Fusion Energy Sciences Perspectives & Plans

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

U.S. DEPARTMENT OF ENERGY
Office of Science

University Fusion Association Meeting
60th APS-DPP Annual Meeting
November 5, 2018

1. Budget Updates

Robust FY 2018 and FY 2019 enacted budgets

Enacted FES appropriations for FY 2018 ($532M) and FY 2019 ($564M) enable accelerated progress throughout the program:

- **ITER**: Continued progress on U.S. Contribution to ITER project with emphasis on highest-priority First Plasma activities
- **DIII-D**: Initiated over $20M of enhancements and infrastructure improvements for the DIII-D user facility to maintain and advance its world-leading research capabilities
- **NTSX-U**: Accelerate the Recovery efforts
- **LaserNetUS**: Established a U.S.-wide network of nine mid-scale laser facilities at universities and national laboratories to expand user access to high-power lasers
- **MPEX Facility**: Initiated the Materials Plasma Exposure eXperiment (MPEX) MIE project as a new world-class high-heat-exposure facility for testing fusion materials
- **Theory & Simulation**: Accelerate progress in Whole-Device Modeling and Exascale readiness; strengthen support for fusion-relevant Machine Learning applications
- **Private-Public Partnerships**: Planning underway to initiate high-impact public-private partnerships as a pilot program to leverage opportunities in critical fusion research areas and accelerate progress toward the development of fusion energy
- **QIS**: Start pilot efforts in Quantum Information Science that can advance both the FES mission and also the development of QIS


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Department of Energy Announces $36.4 Million for Fusion Energy Sciences Research

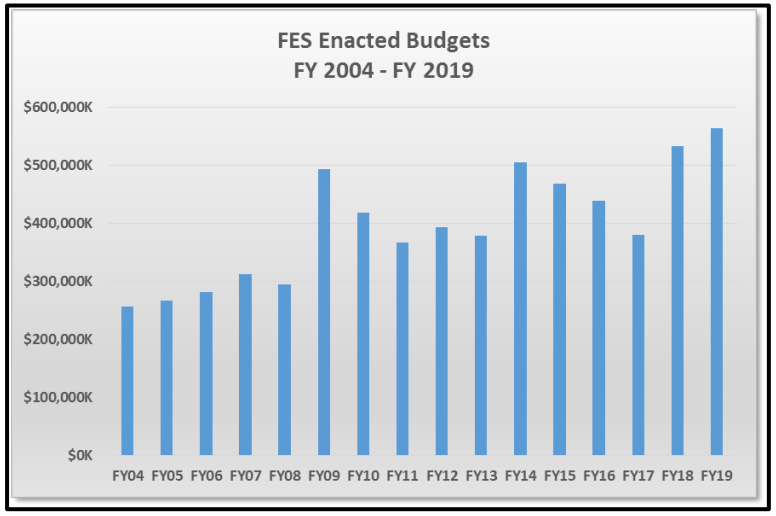
AUGUST 2, 2018

Home » Department of Energy Announces $36.4 Million for Fusion Energy Sciences Research

Projects Seek to Make Fusion Energy Feasible

WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced $36.4 million in funding for 37 research awards at

DOE Website (August 2, 2018)



Budget Trends

FES program can address 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 could 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 would 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:** Private-public collaborations would 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 scientific challenges and rigor of fusion plasma physics research contribute to the development of a well-trained STEM-focused workforce, which would help maintain and advance U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security.

EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C.

July 31, 2018

M-18-22

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

FROM: MICK MULVANEY
DIRECTOR, OFFICE OF MANAGEMENT AND BUDGET

MICHAEL KRATSIOS
DEPUTY ASSISTANT TO THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUBJECT: FY 2020 Administration Research and Development Budget Priorities

The United States is a nation of thinkers, inventors, and entrepreneurs. Empowered by free-market capitalism and driven by bold ideas, Americans created an ecosystem of innovation that is the envy of the world, advancing science and technology and making the Nation prosperous and strong. America brought the miracle of electric light to people's homes, placed millennia of knowledge in people's pockets, and put men on the Moon and brought them safely back to Earth.

Building on a foundation of Federal research and development (R&D) investments, America will also be the nation that leads in today's emerging technologies, from artificial intelligence (AI) and quantum computing, to biotechnology, advanced wireless communications, and space commercialization.

Federal R&D dollars focused primarily on basic and early-stage applied research, paired with targeted deregulation, and investment in science, technology, engineering, and mathematics (STEM) education and workforce development, will strengthen the Nation's innovation base and position the United States for unparalleled job growth, continued prosperity, and national security.

This memorandum highlights the Administration's R&D priorities and provides guidance to agencies as they formulate their Fiscal Year 2020 budget submissions. This memorandum also details priority practices to effectively leverage R&D resources, including R&D workforce and infrastructure.

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

Solicitation status

- A number of **Funding Opportunity Announcements** (FOAs) and companion Lab Announcements have not been issued yet due to changes in the SC FOA approval process
- The past practice of issuing FOAs in the fiscal year before the funding year may not be feasible
- The **Annual "open" SC FOA** is always active; please check with your Program Manager about whether you should consider submitting to this FOA, especially if the due date for the submission of your renewal proposal is past or rapidly approaching
- You are also encouraged to check the SC and FES **Funding Opportunities** pages for updates (https://science.energy.gov/fes/funding-opportunities/)

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FY 2018 CONTINUATION OF SOLICITATION FOR THE OFFICE OF SCIENCE FINANCIAL ASSISTANCE PROGRAM

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER:
DE-FOA-0001820

FOA TYPE: AMENDMENT 000001
CFDA NUMBER: 81.049

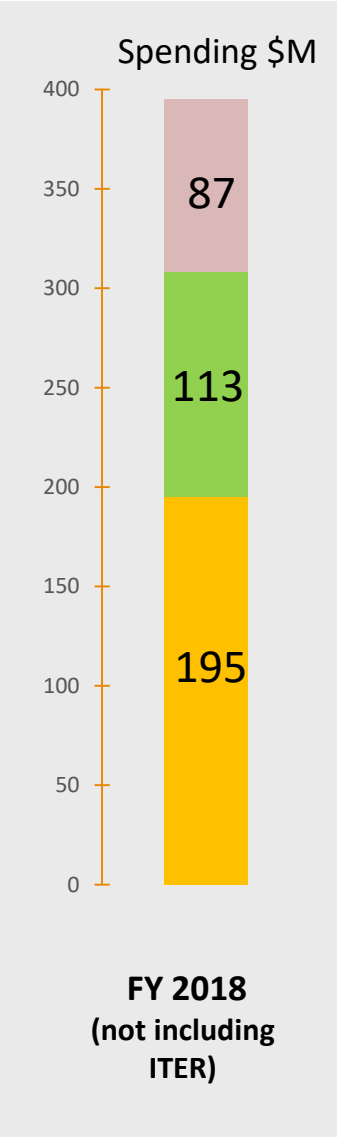
FOA Issue Date:	May 25, 2018
Submission Deadline for Letters of Intent:	N/A
Submission Deadline for Pre-Applications:	A pre-application is optional
Pre-Application Response Date:	N/A
Submission Deadline for Applications:	N/A This FOA will remain open until December 31, 2018 or until replaced by a successor FOA. Applications may be submitted any time during this period.

Amendment 1: The amendment will change the close date to December 31, 2018.

https://science.energy.gov/~/media/grants/pdf/foas/2018/SC_FOA_0001820.pdf

2. Programmatic Updates

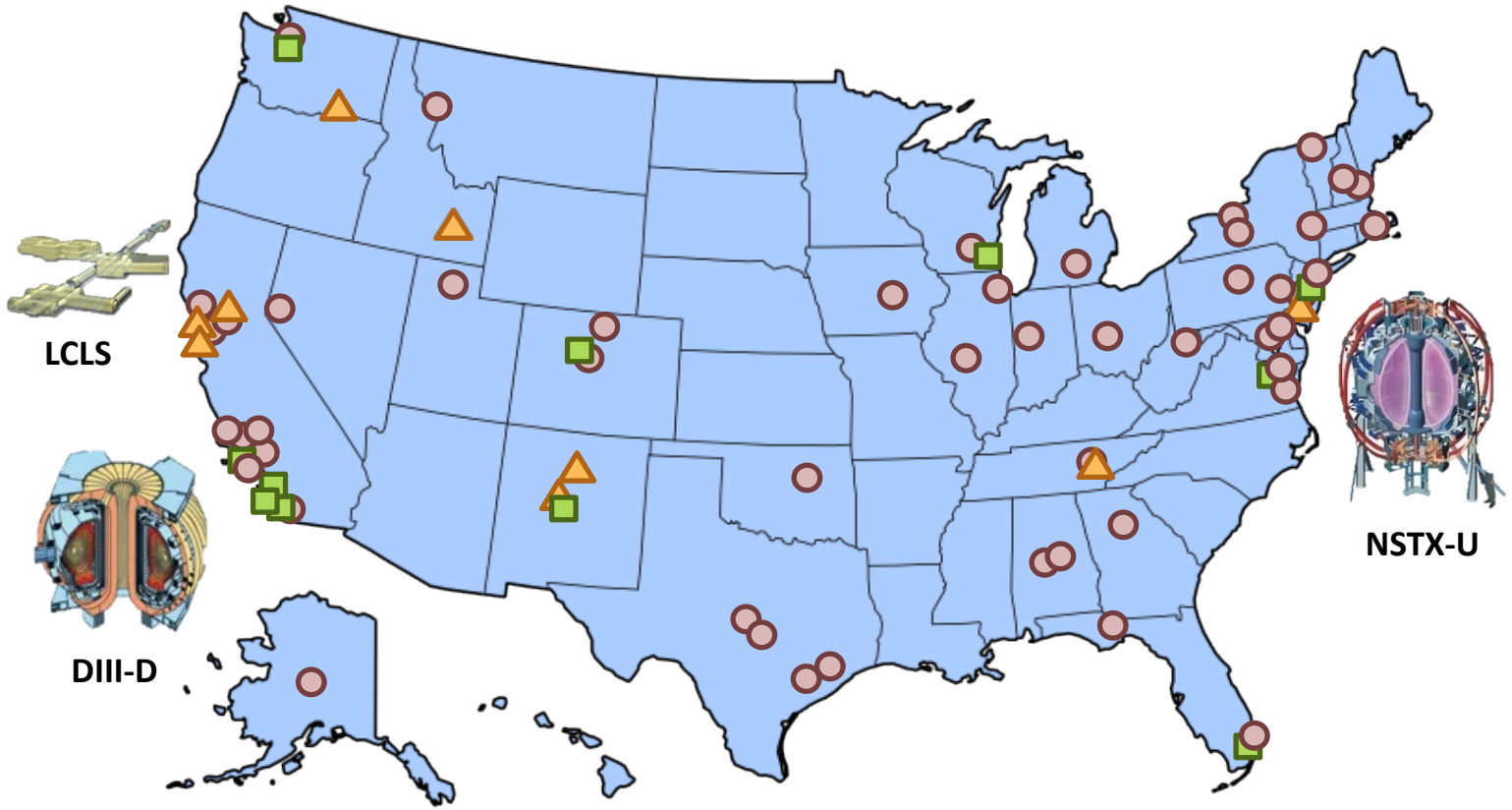
FES research is carried out at a diversity of US institutions



38 universities

11 industry

11 laboratories



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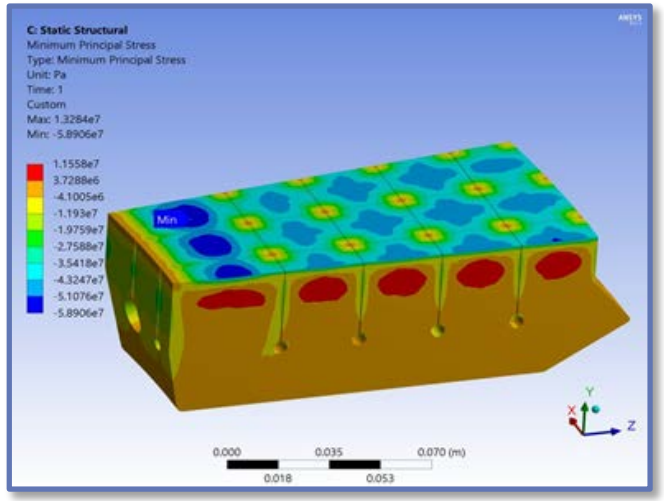
The project team has made progress towards a robust recovery of the NSTX-U

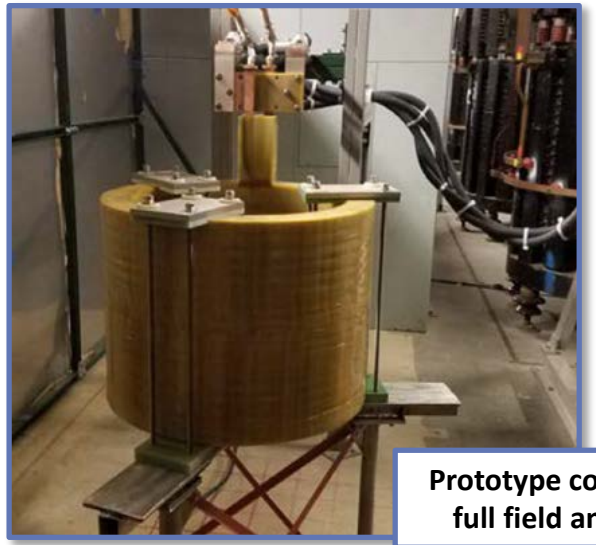
Important reviews, design work, and project activities:

- ✓ A thorough assessment, conducted by 50+ external reviewers, identified all problems requiring repair to recover robust plasma operations
- ✓ PPPL has completed the preliminary design of the NSTX-U Recovery scope
- ✓ Early material procurements, coil prototyping and testing
- ✓ A baseline review of the total project cost and schedule is slated to take place in February of 2019

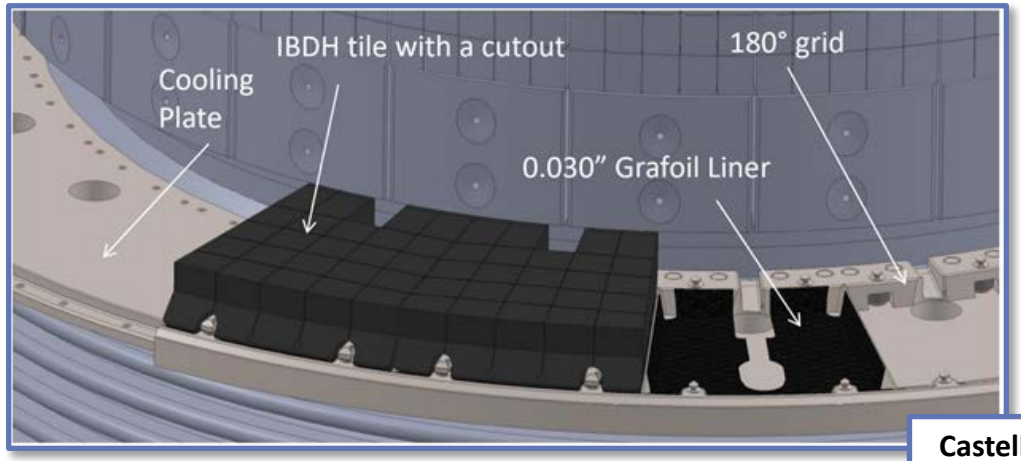


Engineering analysis of new castellated PFC tile design

TF/OH conductor bundle prior to a casing fit-up lift



Prototype coil testing to full field and current



Castellated tile in situ

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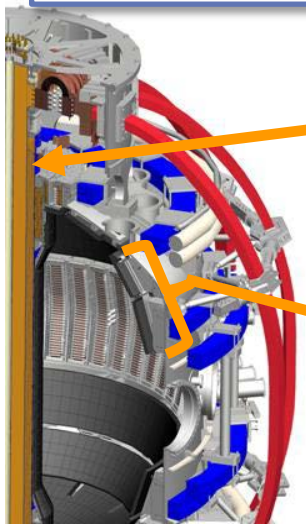
An independent panel of fusion experts reaffirmed the scientific mission for NSTX-U

Ray Orbach led a DOE OPA subcommittee, which found:

- "Full exploitation of the NSTX-U facility is essential for critical tests of the potential advantages of the spherical tokamak for fusion power production."
- "In its chosen domain of exploration of high- performance, high-β, and low-collisionality plasmas, NSTX-U is and will be the world leader."



NSTX-U

NSTX-U central magnet provides **~2 x higher B_T^2** compared to MAST-U

NSTX-U conducting plates provide **~3 x higher total pressure** compared to MAST-U

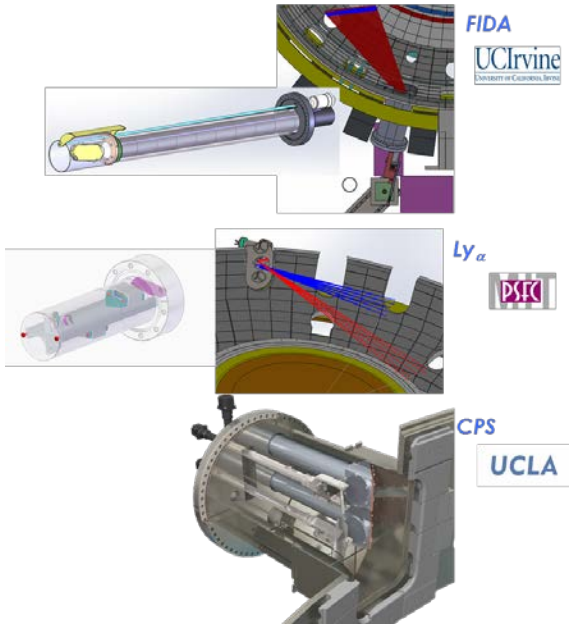
MAST-U
Complementary ST facility in the UK
Dedicated on October 18

Dr. Raymond Orbach *(former DOE Under Secretary for Science, 2006-2009)*

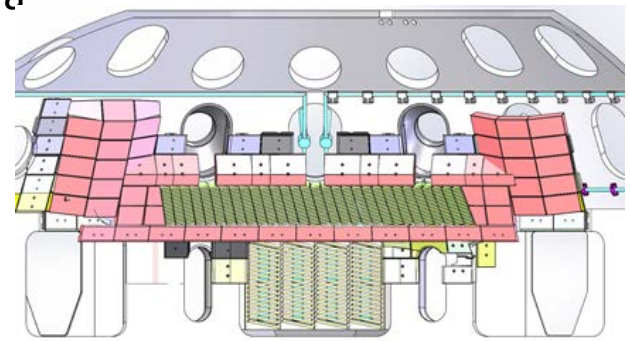
DIII-D Long Torus Opening (LTO)

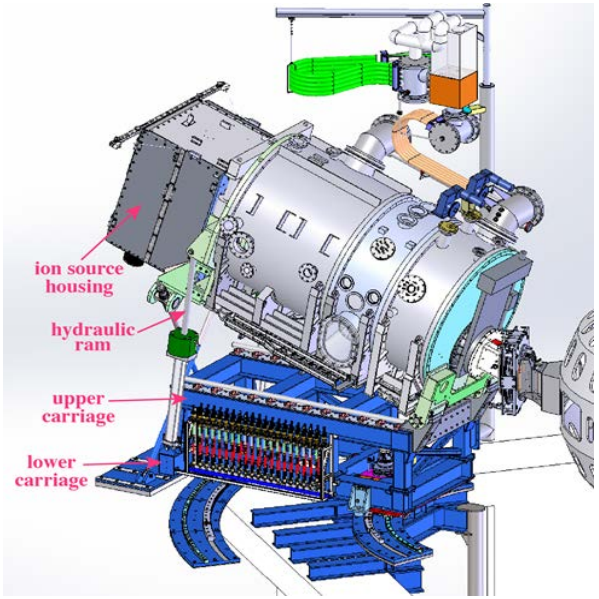
- **DIII-D will complete LTO in April 2019 and operate for up to 12 weeks in FY 2019**
- **Major ongoing LTO tasks include:**
  - New co/counter off-axis neutral beam modification
  - Top-launch ECCD capability
  - Installation of helicon strip-line antenna
  - New/upgraded diagnostics

New diagnostics

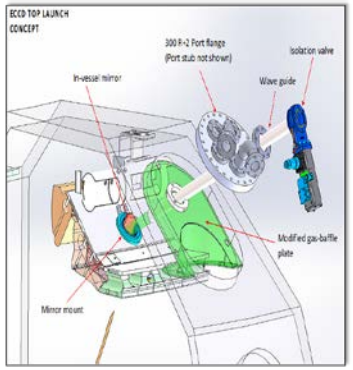


Helicon antenna





Co/counter off-axis neutral beam

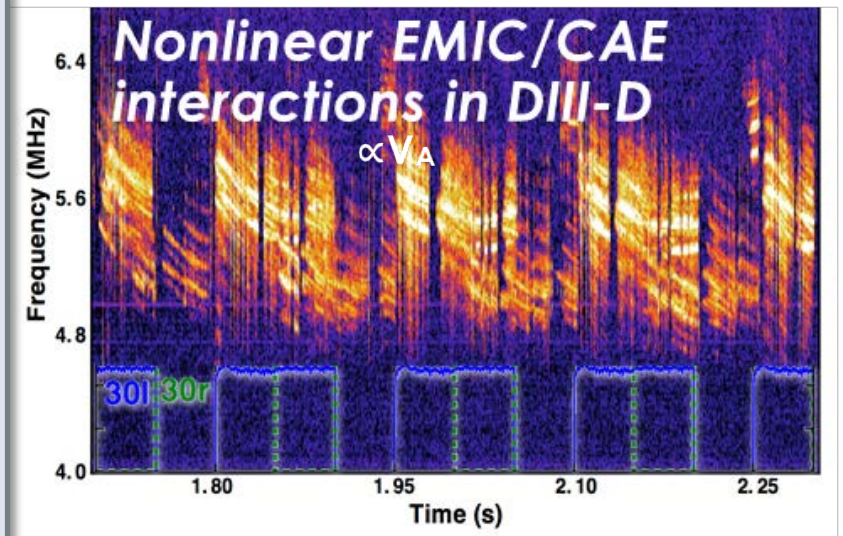


Top launch ECCD

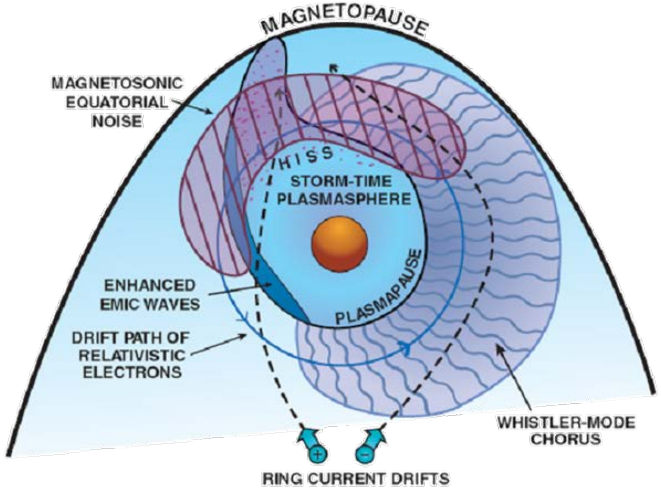
- **Other activities enabled by robust FY 2018 funding include:**
  - New helium liquefier and 3 replacement gyrotrons on order
  - Start of high-field-side LHCD project
  - New collaboration grants
  - Sustaining engineering work to increase facility reliability

Frontier science on DIII-D

- **In FY 2017, FES started a new initiative to focus some DIII-D experiments on frontier plasma science**
- **Whistler wave experiment resulted in a post-deadline invited paper at the 2017 APS-DPP meeting, a recent PRL paper** (Spong et al., 2018 *PRL* 120, 155002), **and 2018 APS-DPP oral presentation by Z. Williams (U. Wisc) -** Wed Afternoon Session PI2
- **Four experiments selected in 2018 utilizing 5 run days:**
  - EMIC waves: Leads W. Heidbrink (UCI)/S. Vincena (UCLA))
  - Runaway electrons & plasma waves: Lead D. Spong (ORNL)
  - Positron generation by runaways: Lead P. Aleynikov (IPP)
  - Sawtooth reconnection studies: Lead W. Fox (PPPL)
- **Engagement very positive, with visiting scientists impressed by the quality of DIII-D data**
- **Focus is now on analysis to obtain results from each study**
- **In FY 2019, the program will be assessed to evaluate progress and to integrate review and selection processes**



EMICs depopulate magnetosphere



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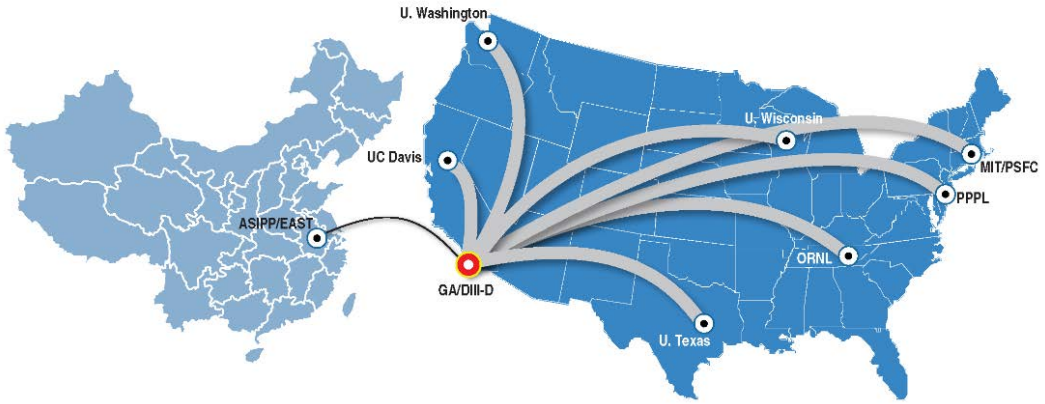
Remote tools are being made available to U.S. institutions to facilitate international collaboration

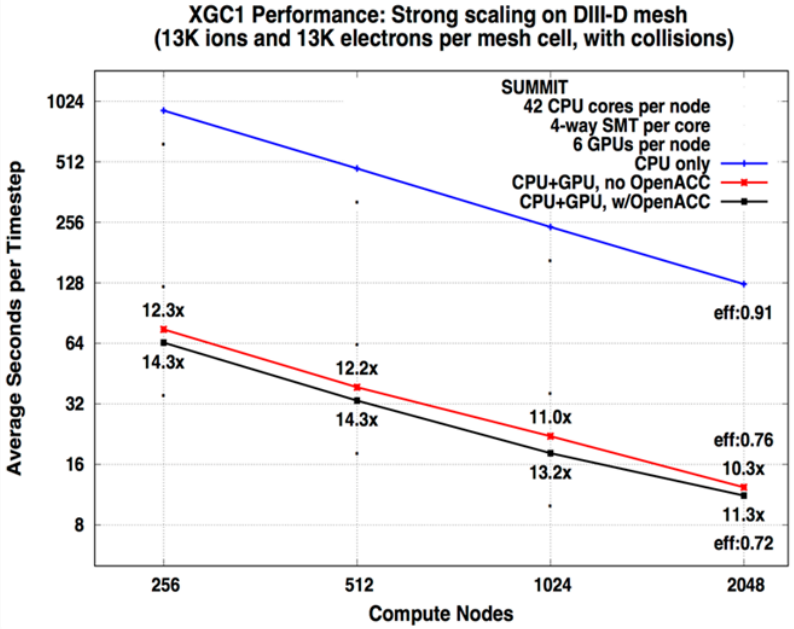
- **In FY 2018, 7 institutions used remote tools to connect remotely to EAST facility during evening in China**
  - GA, Lehigh U., LLNL, MIT, PPPL, UCLA, U. of Texas
  - 10 days of operations, ~250 shots
- **Services support non-trivial utilization of EAST facility, can be made available to any remote control room in U.S.**
  - Fast bulk data transfer avoiding bottlenecks
  - Real-time data, MDSplus data server
  - Multi-channel audio/video
- **Remote control rooms were also used to provide U.S. support to W7-X during recent campaign (OP1.2b)**

68 scientists from 9 U.S. research institutions can already access the services



FES SciDAC portfolio continues to emphasize integration and whole-device modeling

- FES SciDAC-4 portfolio has nine multi-institutional and inter-disciplinary projects (seven supported both by FES and ASCR)
  - The ninth project added in FY 2018 is focused on runaway electron avoidance and mitigation
  - 11 universities, 8 DOE national laboratories, and 5 private industry institutions (including small businesses) in 13 states
  - Five of these projects are led by university scientists and the rest include substantial university participation
  - More details can be found at: https://scidac.gov/partnerships/fusion_energy.html
- FES SciDAC research activities are coordinated to accelerate progress toward whole-device modeling and increase synergy with the Theory and Exascale (ECP) programs
- The new portfolio addresses research opportunities identified in recent community workshops



Strong scaling of the XGC1 code on the maximal available Summit nodes, enabled by the Center for Accelerated Application Readiness (CAAR)

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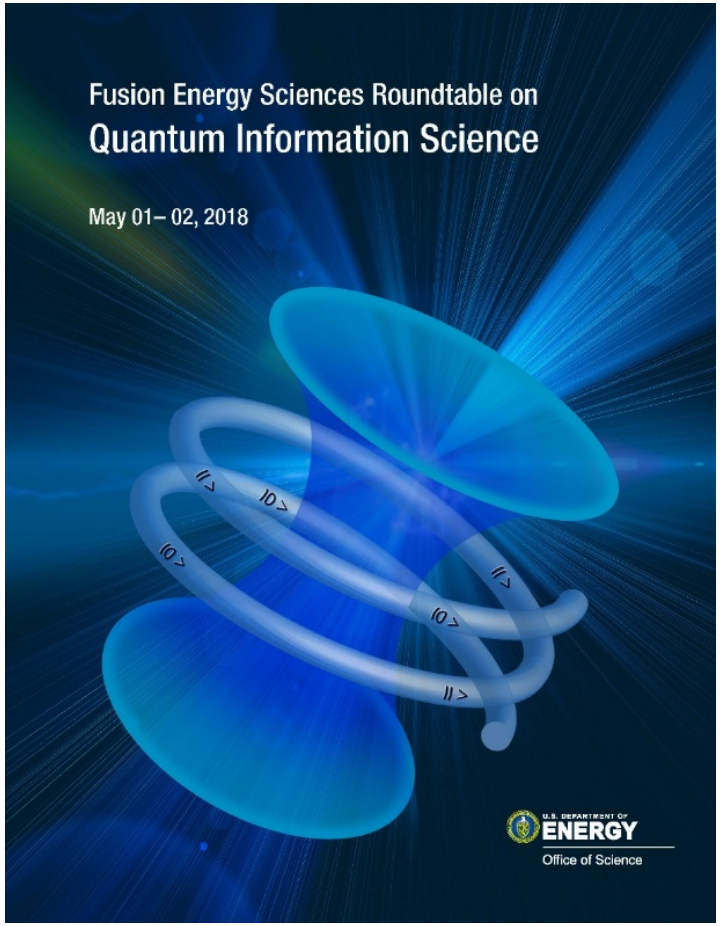
FES is exploring opportunities in QIS

- FES held a Roundtable meeting on **May 1-2, 2018**, to explore its role in **Quantum Information Science (QIS)**
  - Co-chaired by **Thomas Schenkel** (LBNL) and **Bill Dorland** (U Maryland)
  - Attended by **15** participants and several observers
- The meeting objectives were to:
  - Identify fundamental science supported by FES that could advance QIS development; and
  - Explore QIS applications that could have transformative impact on FES mission areas (e.g., fusion and discovery plasma science)
- Identified six compelling **Priority Research Opportunities**



Report available from:
https://science.energy.gov/~/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf

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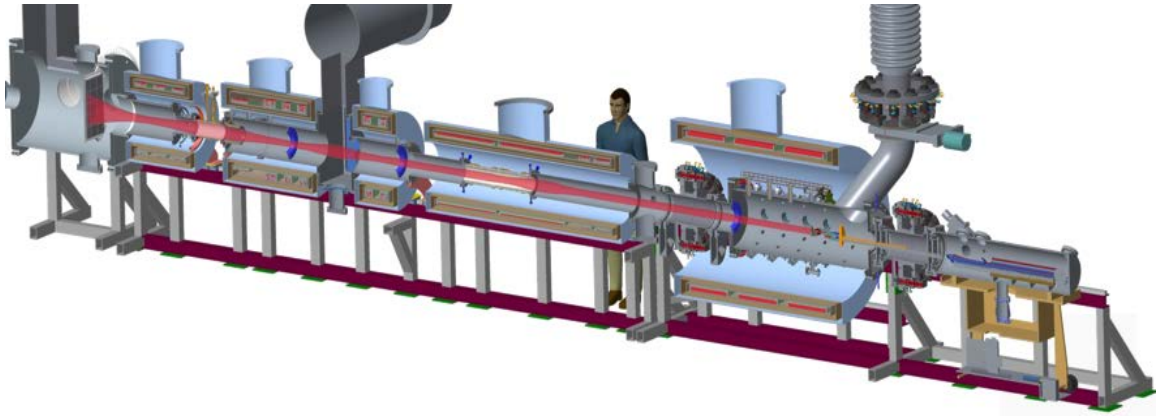
Materials Plasma Exposure eXperiment (MPEX) new MIE Project

- FES has initiated a new Major Item of Equipment (MIE) project with approval of the Scientific Mission Need for a Linear Divertor Simulator in March of 2018
- This project will enable new experimental capability for reactor-relevant plasma-materials interaction studies, including high-heat exposure of neutron-irradiated samples
- In response to the mission need, FES has begun development of the Materials Plasma Exposure eXperiment (MPEX), which is based on the Proto-MPEX Source Experiment at ORNL
  - Conceptual design of the MPEX device began at ORNL in the summer of 2018 and is currently ongoing, with completion expected by the end of summer 2019
- Construction of the MPEX device will result in a significant expansion of fusion materials science experimental capabilities in the U.S.

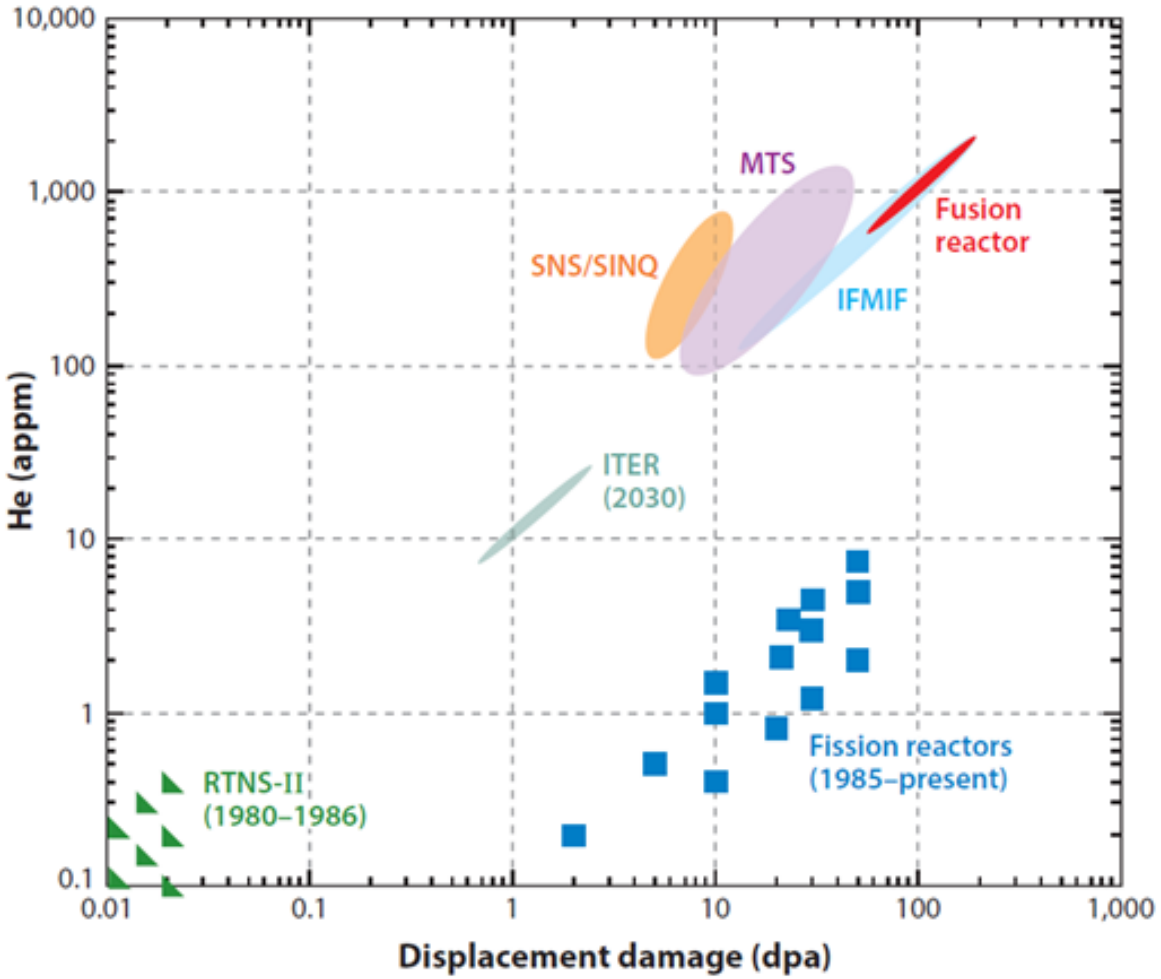
Proto-MPEX Source Experiment

MPEX conceptualization



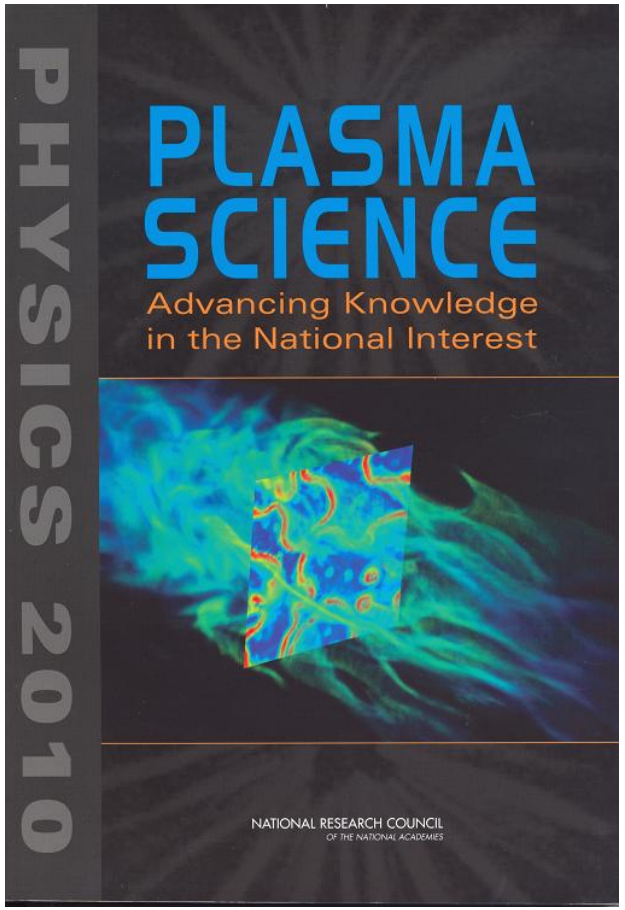
Fusion Prototypic Neutron Source Workshop

- 33 members of the US fusion materials community, the Virtual Laboratory for Technology, and private industry met on August 20-22, 2018 to discuss the possibility of the US exploring a near-term, low cost Fusion Prototypic Neutron Source
- Initial discussion indicated that there is significant scientific value in an intermediate next-step device on the road to IFMIF or one of its variants (e.g., DONES/AFNS)
  - The source must be "near term" (construction possible in ≤ 3 years) and of moderate cost
  - The goal is to provide scientific understanding to enable an Fusion Nuclear Science Facility, not engineering date required for full licensing
- Minimum required source characteristics:
  - 8-11 dpa/CY in the high flux zone
  - ~10 appm He/dpa in Fe
  - ≥ 50 cm3 in the high flux zone
  - 300 – 1000 °C, with three independent temperature zones actively monitored and controlled
  - Flux gradient ≤ 20%/cm in the plane of the sample

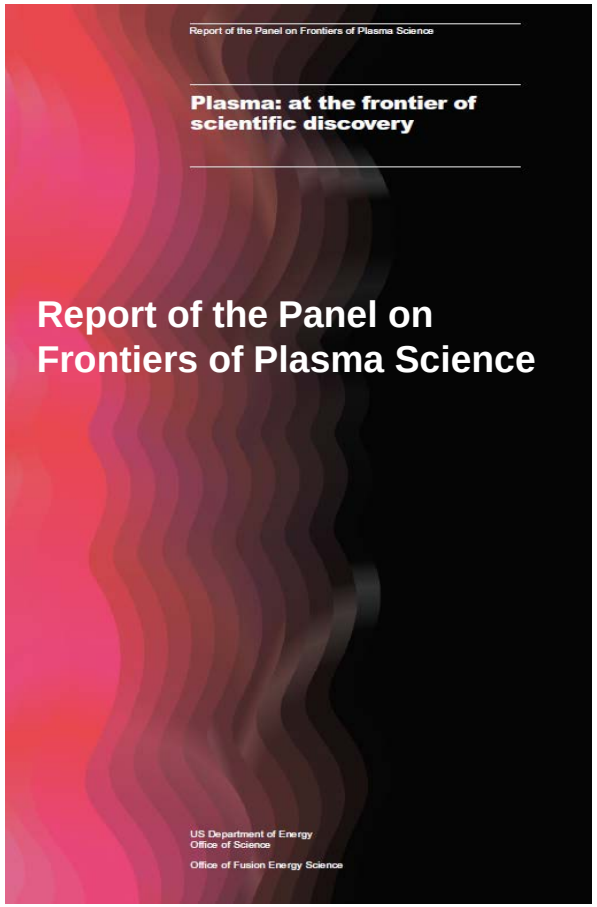


Summary of He dose relationships important for steels

A new intermediate-scale user facility for dusty plasma research was awarded in 2018



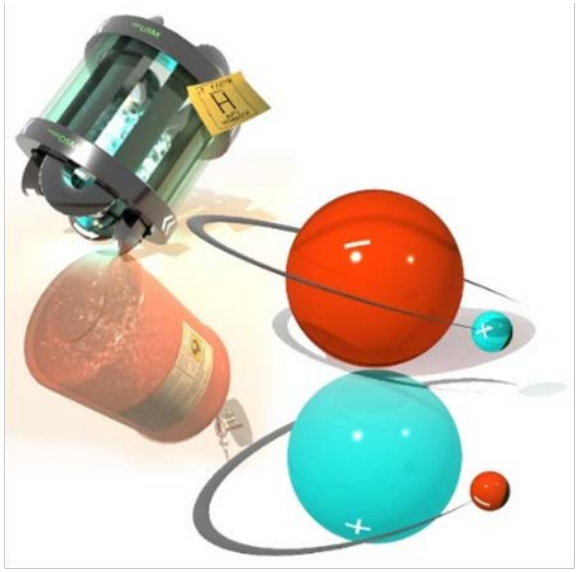
"Several areas of basic plasma science would benefit from new intermediate-scale facilities." (2010 Decadal Study)

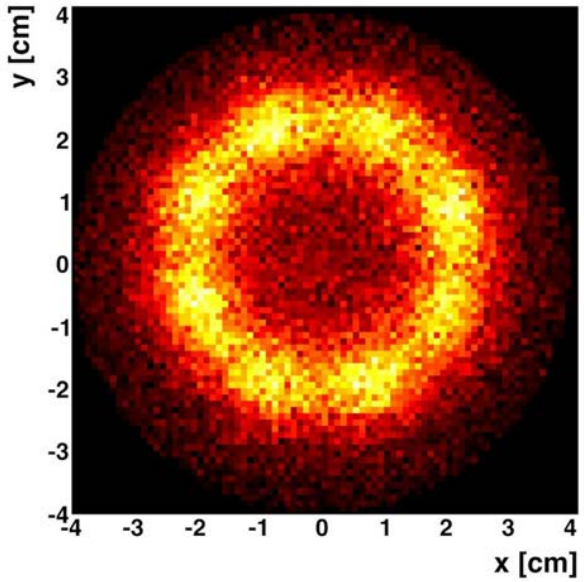


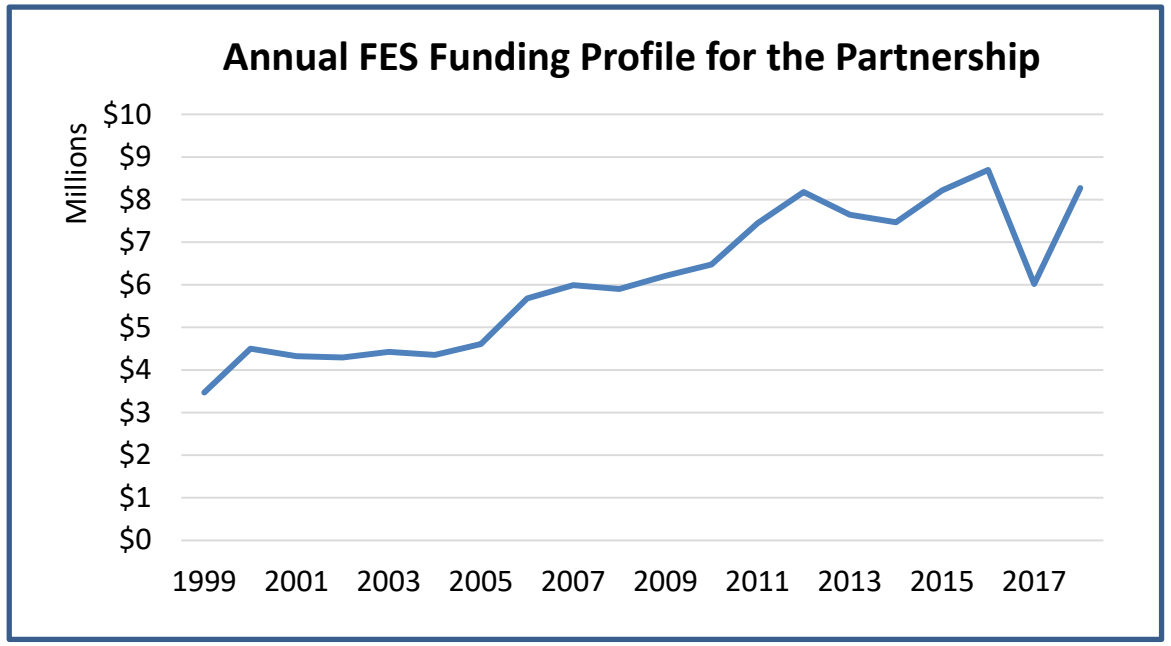
"There is a need for creation and exploration of new regimes in the laboratory." (2016 PSF Report)

FES awarded $1.5M of FY18 funds over three years to Auburn University to operate the Magnetized Dusty Plasma Experiment (MDPX), an intermediate-scale, integrated, collaborative plasma science user facility

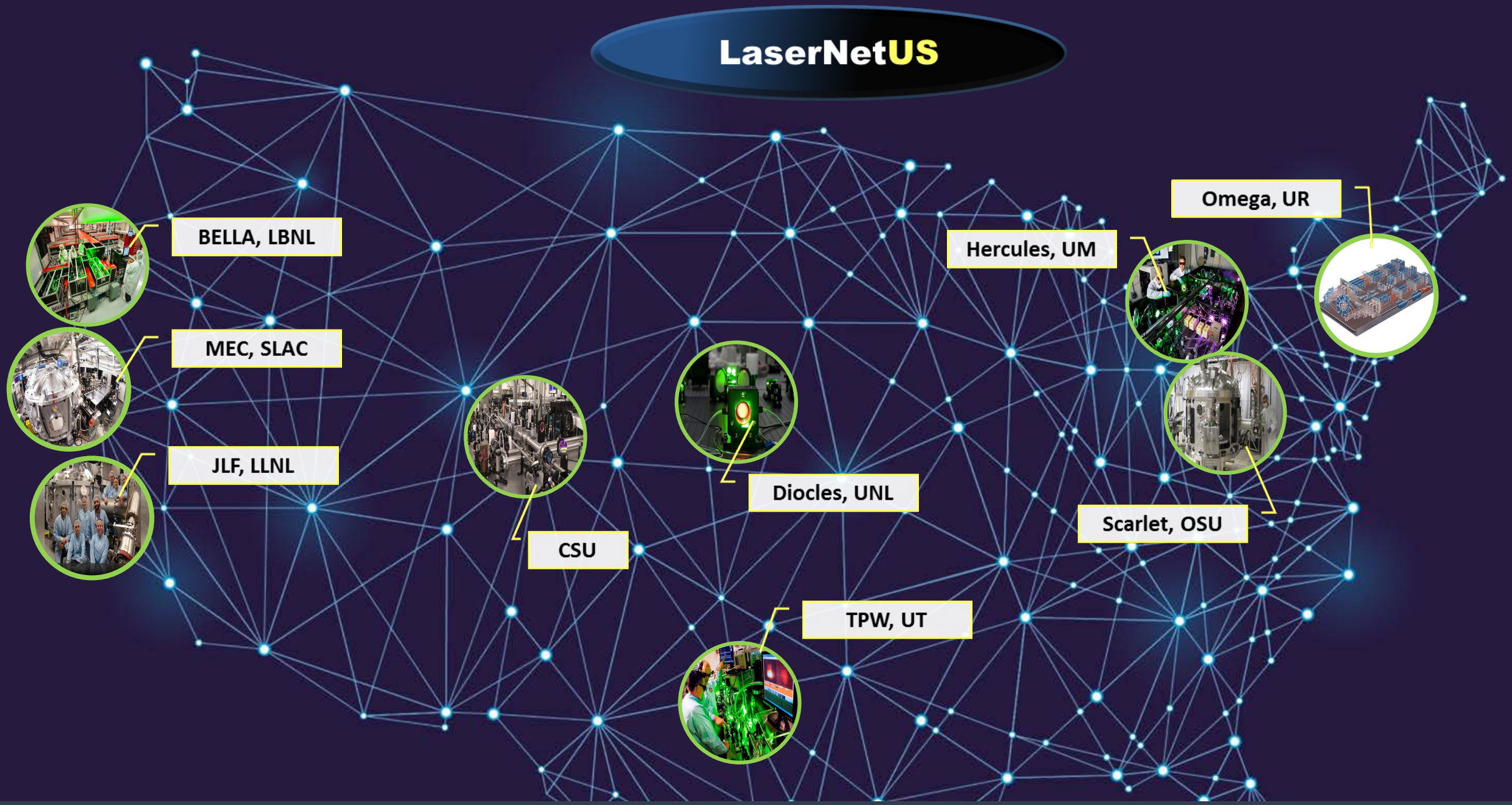
NSF/DOE Partnership: Over $8 million funded by FES in 2018







- FES provided $8.3 million FY18 funds for the Partnership, supporting 11 new or renewal proposals in basic plasma, non-neutral/dusty plasma, HED plasma, and low temperature plasma
- This includes $2.5 million over five years for antihydrogen research led by the University of California-Berkeley, collaborating with ALPHA
- Also, includes $2.3 million for Basic Plasma Science User Facility's (BaPSF) continuing operation and research at UCLA



FES established LaserNetUS in FY18 in response to NAS recommendations

The network provides broad access to state-of-the-art facilities for the entire community

3. ITER Updates

Progress of U.S. ITER project

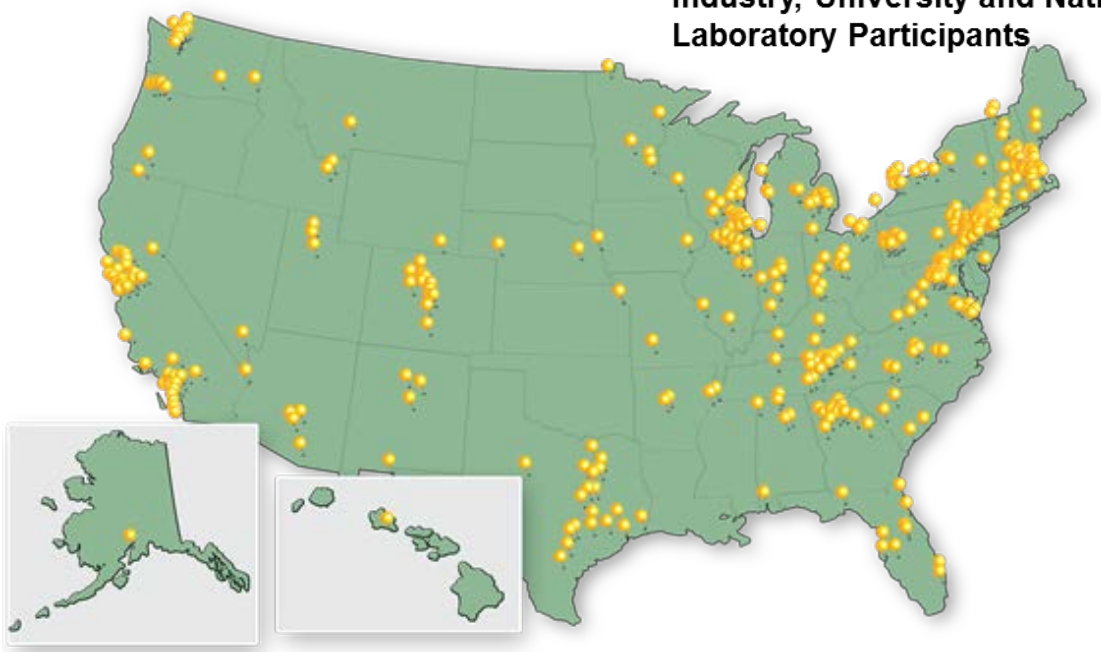
Total Contract Awards: ~$1B

as of June 2018

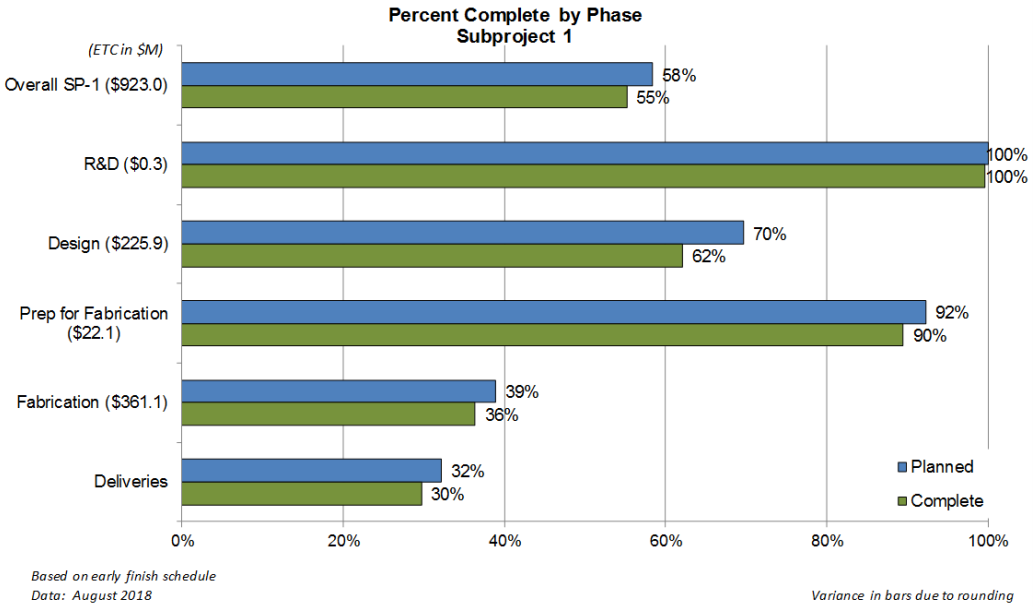
>80% of fabrication awards for U.S. ITER project remain in the U.S.

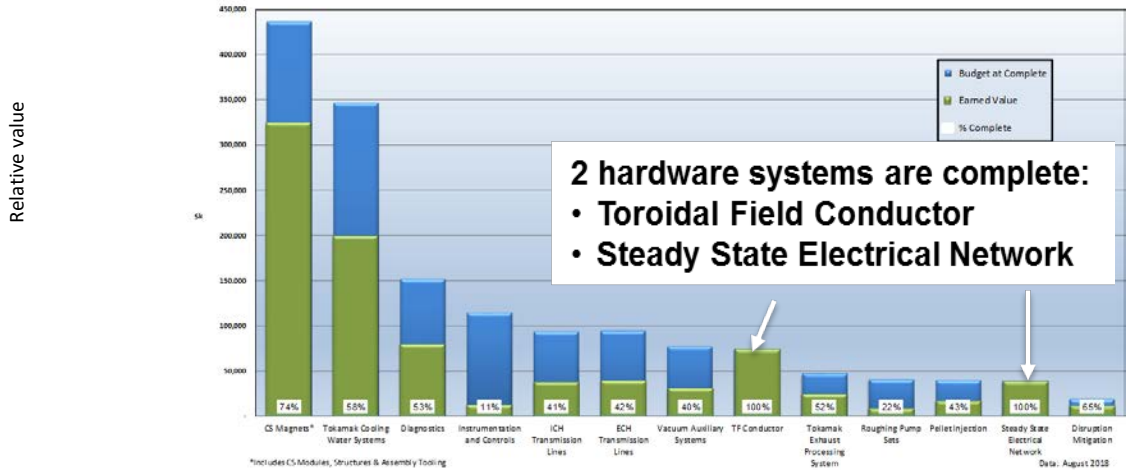
- 600+ contracts to U.S. industry, universities, and national laboratories in 44 states
- 500+ direct jobs, 1100+ indirect jobs per year

Industry, University and National Laboratory Participants



US ITER Subproject-1 (First Plasma) is 55% complete





Current status of ITER complex

Radio Frequency Bldg.
Hosts the radio wave-generating systems that will contribute to heating the plasma.

Assembly Hall
Components will be pre-assembled in this 6,000-square-meter building, equipped with a double overhead traveling crane and powerful handling tools.

Poloidal Field Coils Winding Facility
Four of the six poloidal field coils will be produced by Europe in this 257-meter long facility.

Cryoplant
Will provide coolant to the Magnet Systems, the cryopumps and the thermal shield.

400 kV Switchyard
Connects the site to the grid.

Service Bldg.
Accommodates a large number of industrial support services and systems.

Tritium Bldg.
Houses tritium systems.

Tokamak Bldg.
The crane C1, near the center of the bioshield, marks the approximate axis of the ITER Tokamak.

Diagnostics Bldg.
Houses the electronic and information systems that will receive, record and interpret signals from the operational arena.

Magnet Power Conversion Bldgs.
Host the AC/DC converters that feed power to the magnets.

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Examples of U.S. hardware for ITER

First U.S. hardware installed in the Tokamak Complex
Drain tanks fabricated in the U.S. were also the first nuclear-certified components delivered to the ITER site.

Energizing of the SSEN delivered by the US to the ITER site

Central Solenoid Module 1 at General Atomics Poway, CA facility

Drain tank being lifted to the tokamak facility

4. Community Activities

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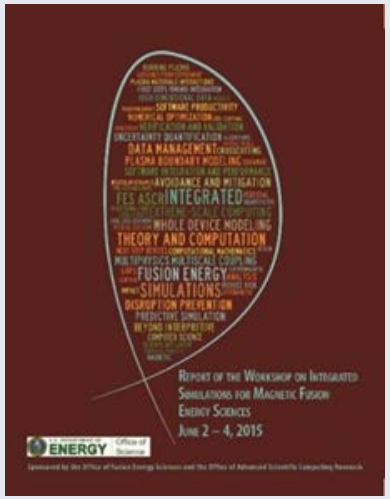
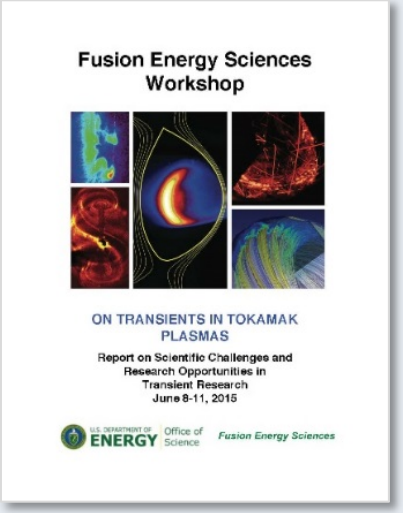
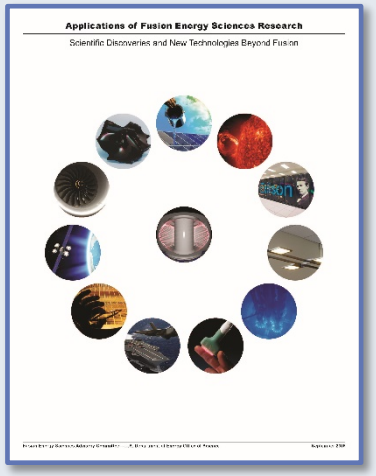
FES strategic choices are informed by community and Advisory Committee input

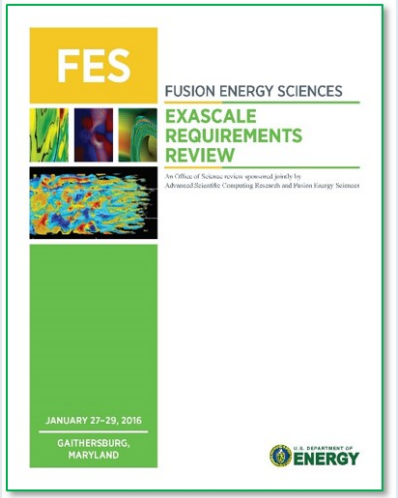




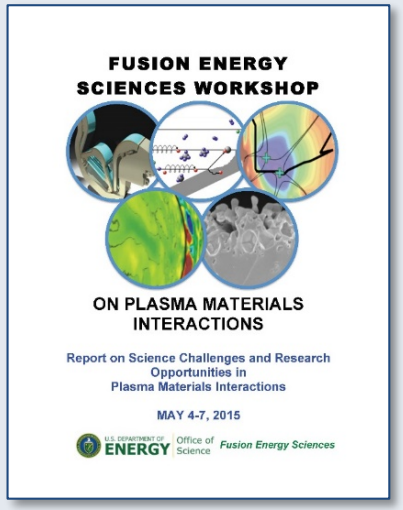


2015 Applications of Fusion Energy Sciences Research

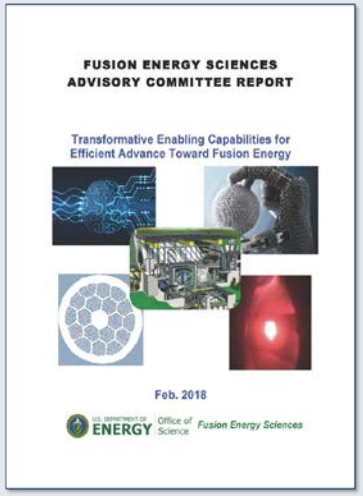
2015 FES 10-year Perspective



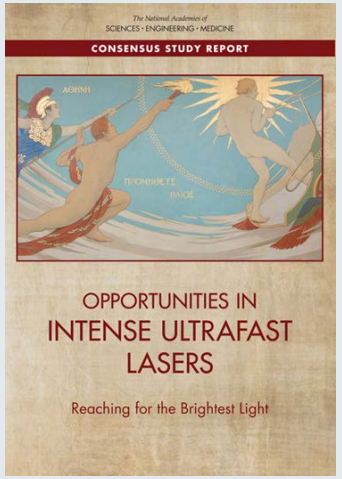
2016 FES Exascale Requirements



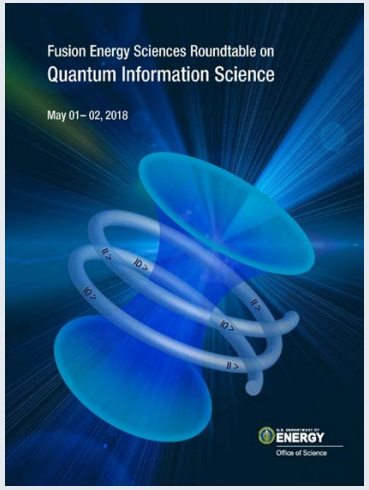
2015 Community Workshops:
Integrated Simulations, Transients, Plasma Materials Interactions, & Plasma Science Frontiers



2018 FESAC Transformative Enabling Capabilities



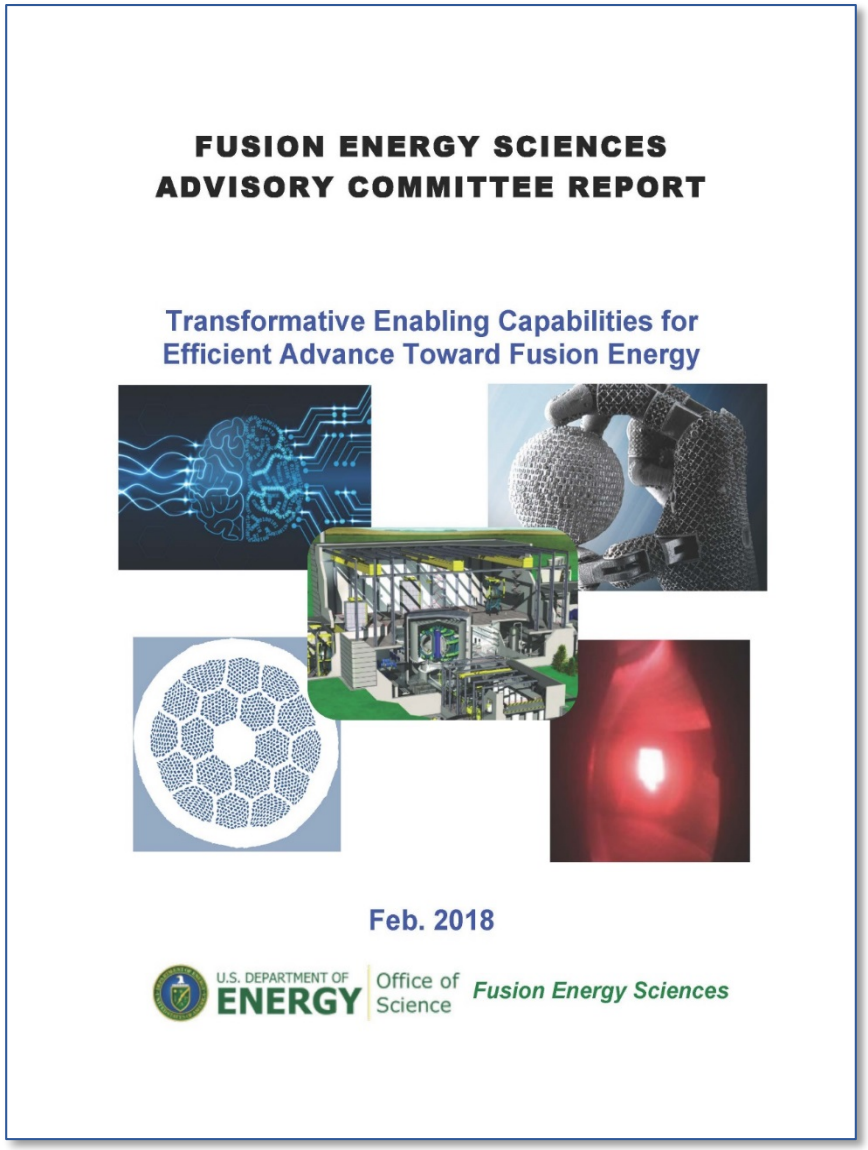
2017 FES NAS Report on Intense Ultrafast Lasers



2018 FES Roundtable on QIS

FESAC report on Transformative Enabling Capabilities toward Fusion Energy

- FESAC was charged with identifying the most promising Transformative Enabling Capabilities (TECs) for promoting efficient advance towards fusion energy, building on burning plasma science and technology
- The fusion community provided 67 white papers and 67 presentations at three meetings as input to FESAC
- The FESAC report identified the following four first-tier (most promising) TECs:
  - Advanced algorithms
  - High critical-temperature superconductors
  - Advanced materials
  - Novel technologies in tritium fuel-cycle control.
- The report also noted one second-tier (promising) TEC:
  - Fast-flowing liquid-metal plasma-facing components.
- The report was presented at the Feb 2018 FESAC meeting


FUSION ENERGY SCIENCES
ADVISORY COMMITTEE REPORT

Transformative Enabling Capabilities for
Efficient Advance Toward Fusion Energy

Feb. 2018

U.S. DEPARTMENT OF ENERGY | Office of Science | Fusion Energy Sciences

National Academy burning plasma interim report was issued on December 21, 2017

PREPUBLICATION COPY – SUBJECT TO FURTHER EDITORIAL CORRECTION

INTERIM REPORT OF THE COMMITTEE ON A STRATEGIC PLAN FOR U.S. BURNING PLASMA RESEARCH

Committee on a Strategic Plan for U.S. Burning Plasma Research
Board on Physics and Astronomy
Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

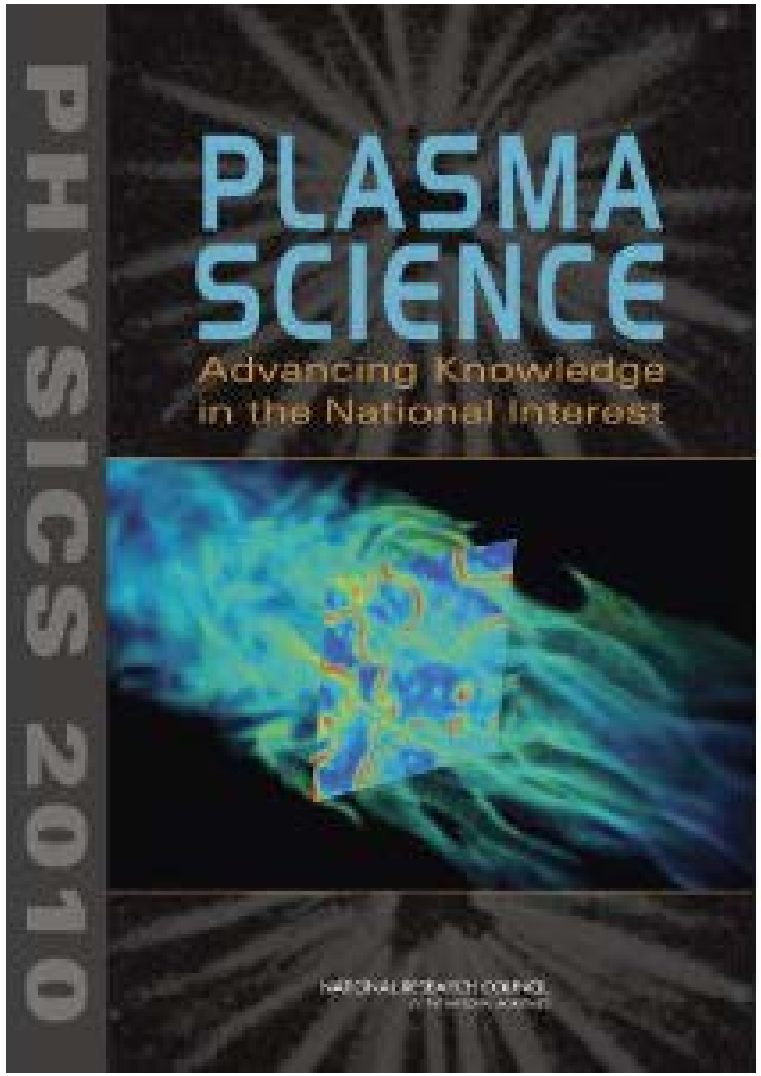
THE NATIONAL ACADEMIES PRESS
Washington, DC
www.nap.edu

The interim report notes that:

- 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

Physics 2020: A Decadal Assessment of Plasma Science



2010 Plasma Decadal Survey
(Chair: Steve Cowley)

- **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)
- **Co-Chairs:**
  – Mark J. Kushner (U. Michigan)
  – Gary P. Zank (U. Alabama-Huntsville)
- **Names and bios of committee members:**
  https://www8.nationalacademies.org/pa/projectview.aspx?key=51149
- **First public committee meeting was held on October 15**

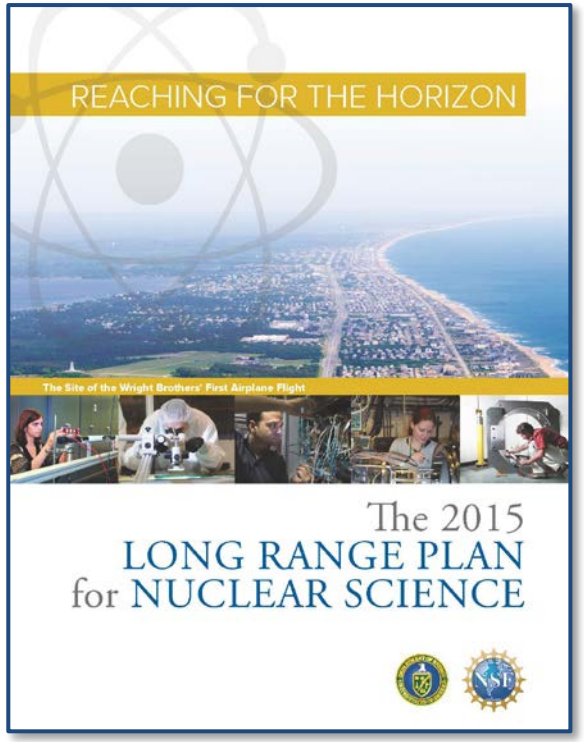
Upcoming FESAC Meeting

- **Next FESAC meeting is scheduled for December 6-7**
  - Detailed information is posted on the FESAC website: https://science.energy.gov/fes/fesac/meetings/
  - Remote participation will be possible

- **Possible agenda items include:**
  - SC leadership presentation (Undersecretary Paul Dabbar)
  - FES status report
  - Report from the August 2018 Committee of Visitors (COV)
  - Report from the May 2018 QIS Roundtable meeting
  - Report from the Fusion Prototypic Neutron Source workshop
  - Report about NAS 2020 Plasma Decadal Survey
  - A new charge on Fusion Program Prioritization Activity

Fusion Program Prioritization Activity

- Recent community input via workshops and other activities have informed the strategic priorities of the FES program, as reflected in the *FES Ten-Year Perspective* plan
- The community self-organized two workshops last year to provide valuable input to the NAS burning plasma study
- We are now ready to take the next step toward the development of a comprehensive long-range plan for the FES program, following a process similar to the one used by the Office of Science HEP and NP programs for the development of the P5 report and Long Range Plan
- The plan will be comprehensive and will include all FES program areas (i.e., MFE, General Plasma Science, HEDLP, etc.)
- A FESAC charge will be issued at the upcoming December meeting
- FESAC subcommittee activities will be preceded by intensive community activities (workshops, townhall meetings, etc.) coordinated by APS-DPP and APS



Fusion program prioritization will adapt the HEP (P5) and NP (LRP) processes

Phase 1: Community-organized activities

Community Awareness
Inform the community that a FESAC charge is coming

↓

Subfield community self-organization
Community plans how to fill gaps from Madison & Austin meetings

↓

FESAC charge issued
18-24 month clock starts with budget guidance/scenarios

↓

FES tasks APS-DPP to convene topical town hall meetings
Subfield white papers, talks, virtual meetings (esp. early-career scientists); build on 2017-2018 community organization and NAS reports; community demographics & diversity; followed by homework revisions & priorities

↓

"Snowmass" meeting
~10 day meeting where all subfields attend

Phase 2: FESAC Working Group

FESAC chair & vice chair select Working Group with FES concurrence
Solicit nominations from community; working group meetings discussing the four frontiers

↓

FESAC Working Group convenes Resolution Meeting
5 days with open & closed sessions; discussions and writing sessions with final draft recommendations

↓

FESAC vote & report transmittal

↓

Stakeholder briefings
FES community, OMB, OSTP, Congress, international partners

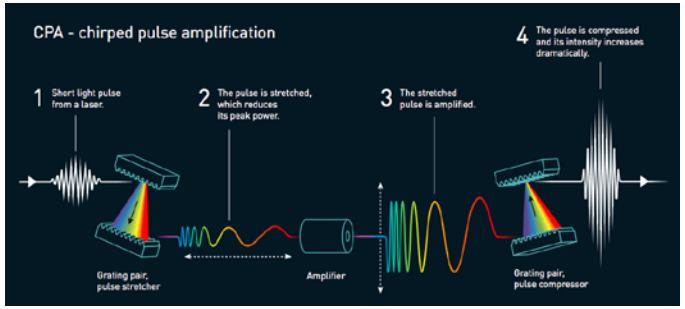
5. People

2018 Nobel Physics Prize for CPA led to the development of high-power lasers for HEDP

2018 Nobel Prize in Physics

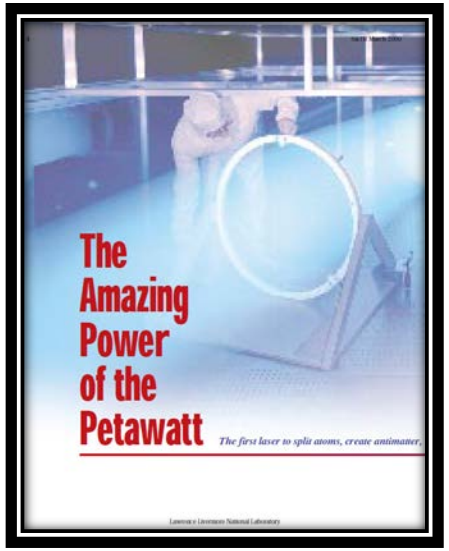
Donna Strickland & Gerard Mourou: "Compression of amplified chirped optical pulses" (Optics Communications, 1985)

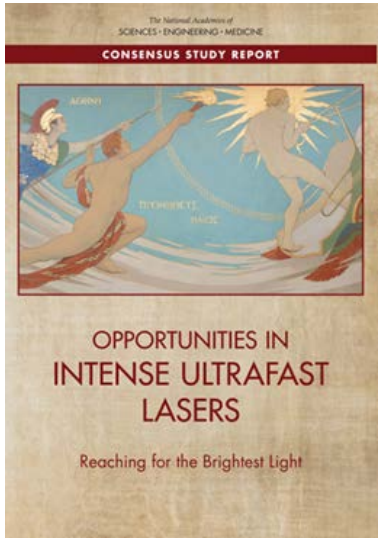
Congratulations!



Chirped pulse amplification (CPA)

- First Petawatt Laser
- LLNL, May 23, 1996





DOE updates since 2017 APS-DPP

Mr. **Paul M. Dabbar** was sworn in as Under Secretary for Science on November 7, 2017

- Has visited a number of U.S. and overseas fusion facilities and institutions

Dr. **Chris Fall** was nominated on May 18, 2018, as the Director of the DOE Office of Science

- Dr. Fall is presently the Principal Deputy Director of ARPA-E
- Senate hearing was held June 26, 2018
- Awaiting final Senate confirmation

Other updates since 2017 APS-DPP

PPPL:

Prof. **Steven Cowley** became the 7th Director of the Princeton Plasma Physics Laboratory

FES:

Dr. **Mark Foster** entered phased retirement status in July 2018

- He is working half-time, assisting Matt Lanctot and Curt Bolton to assume program manager responsibilities for DIII-D and Measurement Innovation programs, respectively

Dr. **Sam Barish** plans to enter phased retirement status in December 2018

- He will work half-time
- He will continue to manage the stellarator program and FESAC
- Other duties will transition elsewhere

U.S. DEPARTMENT OF ENERGY
Office of Science

FES Postdoctoral Researcher Program – CY 2018

FY17&18

Marlene Patino
Plasma Material Interaction Studies at PISCES (UCSD)

Anton Neff
DIII-D Impurity Collector Probe Analysis (ORNL)

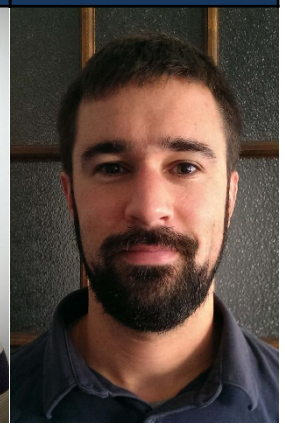
Jacob Nichols
Whole-Device Modeling (U. Tenn. – Knoxville)

FY18&19

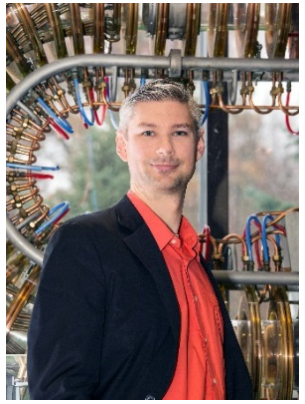
Ben Faber	Reed Hollinger	Ryan Sweeney	Luke Stagner	Noah Hurst
Stellarator Optimization (UW Madison)	Relativistic Laser Interactions (Colorado State)	Disruption Mitigation (MIT)	Runaway electrons (GA)	Electron plasma fluids (UCSD)







2018 FES Early Career Awards



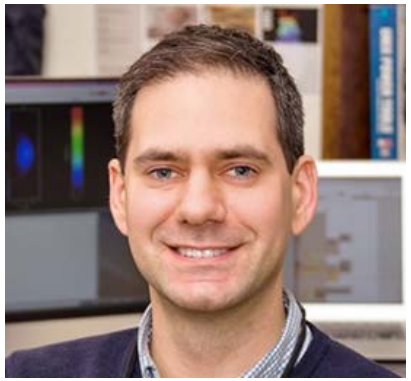
Dr. Sam Lazerson (PPPL)
Energetic particle confinement in Stellarators

Dr. Tammy Ma (LLNL)
Laser-driven particle acceleration for Novel HED and ICF Applications

Dr. Alex Zylstra (LANL*)
Nuclear Astrophysics with Inertial Fusion Implosions
** Moved to LLNL*

Prof. David Donovan (U. Tennessee)
Impurity Transport in magnetically confined fusion

Prof. Kentaro Hara (Texas A&M)
Self-organization in low-temperature magnetized plasmas



Dr. Nate Ferraro (PPPL)
Modeling of ELM suppression and mitigation