The Administration's Proposed Budget for Fusion Energy Sciences in FY 2017

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February 10, 2016

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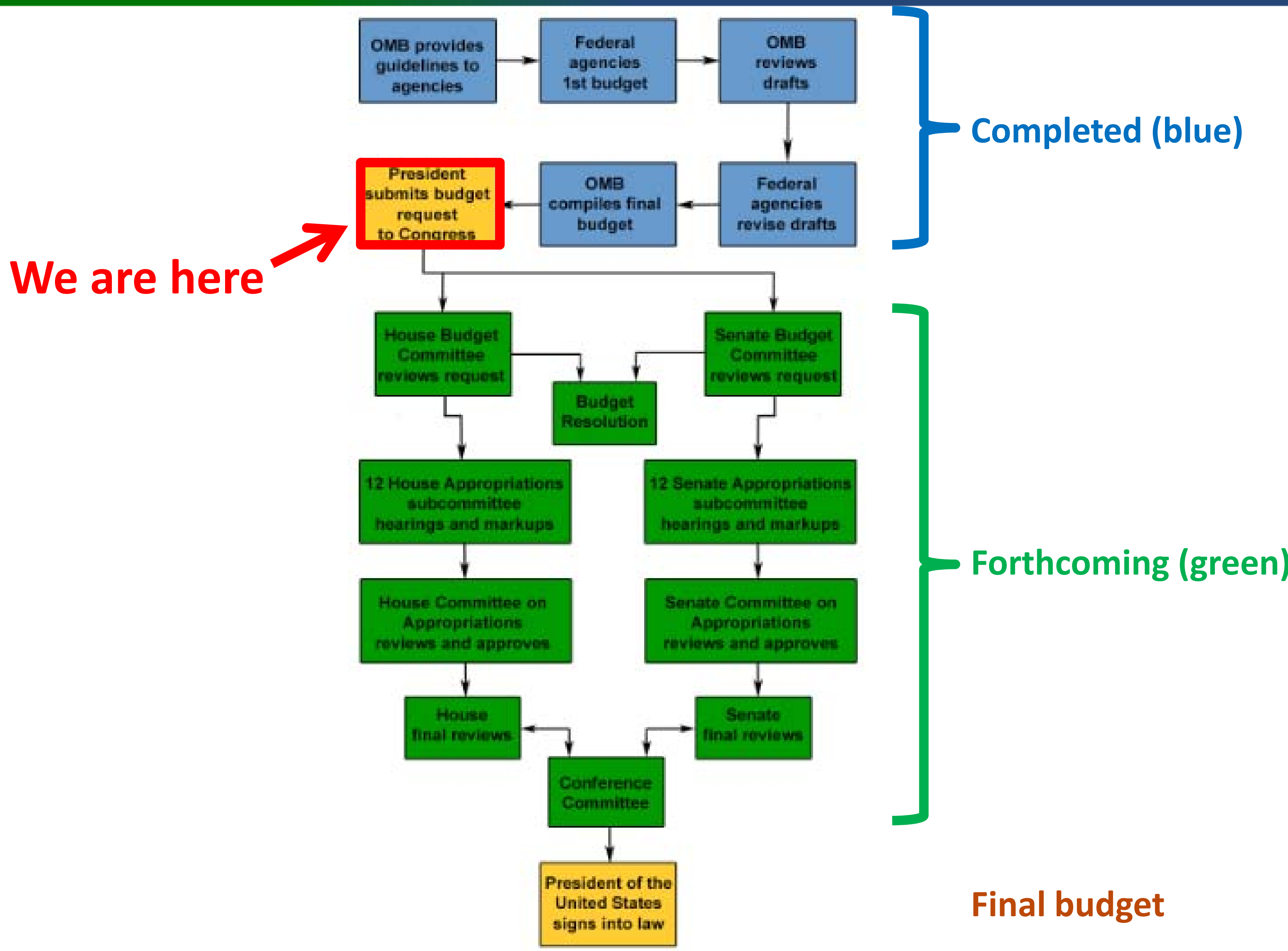
The President's budget roll-out to Congress is one step in a lengthy process



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FY 2017 Budget Request Summary

Budget Categories	FY 2016 request	FY 2016 enacted	FY 2017 request
Burning Plasma: Foundations	191,759	214,755	195,607
Burning Plasma: Long Pulse	30,909	41,021	31,355
Burning Plasma: High Power	150,000	115,000	125,000
Discovery Plasma Science	47,332	67,224	46,216
Total	**420,000**	**438,000**	**398,178**

- **NOTES:**
  - The "FY 2016 Enacted" figures incorporate preliminary allocations and Budget Omnibus language marks, but are still provisional, pending final evaluations
  - Also, funding awards in FY 2016 for several recent solicitations (e.g., DIII-D collaborations, NSTX diagnostics, small-scale AT/ST/stellarator) are still pending final decisions
  - FY 2017 requests are informed by strategic thrusts in the *FES Ten-Year Perspective*

All budget amounts in $K

This budget proposal reflects commitment to burning plasma and discovery science

- **Burning Plasma Science: Foundations**
  - Overall funding for advanced tokamak research is decreased, as operation of Alcator C-Mod will have ended
  - Funding for the DIII-D and NSTX-U research programs is increased to address the high-priority fusion science issues identified by the community research needs workshops held in FY 2015 and to support enhanced collaborations with MIT researchers.
  - Decreased funding for DIII-D and NSTX-U operations results in deferment of some facility enhancements and a slight reduction to operating weeks (14 weeks on DIII-D and 16 weeks on NSTX-U).
  - Funding for SciDAC is increased to accelerate progress toward whole-device modeling.
- **Burning Plasma Science: Long Pulse**
  - Support continues for U.S. research collaborations on international machines, such as EAST (China), KSTAR (Korea), and W7-X (Germany).
- **Discovery Plasma Science**
  - General plasma science activities continue, including the NSF-DOE Partnership (now renewed to 2021).
  - HEDLP research is focused on MEC at LCLS. There is no budget for new research awards as part of the SC/NNSA Joint Program for HEDLP science. Operations and research on NDCX-II at LBNL are not funded.
  - Decreases in Measurement Innovation and General Plasma Science activities result from the completion of targeted research enhancements fully funded in FY 2016.
- **Burning Plasma Science: High Power**
  - The ITER budget request is reduced to $125M (cf. FY16 request of $150M and enacted $115M). Funding is provided for FY 2017 monetary contribution to ITER Organization to support common project expenses.
  - DOE must provide status reports about ITER to Congress by Feb 15 and Aug 15, plus a recommendation by May 2 about whether to continue U.S. participation in the ITER project.

Burning Plasma Science

Foundations

Advanced Tokamak (DIII-D and Smaller Scale) & Spherical Tokamak (NSTX-U and Smaller Scale)

- *Highly collaborative; strong university partnerships*
- *High scientific complementarity between these facilities*
- *High potential for growing student engagement on our nation's major fusion science experimental facilities*

Theory and Simulation

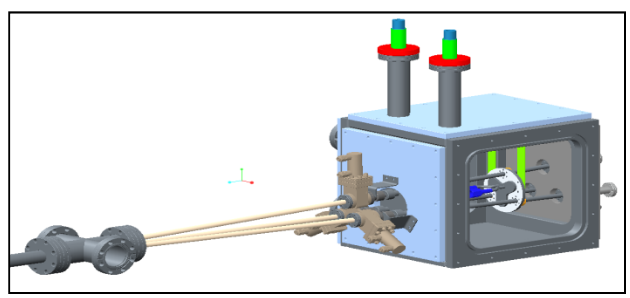
- *US strength in engaging with experiment to develop predictive understanding*
- *Essential if high-risk gaps in fusion are to be closed*
- *Leverages DOE investments in leadership-class computing resources*

Budget Categories	FY 2016 request	FY 2016 enacted	FY 2017 request
Burning Plasma: Foundations	191,759	214,755	195,607

Foundations: Advanced Tokamak

Focuses on optimization of the tokamak approach to magnetic confinement fusion, including addressing near-term scientific issues for ITER and developing advanced scenarios. (The AT line works in concert with the ST line to reveal fundamentals about toroidal confinement overall.)

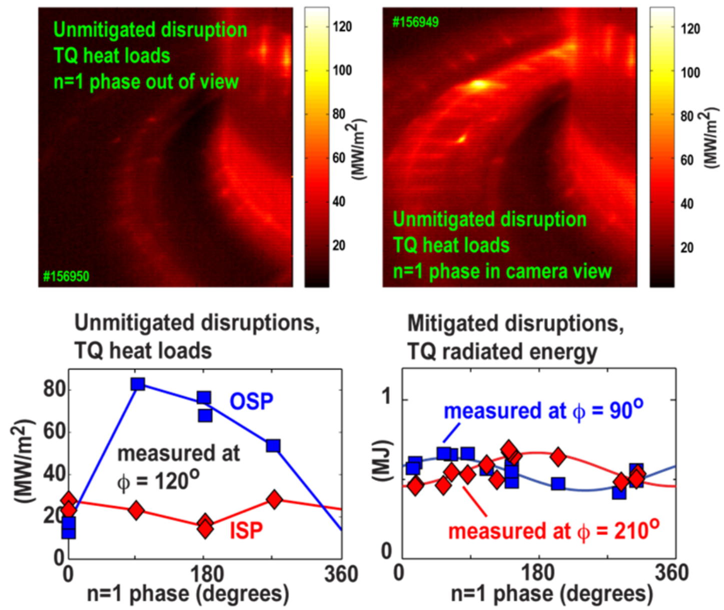
Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 Budget Highlights
DIII-D Research	32,038	35,000	37,000	Conduct experiments to test fast ion transport models, study edge pedestal density structure, and examine impurity generation and transport with high-Z coated tiles.
DIII-D Ops	39,310	45,000	44,100	14 run weeks. Targeted upgrades (ECH, OANB design).
C-Mod Research	6,145	6,145	0	MIT researchers funded for research at national and international facilities under a new cooperative agreement.
C-Mod Ops	11,855	11,855	0	Operation of Alcator C-Mod ceases.
Small-scale AT	973	1,090	973	Provide AT-relevant data . Validate models and codes.
Enabling R&D	2,165	2,165	2,165	Research in superconducting magnet technology, and fueling and plasma heating technologies



Second multi-barrel Shattered Pellet Injector for radiation asymmetry and injection studies (ORNL)

DIII-D and its Upgrades

Interior of DIII-D vacuum vessel



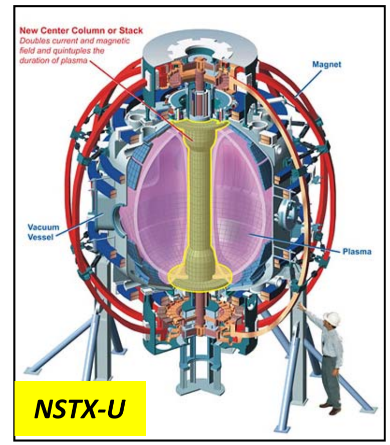
DIII-D infrared camera data used to investigate asymmetries in tokamak disruptions

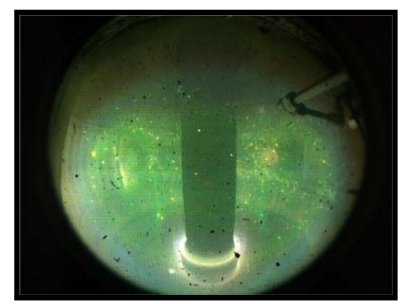
- DIII-D will continue high-priority advanced tokamak studies of transport, edge and divertor physics, disruption physics and tokamak transient mitigation systems. Research priorities will include issues identified by the 2015 community research needs workshops.
- After 14 run weeks, DIII-D will have a planned outage for the installation of targeted facility enhancements, including a new high-power helicon current drive antenna and improvements to the neutral beam injection systems for plasma heating and current drive.

Foundations: Spherical Tokamak

Explore the physics of plasma confined in a low-aspect-ratio geometry at high pressure. (The ST line works in concert with the AT line to reveal fundamentals about toroidal confinement overall.)

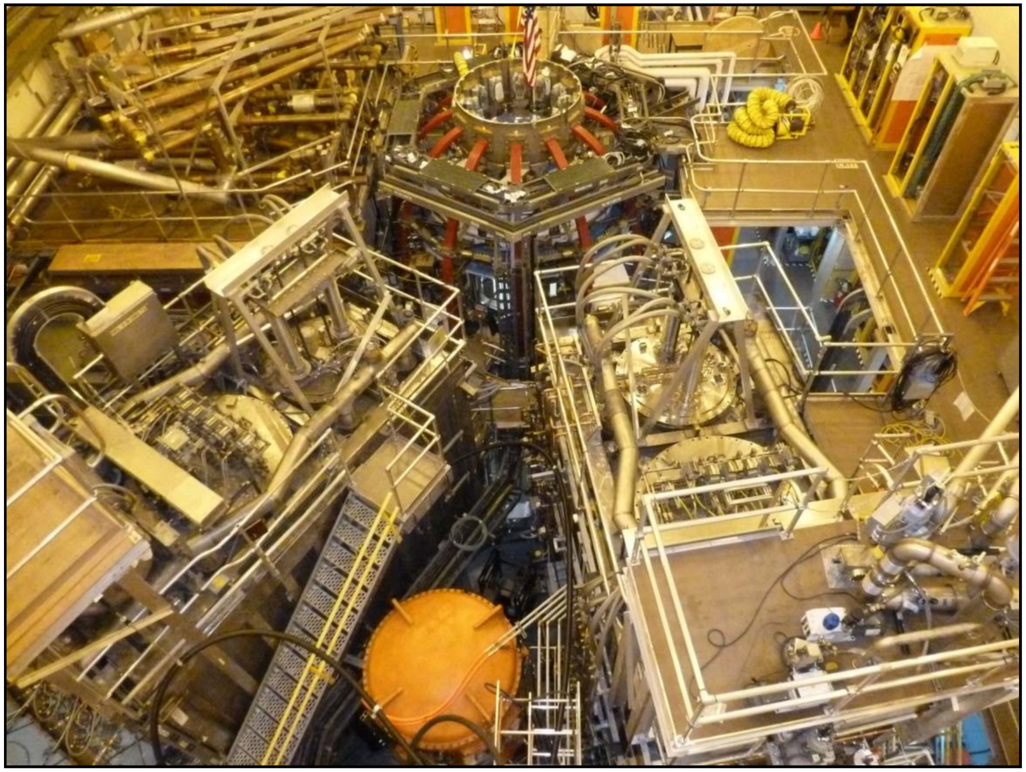
Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 Budget Highlights
NSTX-U Research	26,000	30,000	31,410	Address divertor heat flux mitigation and confinement at full parameters, explore fully non-inductive current drive and sustainment, develop high-performance discharge scenarios, and assess impact of molybdenum divertor tiles.
NSTX-U Operations	36,925	41,000	39,090	16 run weeks. Extend operation to full field and current (1 T, 2 MA).
Small-scale ST	2,699	3,000	2,699	Provide ST-relevant data. Validate models and codes.

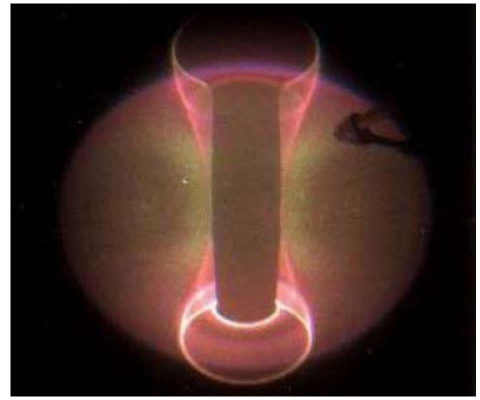




First plasma in NSTX-U achieved September 2015

NSTX-U is essentially a new machine in the U.S. fusion energy sciences portfolio





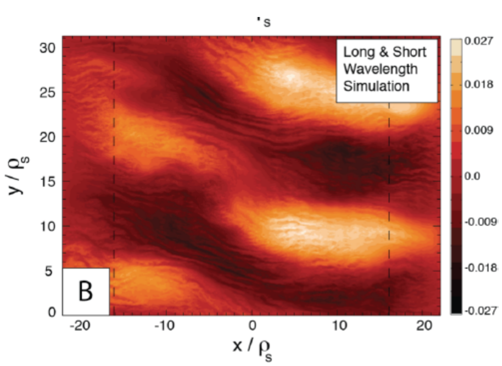
Both H-mode and stationary L-mode operations have been achieved

- The multi-year upgrade project ($94M, completed at end of FY 2015) provides a national user facility with significantly enhanced capabilities– the world's highest-performance spherical tokamak.
- Funding will allow 16 run weeks in FY 2017 (down 2 weeks from FY16 enacted).
- In mid-FY 2016, a shutdown is planned for installation of a row of high-Z metal tiles on the lower divertor shelf for experiments on plasma-wall interaction.
- In FY 2017, plasma performance, divertor heat flux mitigation, and non-inductive discharge sustainment will be tested at the full field and current values (both of which are double what had been achieved prior to the upgrade).

Foundations: Theory and Simulation

Advance scientific understanding of fundamental physical processes governing the behavior of magnetically confined plasmas and develop predictive capability by exploiting leadership-class computing resources.

Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 Budget Highlights
Theory	21,170	24,000	21,170	Emphasis on closing gaps in burning plasma science as identified by the 2015 community workshops and on addressing high-priority needs of integrated simulation
SciDAC	7,000	9,500	12,000	New SciDAC centers, selected via a competitive merit review and set up as partnerships with ASCR, will begin, with a strong emphasis on integration and whole-device modeling, focusing on the highest-priority research directions identified by the 2015 community workshops.



Coupled electron and ion transport simulations with realistic mass ratio

Burning Plasma Science

Long Pulse

Long-Pulse Tokamaks & Long-Pulse Stellarators

- *Using partnerships on international facilities where US expertise is valuable and desired*
- *Creating opportunities for continued US leadership this decade in areas critical to fusion science*
- *Generating access for our scientists and students to what are becoming leading research endeavors around the globe*

Materials and Fusion Nuclear Science

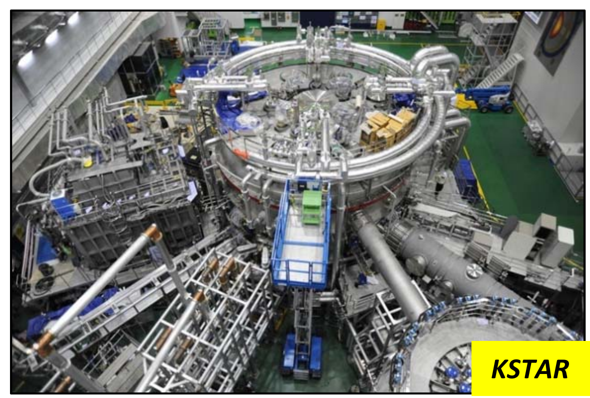
- *Investments will enable US leadership in fusion nuclear materials science and plasma-material interactions*

Budget Categories	FY 2016 request	FY 2016 enacted	FY 2017 request
Burning Plasma: Long Pulse	30,909	41,021	31,355

Long Pulse: Tokamak

Example: Two U.S. teams are performing long-pulse plasma heating and control research at the Experimental Advanced Superconducting Tokamak (EAST) and Korea Superconducting Tokamak Advanced Research (KSTAR) facilities.

Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 budget highlights
Long-Pulse Tokamak	6,045	8,500	6,045	Commission improved control systems. Explore ITER-relevant operating scenarios. Develop RF heating/current drive and NB actuator models.



U.S. collaborations on overseas superconducting facilities

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Experimental Advanced Superconducting Tokamak (EAST) – China

- U.S. scientists conducted experiments at a distance on EAST by operating the machine from a remote collaboration room at General Atomics—the first successful demonstration of "3rd shift" remote operation of this experiment
- EAST data is piped to GA, where it is stored and mirrored to U.S. collaborators

Korea Superconducting Tokamak Advanced Research (KSTAR) – Korea

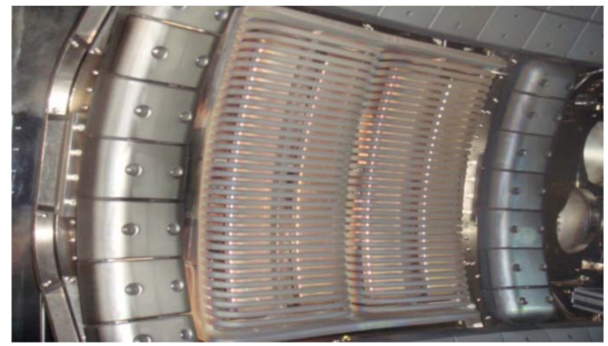
- U.S. contributions have improved dramatically the performance of the ion-cyclotron radio frequency antenna on KSTAR

Wendelstein W7-X Stellarator – Germany

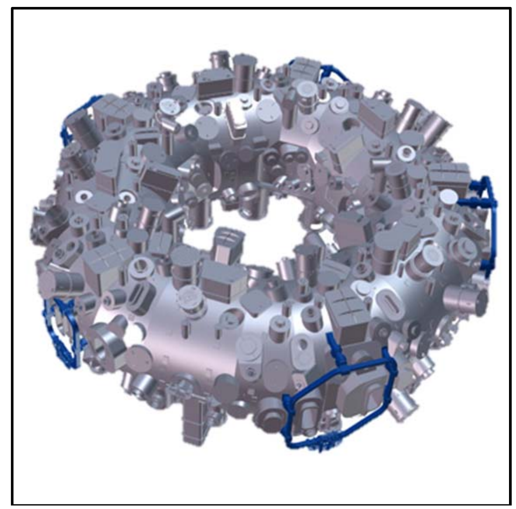
- U.S. designed and constructed powerful trim coils that fine-tune the shape of the W7-X plasma
- W7-X achieved first plasma in December 2015
- Substantial U.S. research involvement

General Atomics remote collaboration room supports 3rd shift operation of EAST by U.S. scientists

U.S.-designed RF wave antenna to heat ions in KSTAR



Five 2,400-pound U.S.-built trim coils (blue) installed on W7-X



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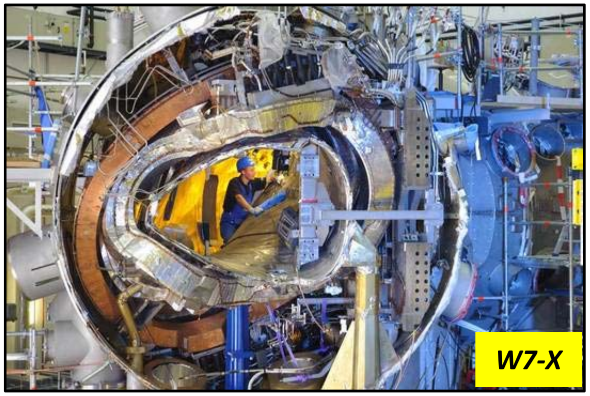
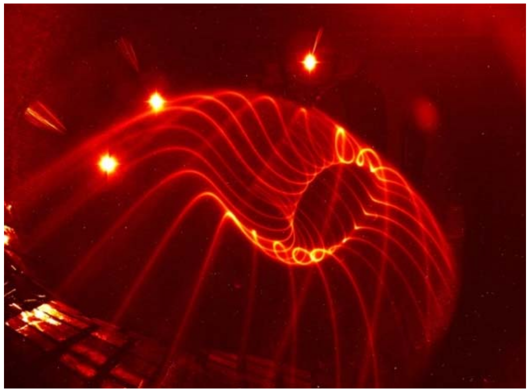
Long Pulse: Stellarator

A U.S. lab/university team is collaborating on the superconducting W7-X stellarator in Germany. The U.S. domestic effort focuses on optimizing the stellarator concept through compact quasi-symmetric magnetic field shaping.

Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 budget highlights
Superconducting Stellarator Research	2,500	4,200	2,515	Participate in W7-X experiments on error fields, islands, plasma control, energetic particles, impurities, PMI, core transport
Compact Stellarator Research	2,569	3,069	2,569	Provide data relevant to mainline stellarator efforts. Validate models and codes.



Magnetic flux surfaces mapped out with an electron beam



Initial W7-X hydrogen plasma operation

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Dec 10, 2015: First operation (with helium)

Feb 3, 2016: First hydrogen plasma operation
(video of the event can be seen at
http://www.ipp.mpg.de/livestream_e_16)

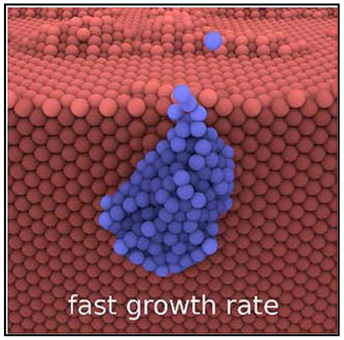
Hydrogen operation (February 3, 2016)
W7-X project leader Thomas Klinger, IPP Director Sibylle Guenter, German Chancellor Angela Merkel

U.S. attendees and collaborating scientists standing by the Start Button

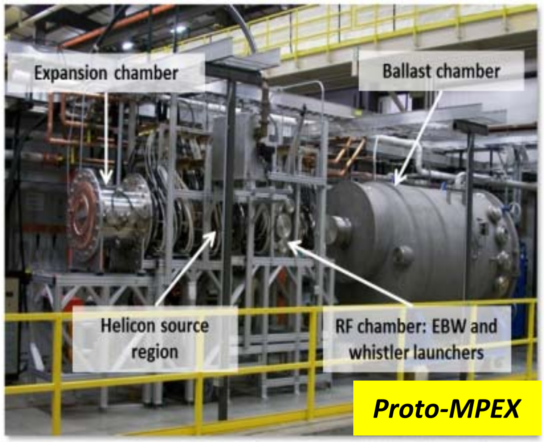
Long Pulse: Materials and Fusion Nuclear Science

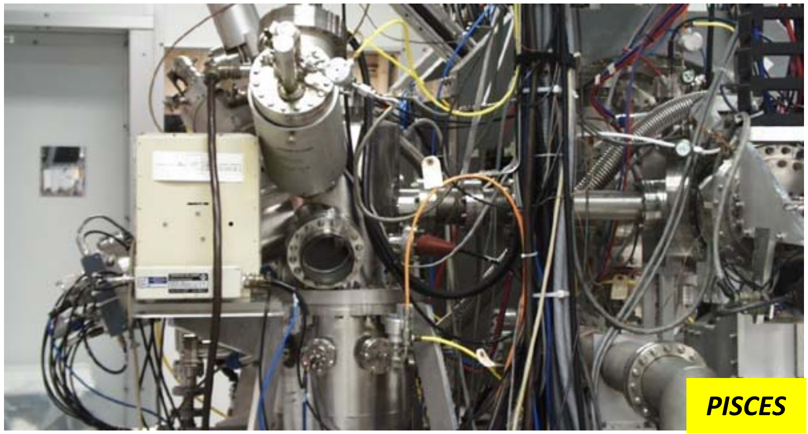
This research supports the development, characterization, and modeling of structural, plasma-facing, and blanket materials for the fusion environment.

Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 budget highlights
Fusion Nuclear Science	9,835	11,252	10,000	Study plasma-facing materials, PMI, tritium retention, neutronics, and material corrosion issues. Scoping studies.
Materials Research	9,960	14,000	10,226	Study structural materials, helium damage, tungsten ductility.



Simulation of helium bubble growth in tungsten with neutron irradiation





Discovery Plasma Science

Plasma Science Frontiers

- *General plasma science portfolio: FES stewardship of non-MFE plasma science areas*
- *High energy density laboratory plasma research: matter at extreme conditions*
- *Exploratory magnetized plasma: small/intermediate-scale MFE experimental research; platforms for verification & validation; study of plasma self-organization*

Measurement Innovation

- *High-impact R&D on new plasma diagnostic techniques*

Budget Categories	FY 2016 request	FY 2016 enacted	FY 2017 request
Discovery Plasma Science	47,332	67,224	46,216

Discovery Plasma Science: Plasma Science Frontiers & Measurement Innovation

Support for a broad portfolio of research projects and small-scale experimental facilities that explore the diverse frontiers of plasma science. The activities of this subprogram are carried out through inter- and intra-agency partnerships and at academic institutions, private companies, and national laboratories.

Budget Element	FY 2016 Request	FY 2016 Enacted	FY 2017 Request	FY 2017 budget highlights
General Plasma Science	15,500	16,125	15,500	Research on basic plasma behaviors, including low temperature plasmas. Continue the NSF-DOE Partnership.
High Energy Density Laboratory Plasmas	6,700	20,250	7,000	Emphasis on MEC research. No new SC/NNSA Joint Program awards. No funding for NDCX-II.
Exploratory Magnetized Plasma	10,409	10,409	9,416	Research directions informed by high-priority research identified by the 2015 PSF workshops.
Measurement Innovation	3,575	6,700	4,000	Continue developing innovative diagnostic techniques.

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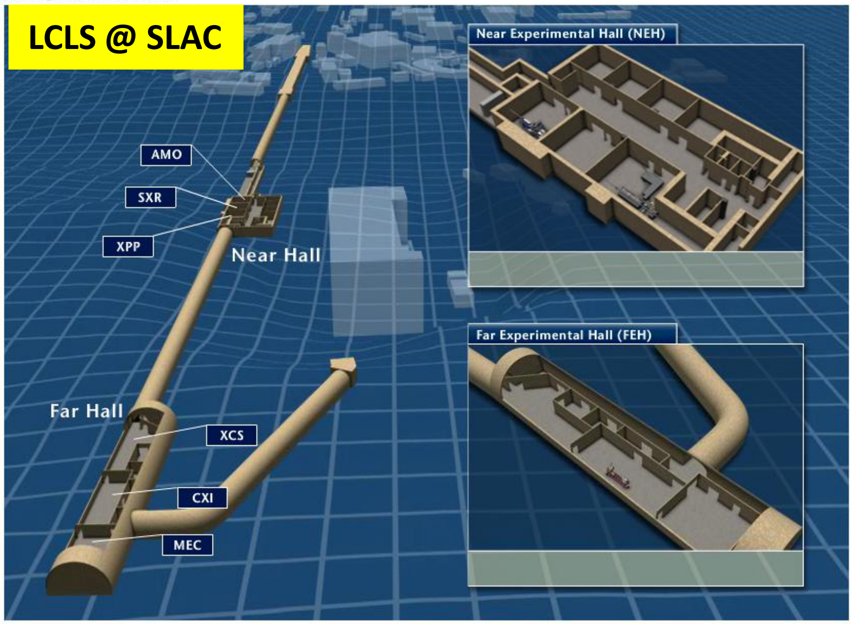
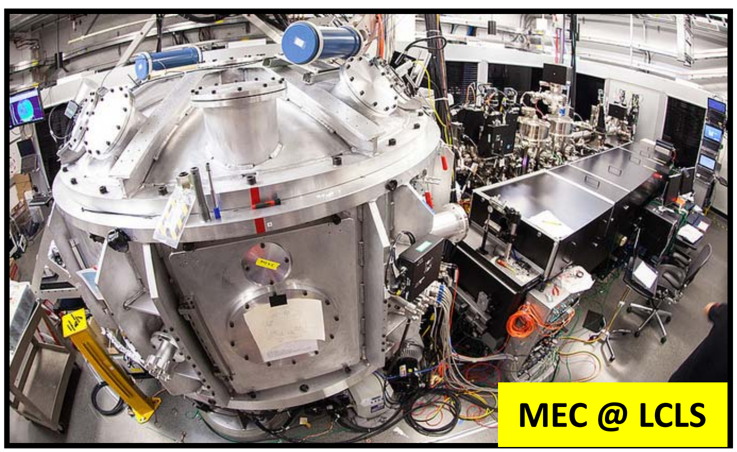
Some Plasma Science Frontier activities

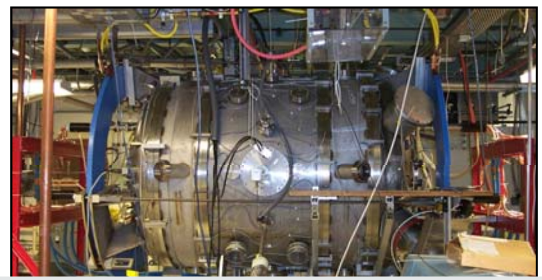
INSTRUMENT MAP

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





Large Plasma Device @ UCLA Basic Plasma Science Facility



Magnetic Recconnection Experiment (MRX) @ PPPL

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

PSC

Department of Energy Plasma Science Center

Burning Plasma Science

High Power

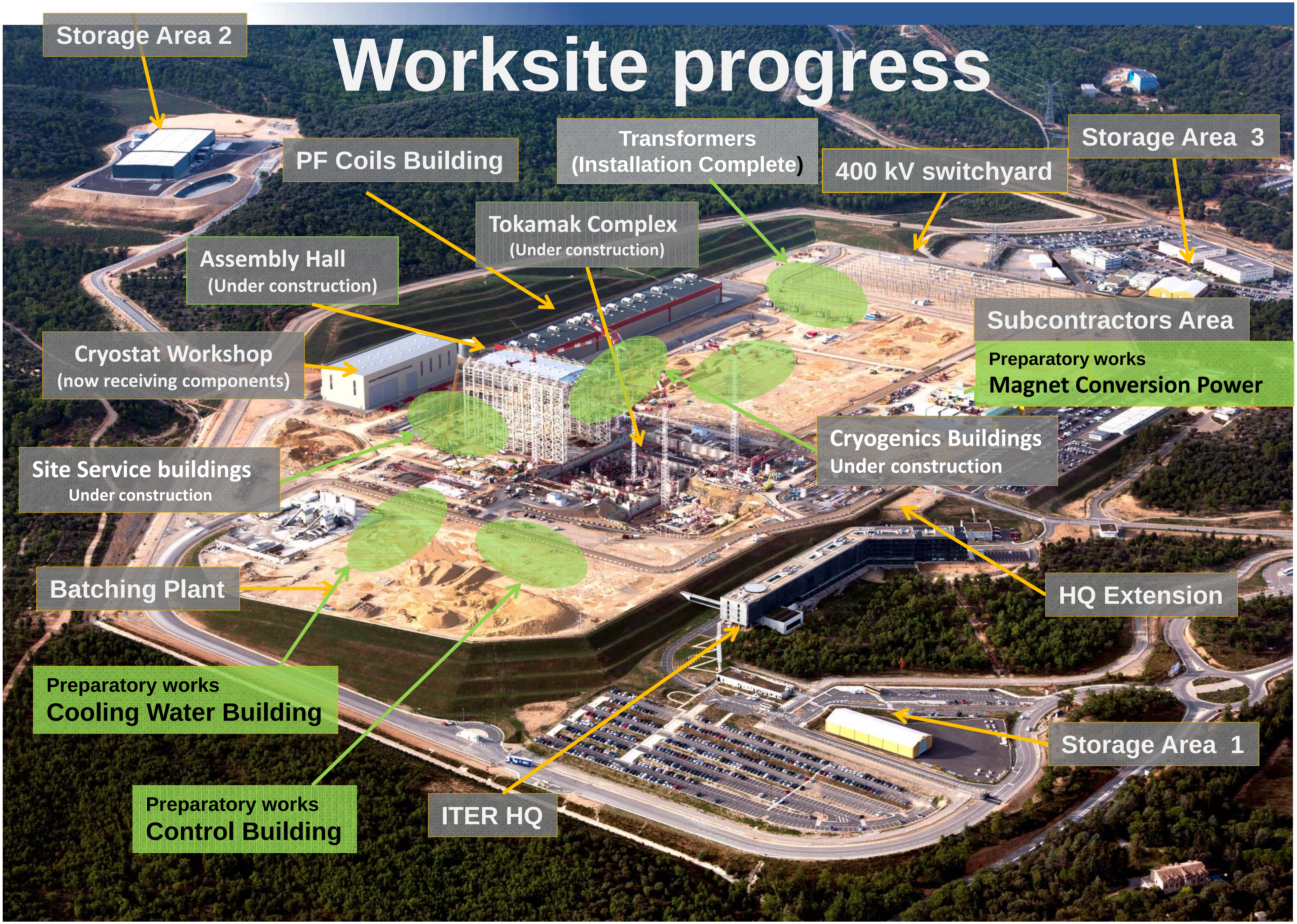
US Contributions to ITER project

- **The funding request** supports U.S. in-kind hardware contributions; funds the USIPO staff and support contractors at ORNL, PPPL, and SRNL; and provides funding toward the FY 2017 monetary contribution to the IO for common project expenses.

- **U.S. ITER Project Office**: FY 2017 in-kind hardware contributions include central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady--state electrical network components, diagnostics development, tokamak cooling water system, and vacuum system.

Budget Categories	FY 2016 request	FY 2016 enacted	FY 2017 request
Burning Plasma: High Power	150,000	115,000	125,000

Worksite progress



Slide from Dr. Bernard Bigot (Jan 13 FESAC talk)

U.S. fabrication of ITER hardware is progressing

ITER recent developments

ITER Director-General Bernard Bigot
photo ITER

- **IO/DG/IC activities:**
  - The DG and IO are implementing his Action Plan to address the 11 recommendations of the 2013 Management Assessment report
  - The DG has changed the ITER org structure, reduced the number of Deputy Director Generals to two, instituted an Executive Project Board that involves the ITER Organization and the seven Members, and set up Project Teams
  - The DG attended the FPA Meeting (Dec 2015) and the FESAC Meeting (Jan 2016), plus visits to OMB, OSTP, SEWD, and HEWD
  - The 2015 Management Assessment is underway
- **Project schedule has been updated:**
  - The IO presented an Updated Long-Term Schedule to ITER Council (Nov 2015). The IC set up an independent panel of international project experts to review the new schedule and human resources, with an interim report due in April
  - The IC approved 29 milestones to monitor IO progress during for 2016-2017, of which 4 have been completed
- **U.S. ITER Project Office continues its progress:**
  - U.S. hardware contributions are 28% complete; U.S. deliveries for ITER First Plasma are 15% complete
- **Secretary of Energy is to submit ITER status reports to Congress by Feb 15 and Aug 15, and a recommendation about continued U.S. participation in ITER by May 2**

Annual Joint Research Target for FES facility-based experiments

FY 2016 Joint Research Target (underway this year)

Conduct research to detect and minimize the consequences of disruptions in present and future tokamaks, including ITER. Coordinated research will deploy a disruption prediction/warning algorithm on existing tokamaks, assess approaches to avoid disruptions, and quantify plasma and radiation asymmetries resulting from disruption mitigation measures, including both pre-existing and resulting MHD activity, as well as the localized nature of the disruption mitigation system. The research will employ new disruption mitigation systems, control algorithms, and hardware to help avoid disruptions, along with measurements to detect disruption precursors and quantify the effects of disruptions.

FY 2017 Joint Research Target (planned for next year)

Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices, including ITER. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.

FES 2015 Joint Research Target

Impact of broadened current and pressure profiles on tokamak plasma confinement and stability.
Mario Podesta et al. (http://science.energy.gov/fes/community-resources/)

Annual Theory/Simulation Performance Target

FY 2016 Theory & Simulation Performance Target (underway this year)

Predicting the magnitude and scaling of the divertor heat load width in magnetically confined burning plasmas is a high priority for the fusion program and ITER. One of the key unresolved physics issues is what sets the heat flux width at the entrance to the divertor region. Perform massively parallel simulations using 3D edge kinetic and fluid codes to determine the parameter dependence of the heat load width at the divertor entrance and compute the divertor plate heat flux applicable to moderate particle recycling conditions. Comparisons will be made with data from DIII-D, NSTX-U, and C-Mod.

FY 2017 Theory & Simulation Performance Target (planned for next year)

Lower hybrid current drive (LHCD) will be indispensable for driving off-axis current during long-pulse operation of future burning plasma experiments including ITER, since it offers important leverage for controlling damaging transients caused by magnetohydrodynamic instabilities. However, the experimentally demonstrated high efficiency of LHCD is incompletely understood. In FY 2017, massively parallel, high-resolution simulations with 480 radial elements and 4095 poloidal modes will be performed using full-wave radiofrequency field solvers and particle Fokker-Planck codes to elucidate the roles of toroidicity and full-wave effects. The simulation predictions will be compared with experimental data from the superconducting EAST tokamak.

FES 2015 Theory & Simulation Performance Target

Perform massively parallel plasma turbulence simulations to determine expected transport in ITER

Jeff Candy et al. (http://science.energy.gov/fes/community-resources/)

SC Increases Academic Research by $100M (Mandatory) in FY 2017

Investments are made in all of the SC programs, emphasizing emerging research areas, especially those recently identified by Federal Advisory Committees or other community activities. A few examples are:

- **ASCR**: Applications software, applied mathematics, and computer science for capable exascale computing; mathematics for large-scale scientific data; neuromorphic computing architectures and information processing for extreme and self-reconfigurable computing architectures
- **BES**: Topics described in the 2015 BESAC Report *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, including hierarchical architectures, non-equilibrium matter, non-ideal systems, coherence in light and matter, modeling & computation, and imaging across multiple scales.
- **BER**: New platform microbes for biofuels and bioproducts engineering; biofuel crop modeling for incorporation into a predictive framework.
- **FES**: Plasma/fusion research centers emphasizing the results of the 2015 community workshops, including for example low-temperature plasmas, plasma measurements, and verification & validation for magnetic fusion.
- **HEP**: Topics described in the 2014 HEPAP Long Range Plan and also topics that span multiple SC programs, including quantum information sciences/the entanglement frontier and quantum field theory across disciplines.
- **NP**: Topics described in the 2015 NSAC Long Range Plan, including research to accelerate discovery at FRIB, fundamental nuclear structure and nuclear astrophysics, fundamental symmetries, and super-heavy elements.

Slide from Dr. Cherry Murray (Feb 9 SC budget rollout)

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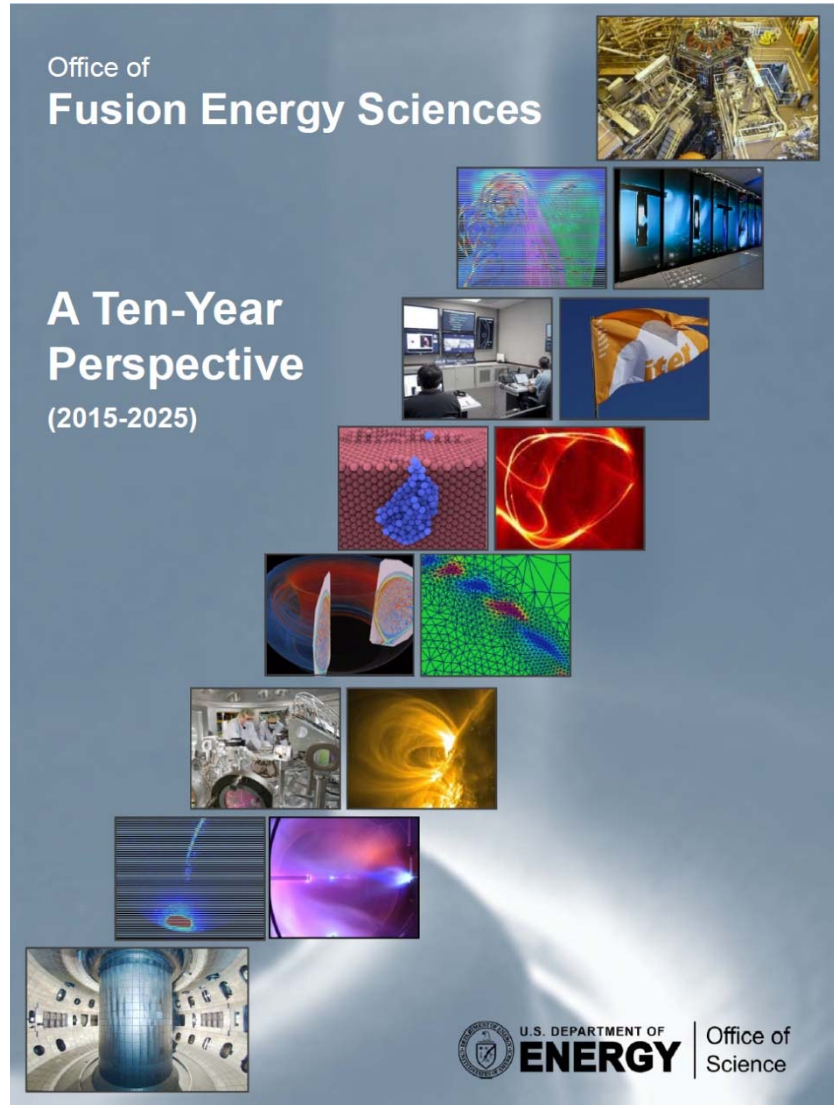
FES ten-year strategic plan

- Chronology:
  - April 2015: Submitted for DOE/Administration concurrence
  - December: Submitted to Congress
  - February 2016: Congressional approval for public distribution (with new cover)

- The high-level vision described herein builds on the present U.S. activities in fusion plasma and materials science relevant to the energy goal and extends plasma science at the frontier of discovery



http://science.energy.gov/fes/community-resources/

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Community engagement workshops

- **FES held community workshops in 2015:**
  - Plasma-Materials Interactions
  - Integrated Simulations for Magnetic Fusion Energy
  - Plasma Transients
  - Frontiers of Plasma Science
- **Each workshop is delivering a report** [ ] that describes (1) scientific challenges and (2) implementation options to address them
- **FESAC commended the workshops:**
  - "At this FESAC meeting…we heard from the workshop chairs about the enormous community-wide effort to carry out these workshops, and the high degree of consensus in identifying priority research directions within these topics. We heard from FES that the workshop results are being used to help explain and shape the Fusion Energy Sciences program within the U.S. government. We were pleased to hear the workshop chairs unanimously express their satisfaction with both the community's support of the workshop goals and with FES's response to the results." [*Letter to Dr. Cherry Murray, Jan 14, 2016*]

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Recent FESAC report on non-fusion-energy applications

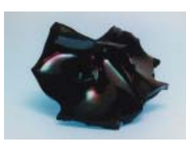
This FESAC report is being submitted to Congress to respond to the request in the 2014 Consolidated Appropriations Act

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

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

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

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



Waste Treatment: FES researchers have developed commercial plasma arc heating technologies to transform hazardous waste into vitrified products—a stable, solid form suitable for safe long-term disposal. Plasma arc vitrification. *Photo courtesy of Pacific Northwest National Laboratory.*

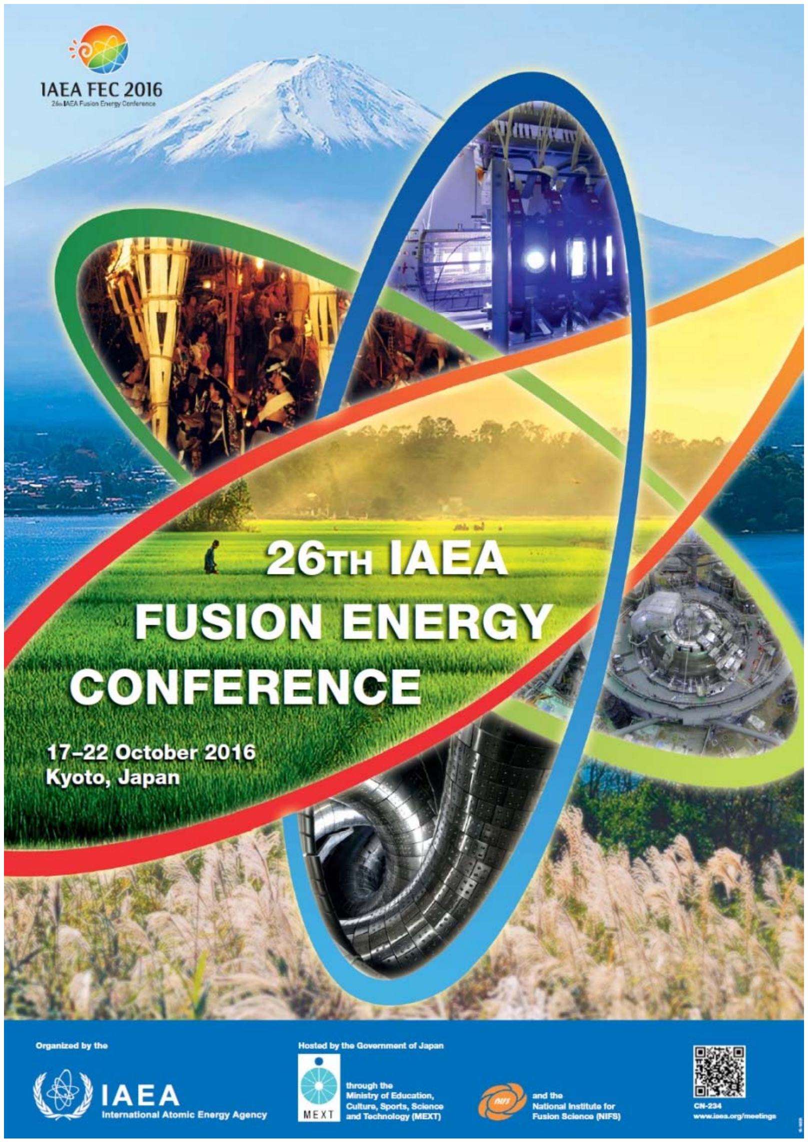
Applications of Fusion Energy Sciences Research

Scientific Discoveries and New Technologies Beyond Fusion

Fusion Energy Sciences Advisory Committee—U.S. Department of Energy Office of Science September 2015

http://science.energy.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf

2016 IAEA Fusion Energy Conference



- **26th IAEA Fusion Energy Conference (FES 2016)**
  - To be held in Kyoto, Japan, 17-22 October 2016
- **US paper selection**
  - Mark Foster (FES) is the lead
  - U.S. Paper Selection Committee had its meeting February 1 and 2.
- **IAEA FEC International Programme Committee**
  - Will meet in Vienna in April
  - U.S. to be represented by five persons: R. Buttery, D. Gates, H. McLean, D. Spong, and M. Foster

Thank you