG	White, Anne	MIT
Validation of energetic particle transport models for time-dependent integrated simulations of burning plasmas	JET, AUG, TCV	Podesta, Mario	PPPL
Disruption Mitigation Solutions for Long-Pulse Tokamaks	JET, KSTAR	Baylor, Larry	ORNL
Fast Particle-Wave Interactions and Alfvén Eigenmodes in the JET Tokamak Plasmas	JET	Porkolab, Miklos	MIT
Design and Development of an Electron Cyclotron Emission Diagnostics Suite for Compass Upgrade Tokamak	COMPASS-U	Houshmandyar, Saeid	University of Texas

Construction projects for new world-leading facilities

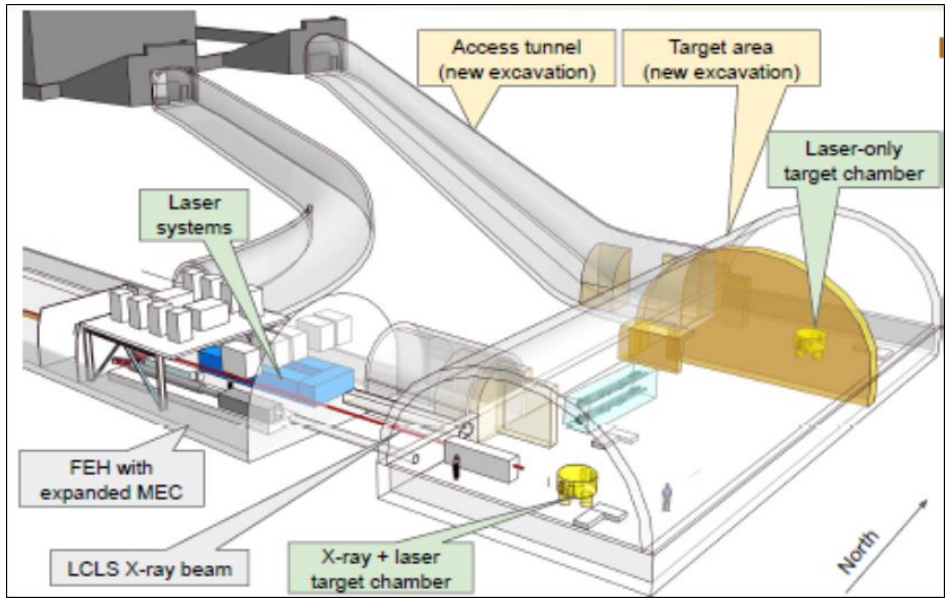
- **FES has initiated a new Major Item of Equipment project for a Linear Divertor Simulator**
  - Mission Need and CD-0 approval were achieved in FY 2018
  - CD-1 Independent Project Review is scheduled for October 16-18, 2019

- **FES is considering an MEC petawatt laser facility upgrade**
  - Mission Need and CD-0 approval were achieved in FY 2019
  - Addresses a recommendation in the 2017 NAS report *Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light*

MPEX



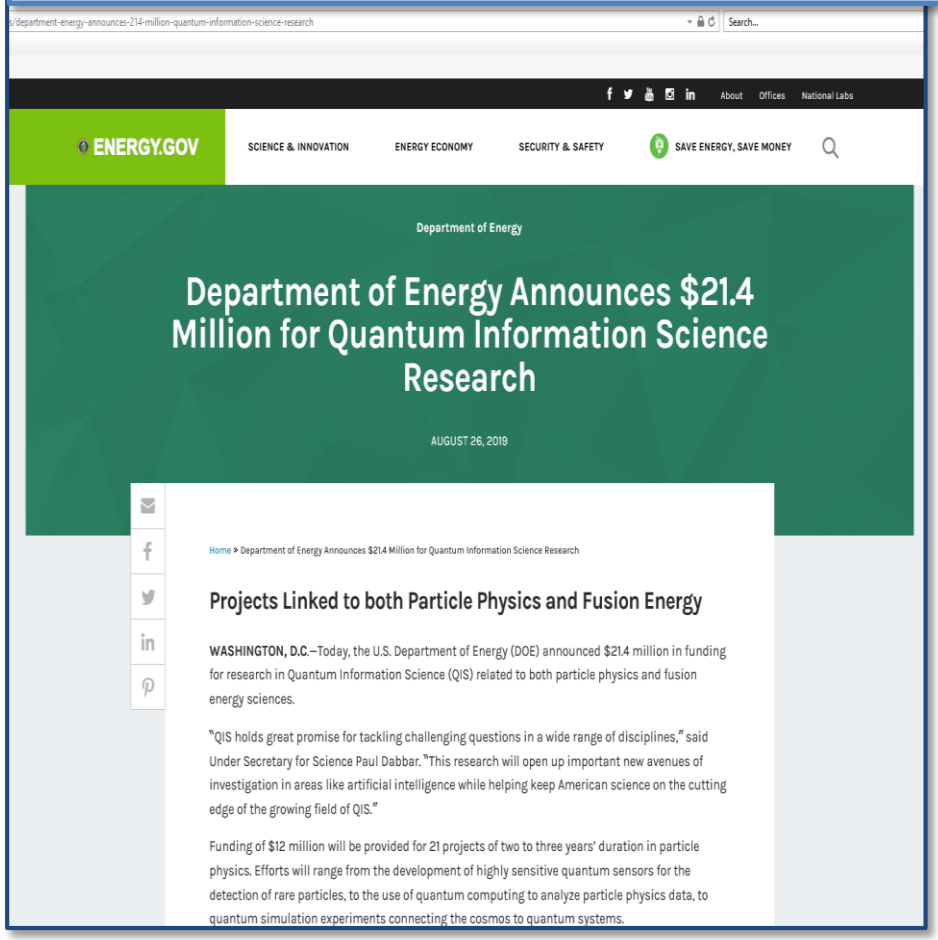
MEC Upgrade



U.S. DEPARTMENT OF ENERGY
Office of Science

FES selected its first awards in QIS

Projects include the exploration of near- and long-term quantum computing opportunities for fusion and plasma science; the use of plasma science techniques to simulate trapped ion crystals of relevance to quantum simulation and sensing; the exploration of new realms of quantum behavior at high-energy-density conditions; and the use of near-term quantum computer hardware to formulate fusion-relevant chemistry and materials science phenomena.



PI Name	Institution	Project Title
Parker, Scott	University of Colorado, Boulder	Plasma Theory Connections to Quantum Information
Gomes Loureiro, Nuno	Massachusetts Institute of Technology	Quantum algorithms for fusion-plasma dynamics
Kostuk, Mark	General Atomics	Quantum Computing for Fusion Energy Materials
Alexeev, Yuri	Argonne National Laboratory	Quantum Computing for Fusion Energy Materials
Joseph, Ilon	Lawrence Livermore National Laboratory	Quantum Leap for Fusion Energy Sciences
Collins, Gilbert	University of Rochester	High Energy Density Quantum Matter

Machine Learning / AI Workshop

- FES & ASCR held a joint workshop April 30 – May 2, 2019, on **Advancing Fusion with Machine Learning**
- **Chair** & **Co-Chair**: David Humphreys (General Atomics), & Ana Kupresanin (LLNL)
- Among the objectives was to identify areas where application of Machine Learning / Artificial Intelligence (ML/AI) techniques and data science more broadly can have a transformative impact on FES mission areas
- Seven Priority Research Opportunities were identified
- A presentation will be provided at the next FESAC meeting

Workshop on Advancing Fusion with Machine Learning Priority Research Opportunities (PROs)

Accelerating Science	Enabling Fusion Energy
PRO 1: Science Discovery with ML *Hypothesis Generation and Experimental Guidance*	**PRO 4: Control Augmentation with ML** *Diagnostics to Data, Dynamic Models for Control, Fusion Trajectory Design*
PRO 2: ML Boosted Diagnostics *ML Boosted Diagnostics, Physics Enhanced Data*	**PRO 5: Extreme data algorithms** *Extreme-scale Processing, In-situ Data Analysis*
PRO 3: Model Extraction and Reduction *Data-driven Models, Reduction of Complex Code Algorithms*	**PRO 6: Data-enhanced Prediction** *Prediction of Disruption Events and Effects, Plasma Phenomena and State Prediction*
PRO 7: Fusion Data ML Platform	

New INFUSE private-public partnership program for fusion R&D

OAK RIDGE National Laboratory

PPPL

https://infuse.ornl.gov/

- The **Innovation Network for Fusion Energy (INFUSE)** program was announced in June
- INFUSE accepted basic research applications focused on innovation for fusion energy in enabling technologies, materials science, plasma diagnostics, modeling & simulation, and MFE experimental capabilities
- INFUSE partnership awards (@$50K-$200K) are made to DOE national laboratories to help eligible private-sector companies overcome critical scientific and technological challenges in the pursuit of fusion energy
- Request for Assistance (RFA) call issued on June 1 and closed on July 7, 2019
  - 21 RFA proposals were received from 11 companies
  - ORNL and PPPL carried out the merit review of the RFA proposals
  - FES selected 12 projects for awards

Planned FY 2020 Funding Opportunity Announcements*

FOA Title	Companion Lab Call
Collaborative NSTX-U Diagnostics	No
Collaborative Research on International and Domestic Spherical Tokamaks	No
High-Energy-Density Laboratory Plasma Science	No
Machine Learning for Fusion Energy Sciences	Yes
Measurement Innovations for Magnetic Fusion Systems	Yes
Opportunities in Frontier Plasma Science	Yes
Quantum Information Science Research for Fusion Energy Sciences	Yes
Theoretical Research in Magnetic Fusion Energy Science	No
Early Career Research Program	Yes

** Tentative, subject to FY 2020 budget appropriation by Congress*

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

3. ITER Updates

ITER Complex

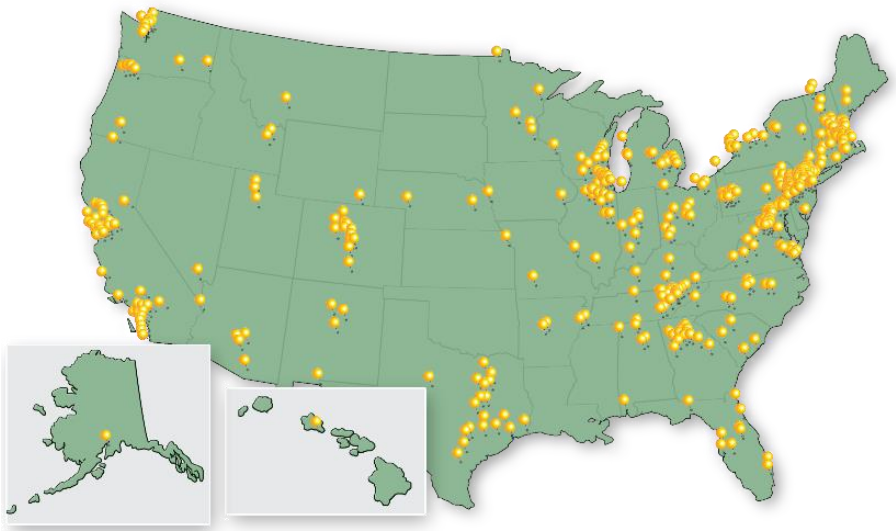
U.S. DEPARTMENT OF ENERGY
Office of Science

Progress of US Contributions to ITER project

>80% of US ITER funding remains in the U.S.

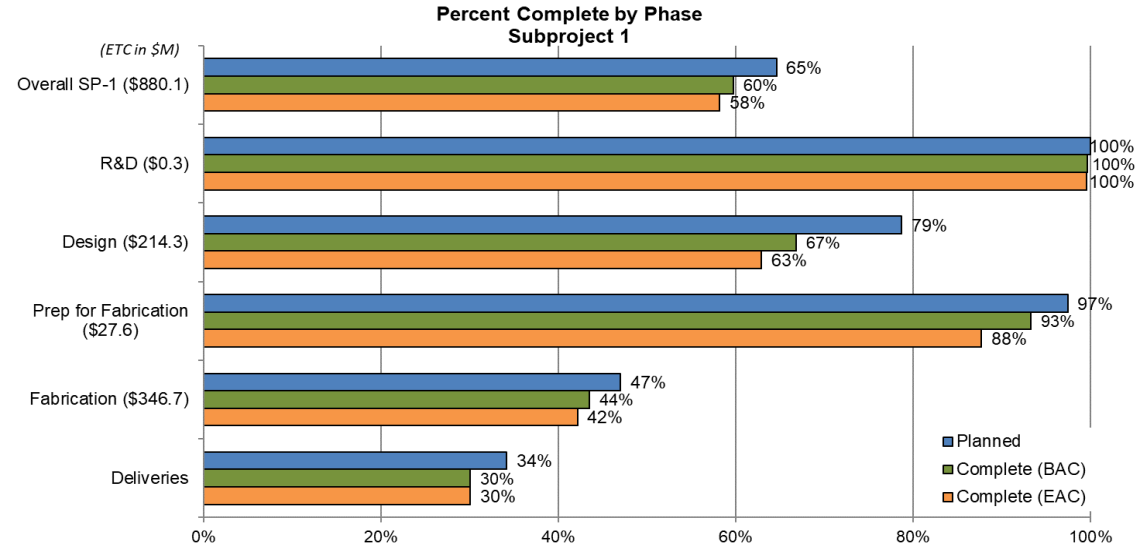
- 600+ contracts to US industry, universities and national laboratories in 44 states
- 500+ direct jobs, 1100+ indirect jobs per year

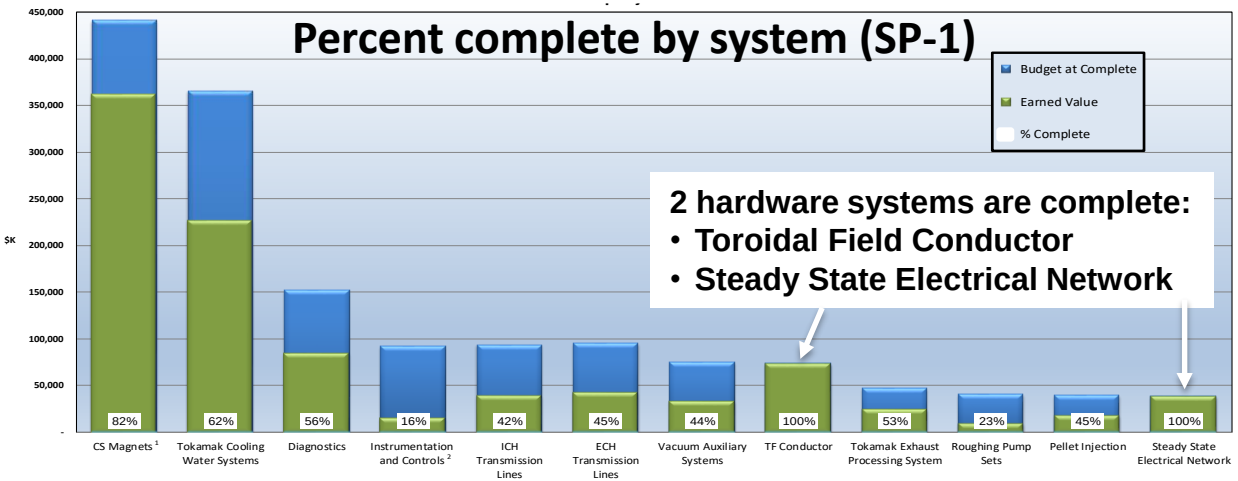
Industry, University and National Laboratory Participants



Total Awards: ~$1.2B
as of June 2019

US ITER Subproject-1 (First Plasma) is 60% complete





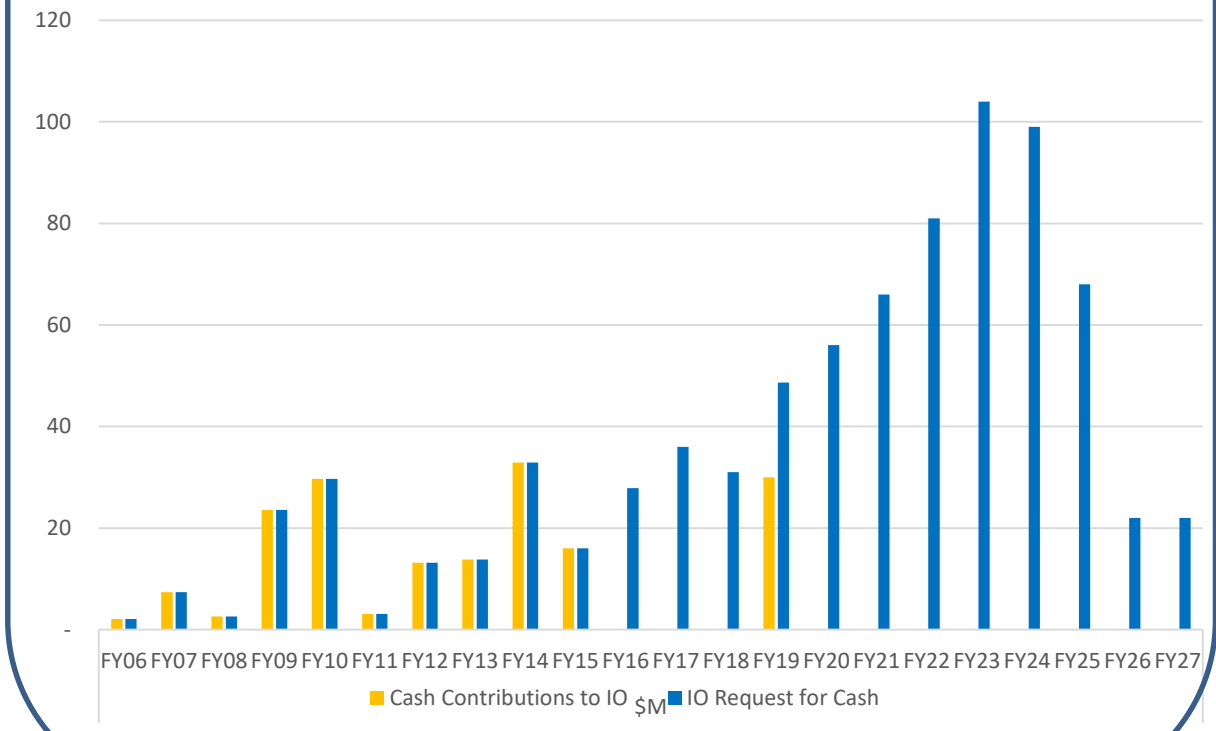
Based on Baseline Data. Does not include full impact of funding constraints.
[1]Includes CS Modules, Structures & Assembly Tooling
[2]Instrumentation & Controls for Tokamak Cooling Water, Diagnostics, ICH Transmission Lines, ECH Transmission Lines, Vacuum Auxiliary, Roughing Pumps and Pellet Injection
Disruption Mitigation is not reported since the US contriution is voluntary up to a capped value.

Data: June 2019

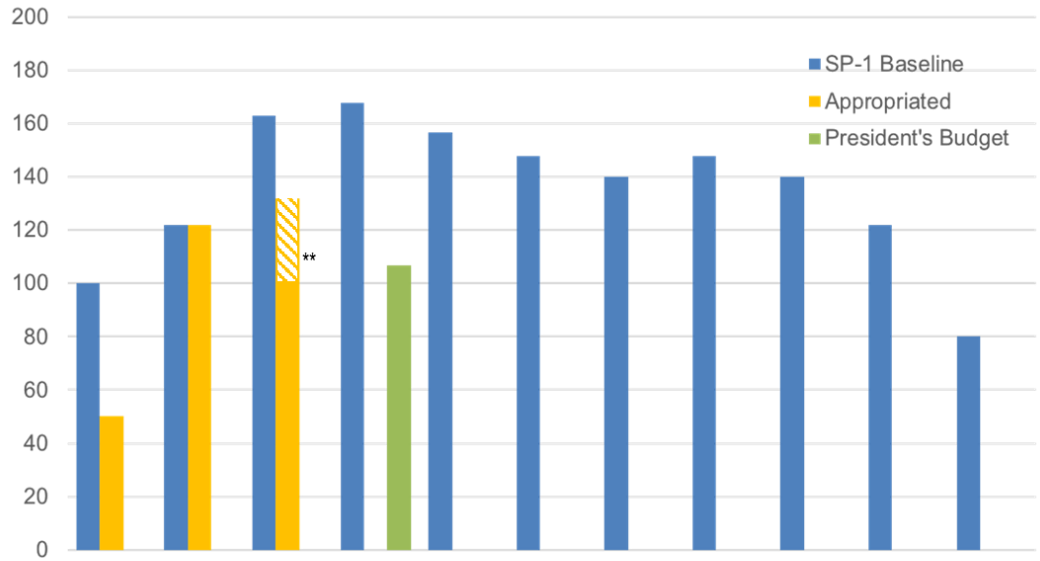
U.S. DEPARTMENT OF ENERGY
Office of Science

Progress of U.S. Contributions to ITER project

Cash contributions



Funding for in-kind hardware components



$M	Prior Years*	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	Total
SP-1	1,012	100	122	163	168	157	148	140	148	140	122	80	2,500
App.	1, 012	50	122	132**	107 (PB)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

U.S. ITER Subproject-1 (First Plasma) is 60% complete

4. Program Planning

Update on 2020 Plasma Decadal study

NAS Decadal Assessment of Plasma Science

[update from Prof. Mark Kushner, co-lead of study committee]

- Plasma 2020 is in the process of finalizing the first draft. The goal is to have a final draft ready for reviewers by early November.
- If there are pressing issues that FESAC wants the committee to be aware of (on any topic in any area of plasma science and engineering), please send a few paragraphs to Prof. Kushner (mjkush@umich.edu) on each issue. Additional white papers should not be submitted at this point.
- Input that would be highly valued (even at this late date) are possible inter-agency collaborations (or inter-program collaborations within a single agency) that would, for example, advance both plasma science and also applications that utilize plasmas. This input (Agency 1, Agency 2; topic; why this is important to both agencies) should be sent to Prof. Kushner.

Fusion regulatory framework

- 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
  - Acknowledge Kurt Heckman for initiating this

- DOE and NRC senior management are aware of this activity and have been involved in planning future engagements
  - Acknowledge Undersecretary Paul Dabbar and NRC Chair Kristine Svinicki for help and support

- Currently planning to hold a one-day public forum on fusion regulation in the March 2020 time frame, in the D.C. area, hopefully in conjunction with the planned FESAC meeting
  - DOE and NRC are developing a draft agenda for this public forum

Enhanced inter-agency interactions

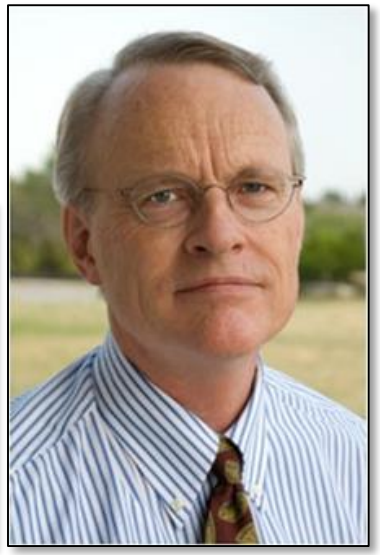
- **Advanced Research Projects Agency–Energy**
  - Talk by Dr. Scott Hsu (ARPA-E) at this meeting

- **National Institutes of Health**
  - DOE began partnering with NIH in 2016 to transform cancer research through advances in high-performance computing technology and AI under the Cancer Moonshot program.
    - The partnership is jointly funded by NIH, NNSA, and SC-ASCR (ECP)
  - Recent meeting of all SC program offices with several NIH institutes
    - SEAB Task Force Report on Biomedical Sciences (2016)
    - HEWD mark-up language for FY 2020 budget
  - Possible coordination areas: data science and artificial intelligence, bio-imaging, cancer therapy, medical isotopes

5. People

Updates since the last FESAC meeting

Dr. Chris Fall was sworn in on May 31, 2019, as the Director of the DOE Office of Science



Dr. James Van Dam became the permanent Associate Director of Science for Fusion Energy Sciences on May 26, 2019

After a little more than a year of phased retirement, **Dr. Mark Foster** will fully retire on October 26, 2019

FY 2019 Early Career Research Awards

FES made four university awards and two laboratory awards in FY 2019

Dr. Arianna Gleason
SLAC
Ultrafast visualization of hydrodynamic evolution: understanding void collapse at extreme high pressure conditions

Dr. Timothy Stoltzfus-Dueck
PPPL
Development and Testing of Reduced Models of the Edge Radial Electric Field

Prof. Ryan McBride
Univ. Michigan
The Physics of Micro-Pinches

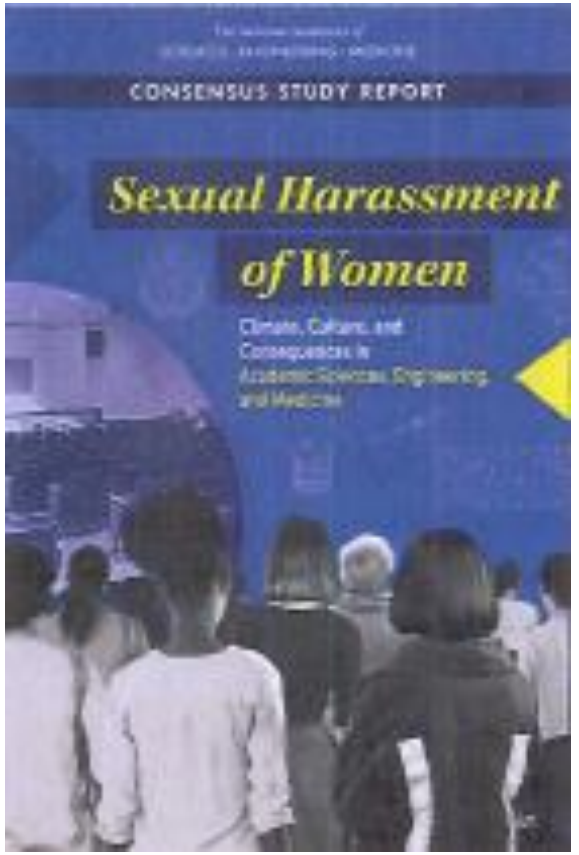
Prof. Hussein Aluie
Univ. Rochester
Scale-Aware Modeling of Instabilities and Mixing in HED Flows

Prof. Karl Hammond
Univ. Missouri-Columbia
Lithium–Divertor Interactions and Helium/Hydrogen Trapping in Lithiated Metals

Prof. Elijah Thimsen
Washington Univ.
Structure of Plasma-Water Interface

Diversity, Equity, and Inclusion

- **Office of Science activities**
  - The Office of Science invited the National Academies to brief our Federal Advisory Committees about the 2018 NAS Report on *Sexual Harassment of Women in Academia*. The briefing to FESAC today completes the briefings to SC's six Federal Advisory Committees.
  - DOE has long had policies prohibiting discrimination and harassment.
  - SC launched a website in April (2019) that consolidates DOE's policies and procedures; SC posted a Statement of Commitment to DEI on its website.
  - SC coordinates with the OSTP Director's Subcommittee on Safe and Inclusive Research Environments.
  - Since 2016, SC has used the Annual Laboratory Plans to evaluate the national laboratories' efforts in DEI; each of the six SC offices does a review of the DEI plan for each of the labs.
  - SC is convening a panel of experts later this year to evaluate the DEI efforts of all SC labs.
  - At its next meeting, FESAC will be briefed on the details of these activities.



- **APS is considering establishment of a Forum on Diversity and Inclusion**

Sincere appreciation to FESAC members

- **Retiring members**
  - Siegrid Close (Stanford)
  - Charles Greenfield (GA)
  - Richard Groebner (GA)
  - George (“Hutch”) Neilson (PPPL)
  - Juergen Rapp (ORNL)
  - Amy Wendt (Wisconsin)

- **New members**
  - Ralph Izzo (PSEG)
  - Charles Kessel (ORNL)
  - Lorin Matthews (Baylor)
  - Scott Parker (Colorado)
  - Fred Skiff (Iowa)
  - Philip Snyder (GA)