

Fusion Energy Sciences: Program Overview

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

Fusion Energy Sciences Advisory Committee Meeting
May 25, 2022

FESAC Chair transition: Appreciation



Dr. Donald J. Rej

FESAC Chair 2016-2022



Prof. Anne E. White

New FESAC Chair

White House Fusion Summit (March 17) launched a new “bold decadal vision”

- Stakeholders from government, private sector, energy justice, and non-profit communities (>1,200 live-stream viewers)
- DOE established a fusion crosscutting team with OSTP in S4 office, led by a lead fusion coordinator
- Future budget requests to be coordinated across DOE in support of decadal vision
- DOE workshop “Fusion Energy Development via Public-Private Partnerships”, June 1-3, Wash, DC
- Funding Opportunity Announcement for a milestone-based, cost-share program is being prepared



Fusion Summit key messages

- Signal U.S. commitment to lead in the development of commercial fusion energy in partnership with the private sector
 - Long-term DOE investments in fusion research have enabled this moment
- Fusion is an opportunity for America to unite around the common purpose and daunting challenge of delivering a timely, sustainable, carbon-neutral future for the world
- Energy justice and diversity, equity, and inclusion are key to the success of fusion energy
- Summit starts engagement with stakeholders to pursue a bold decadal mission
 - Highlights the role of public-private partnerships in accelerating fusion RD&D
- Sets the stage for further, in-depth stakeholder engagements to define metrics and technology roadmaps for new public-private partnerships in fusion RD&D

Introducing the new Lead Fusion Coordinator



Scott C. Hsu

- Program Director, ARPA-E (2018–2022)
- Plasma/fusion research scientist, LANL (2002–2022)

Talk by Dr. Scott Hsu

Key responsibilities:

- Lead DOE cross-cut team in developing strategies for accelerating fusion energy RD&D in partnership with the private sector
- Make recommendations on key budget, programmatic, and policy decisions to the Under Secretary for Science & Innovation (S4)
- Coordinate fusion energy RD&D annual budget requests across key DOE program offices
- Serve as POC for internal and external stakeholder engagements

Immediate priorities:

- Working with SC to plan a workshop to discuss a new fusion-development public-private partnership program
- Stand up a cross-cut team
- Coordinate FY 2024 budget requests for fusion energy RD&D
- Identify/recommend Energy Justice and DEI initiatives for fusion

The FES Budget: FY 2021-2023

	FY 2021 Enacted		FY 2022 Enacted		FY 2023 Request	
	Dollars (\$K)	Percentage	Dollars (\$K)	Percentage	Dollars (\$K)	Percentage
Research	262,149	39.0%	308,230	43.2%	337,722	46.7%
Facility Operations	129,211	19.2%	125,270	17.6%	129,000	17.8%
Projects	278,000	41.4%	278,000	39.0%	255,000	35.3%
Other	2,640	0.4%	1,500	0.2%	1,500	0.2%
Total	672,000	100%	713,000	100%	723,222	100%

- **The FY 2023 Request includes:**

- SC initiatives: “FAIR” and “Accelerate Innovations”
- Milestone-based cost-share public-private partnership program
- Inertial fusion energy program

FY 2023 budget request numbers

Burning Plasma Science

Foundations
\$326.5M

Long Pulse
\$67M + \$14M

High Power
\$2M + \$240M

Discovery Plasma Science
\$72.5M + \$1M



Advanced Tokamak
\$127M

Spherical Tokamak
\$101M

Theory & Simulation
\$51M

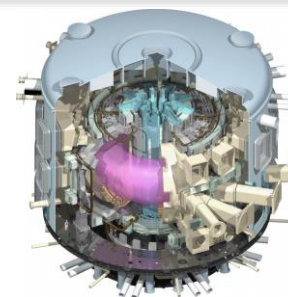
Public-Private Partnerships
\$32M



International Collaborations
\$22.5M

Fusion Materials and Nuclear Science
\$40.5M

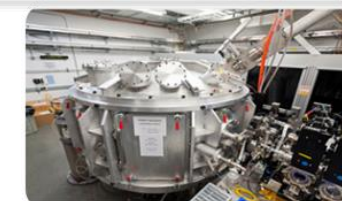
MPEX Project \$14M



US Contributions to ITER Project \$170M

ITER Organization Financial Contributions \$70M

ITER Research \$2M



Plasma Science and Technology \$37M

MEC-Upgrade Project \$1M

Quantum Info Science \$10M

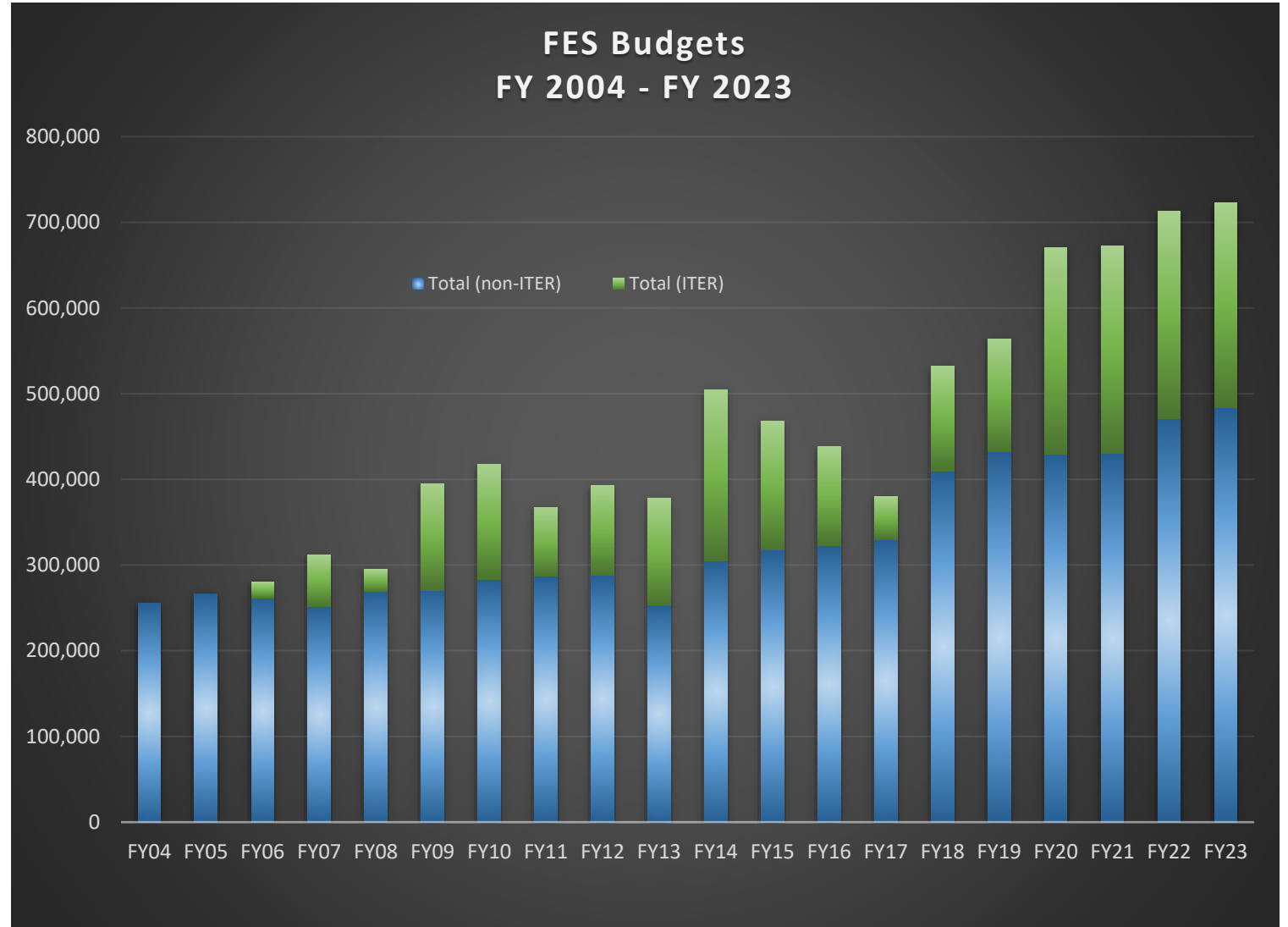
Yellow = projects

FY 2023 cross-cutting initiatives

Initiative	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request
Accelerate Innovations in Emerging Technologies (Accelerate)	--	--	6,000
Accelerator Science and Technology Initiative	--	3,073	--
Advanced Computing	--	--	2,000
Artificial Intelligence and Machine Learning	7,000	7,000	11,000
Fundamental Science to Transform Advanced Manufacturing	--	3,000	3,000
Funding for Accelerated, Inclusive Research (FAIR)	--	--	2,000
Microelectronics	5,000	5,000	5,000
Quantum Information Science	9,520	10,000	10,000
Reaching a New Energy Sciences Workforce (RENEW)	--	3,000	6,000
Total, Research Initiatives	21,520	31,073	45,000

FY 2024 budget request is under preparation

- Addressing the FESAC Long-Range Plan recommendations, White House bold decadal vision, and Congressional authorizations is an opportunity going forward



FY 2022 Funding Opportunity Announcements: status

FOA	Title	Status
DE-FOA-0002635	Opportunities in Frontier Plasma Science	Applications under review
DE-FOA-0002693	Collaborative Research on International and Domestic Spherical Tokamaks	Applications under review
DE-FOA-0002702	Collaborative Research in Magnetic Fusion Energy Sciences on International Tokamaks	Pre-applications reviewed; full applications due on June 2
DE-FOA-0002633	High Energy Density Laboratory Plasma Science	Reviews complete; award selection in progress
DE-FOA-0002563	SC Early Career Research Program	Selections made and approved; awaiting SC public announcement
DE-FOA-0002758	FES-Reaching a New Energy Sciences Workforce (RENEW)	To be issued soon
NSF 16-596	NSF/DOE Partnership in Basic Plasma Science and Engineering	Selections in progress

FES-Reaching a New Energy Sciences Workforce (RENEW)

- Targeted effort to increase participation and retention of under-represented groups in fusion/plasma science and technology (part of the new SC-wide RENEW initiative)
- This new FY 2022 solicitation provides up to \$3M/year over 3 years; ~20 projects will be funded
- Will support sustainable research collaboration and undergraduate, graduate, and early career training opportunities
 - Non-R1 institutions and/or MSIs
 - DOE National Labs
 - SC User Facilities
 - DOE-sponsored Facilities
- Priority support for traineeships (undergrads, grads, postdocs); includes a call for a Center
- RENEW webpage: <https://science.osti.gov/Initiatives/RENEW>
- FES-RENEW Webinar: https://science-doe.zoomgov.com/webinar/register/WN_5entzda1Ty-G9gDs2o4wPA

Tribute to ITER Director-General Bernard Bigot



- Dr Bernard Bigot, Director-General of the ITER Organization, passed away on May 14 at the age of 72 due to illness
- Before joining ITER Organization, he served as the Chairman and CEO of the French Alternative Energies and Atomic Energy Commission (CEA), French High Commissioner for ITER, and President of the Ecole Normale Supérieure de Lyon
- Dr Bigot saw fusion energy inextricably linked to socio-economic progress for the world
- DDG Eisuke Tada is interim DG while the ITER Council searches for a permanent replacement

Status of US Contributions to ITER Project

To date, 93% of fabrication awards for the U.S. ITER project remain in the U.S.

- 600+ contracts to U.S. industry, universities, and national laboratories in 46 states and D.C.
- 500+ direct jobs, 1100+ indirect jobs per year



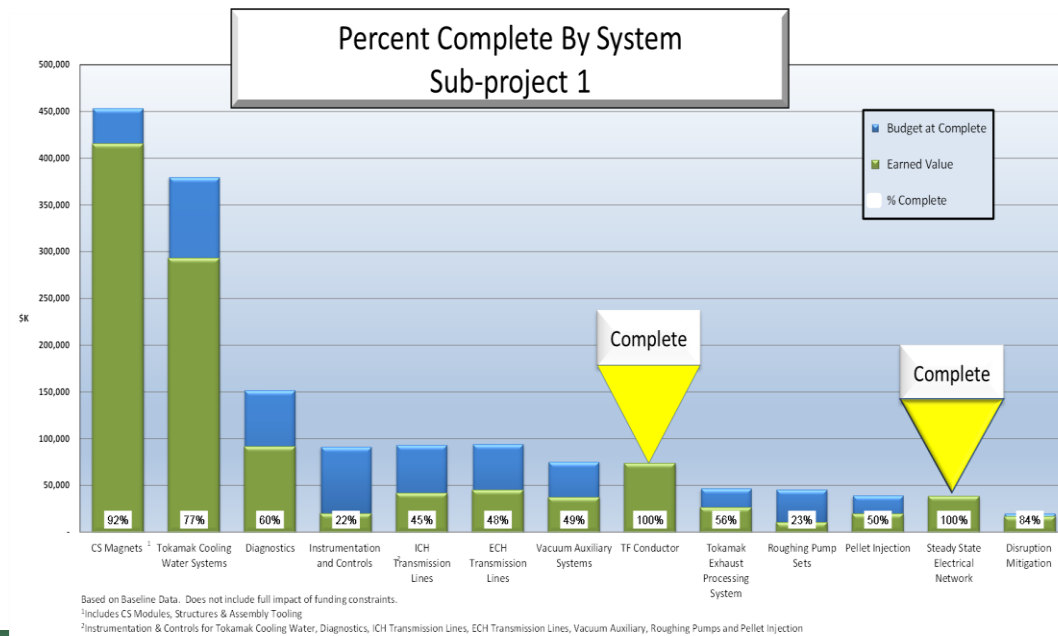
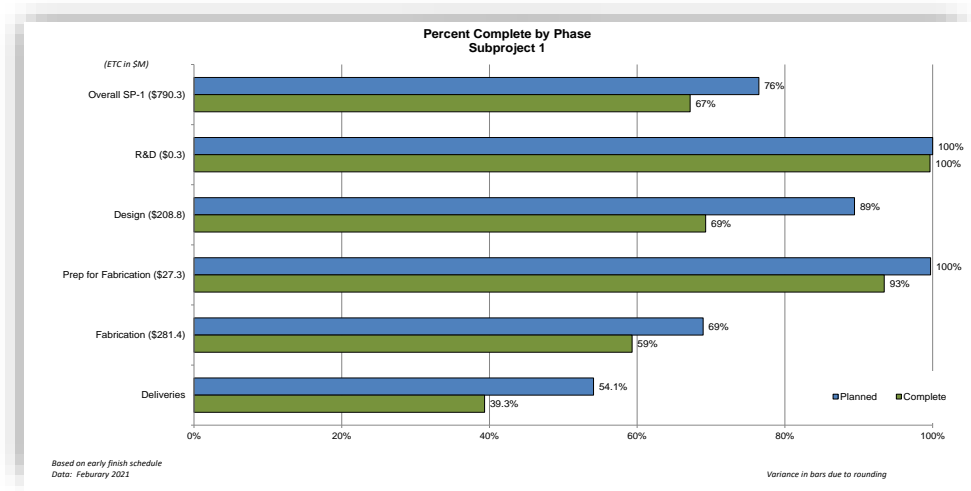
Total Funds spent in the U.S.: ~\$1.4B
(June 2021)

Awards to industry: ~\$729M

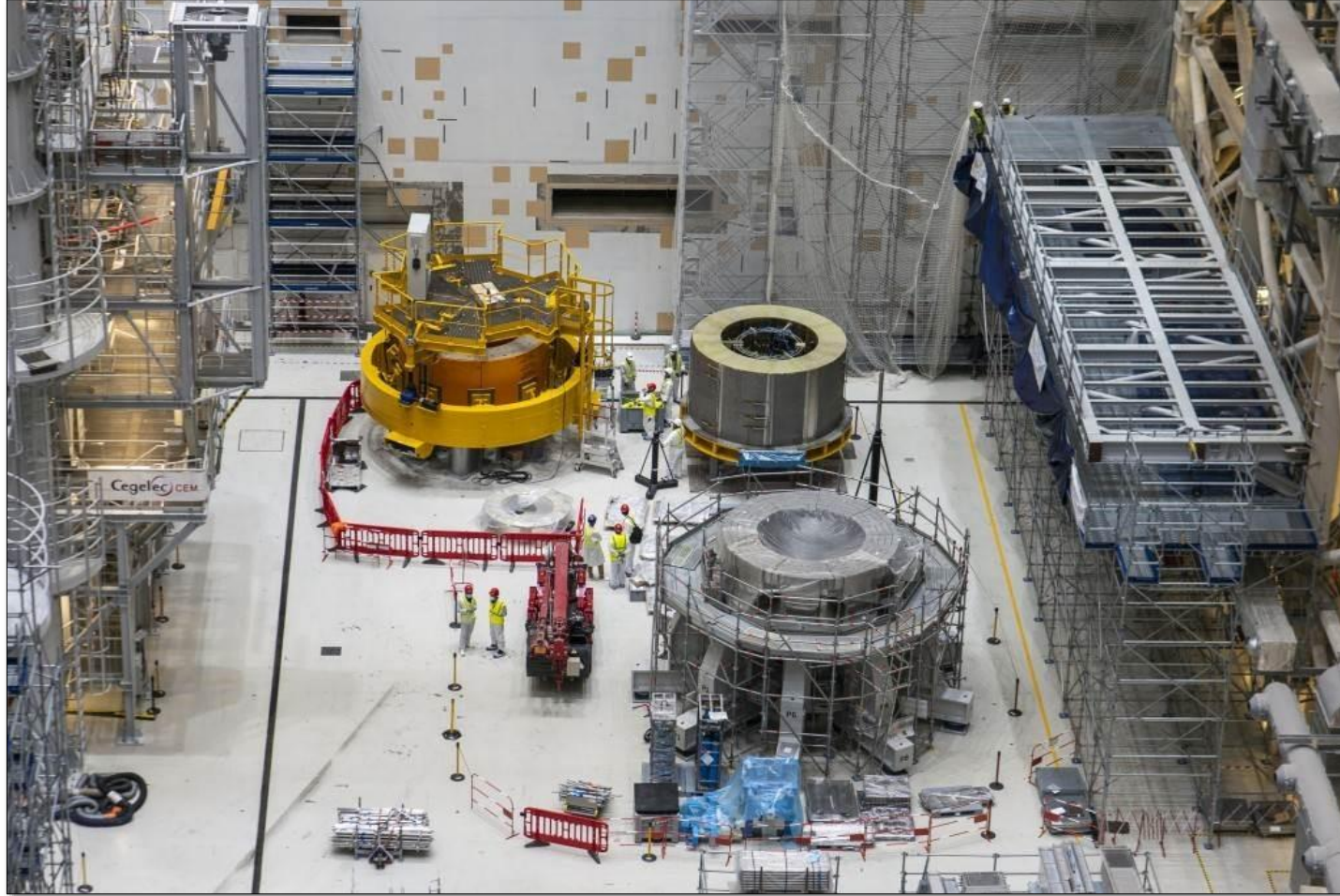
Awards to universities: ~\$26M

Obligations to National Laboratories: ~\$506M

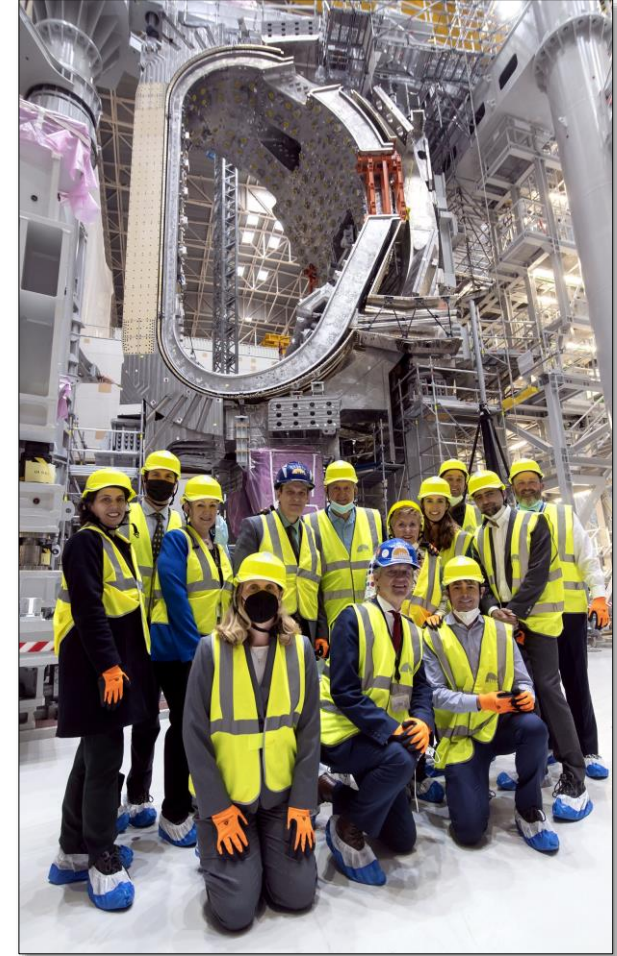
U.S. ITER Subproject-1 (First Plasma) is 67% complete & the international ITER project is 73% complete towards First Plasma



ITER assembly progress



Central solenoid magnet module, lifting fixture (yellow), and assembly platform (foreground) in Tokamak Assembly Hall



Senator Joe Manchin visit (March 2022)

Summer Schools this year

11th ITER International School



- Hosted by US Burning Plasma Organization, with ITER Organization, UC San Diego, and General Atomics
- At UC San Diego July 25-29, 2022
- Topic: "ITER Plasma Scenarios and Control"

<https://iis2022.burningplasma.org/>

3rd Computational Physics School for Fusion Research



- Hosted by MIT PSFC
- On campus, August 22-27, 2022
- Computational Statistics, Machine Learning, Optimization methods, Parallel Programming and HPC, as well as best coding practices

<https://www.psf.mit.edu/events/2022/computational-physics-school-for-fusion-research-cps-fr-2022>

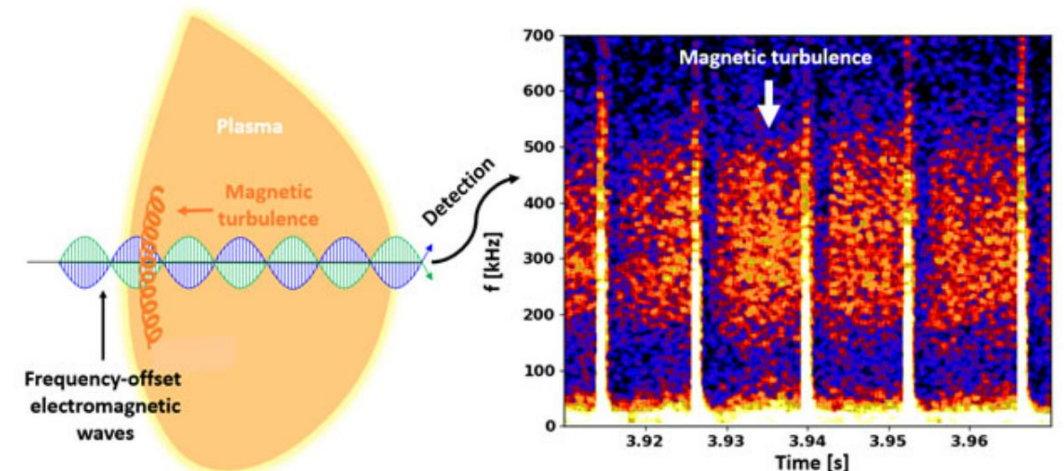
DIII-D is pursuing a 2-year, 40-week research program

- **Following Research Opportunities Forum, DIII-D developed 40-week program for FY 2022-2023**
 - 620 ROF proposals → 180 full experiments and 52 three-hour sessions
 - FY 2022 program is 23% complete
- **Key program elements**
 - High a_{\min} steady-state scenario
 - Diverted negative-triangularity scenario
 - Non-ELMing scenario (under Joint Research Target)
 - Several task forces: ITER, DIII-D/EAST, Core-edge, Push the Limits
 - Several special programs: Frontier Science, Torkil Jensen award, Ph.D. student allocation
- **FES and GA are improving DIII-D user agreements to allow for non-proprietary and proprietary facility usage by private industry**

LLAMA used to measure neutral density in DIII-D



RIP used to measure magnetic turbulence from micro-tearing modes in DIII-D



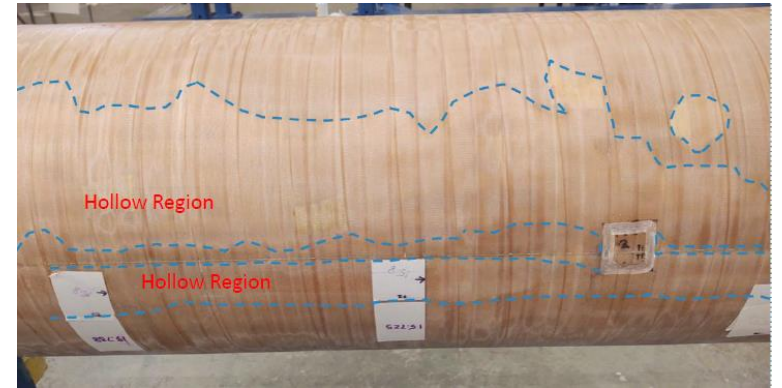
Spherical tokamak research

Status of NSTX-U Recovery

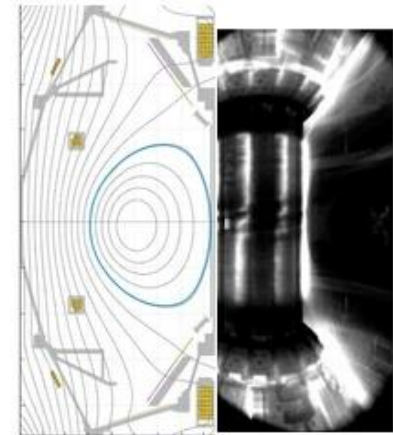
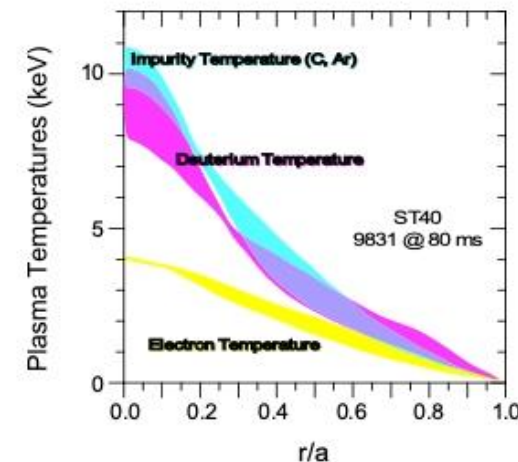
- Major issue discovered with existing TF bundle, which requires replacement, resulting in the delay of project completion by >1 year
- New Recovery cost and schedule baseline is planned for late summer of FY 2022

ST40 achieves record temperatures in compact ST

- Main ion temperatures of ~ 8.6 keV at $B_T = 2$ T have been realized on ST40 through a CRADA between PPPL and ORNL and the private company Tokamak Energy
- Discharges similar to TFTR “supershots” were used
- The PPPL-developed TRANSP code computed main ion temperatures from measured impurity ion temperature profiles enabled by PPPL, ORNL, and TE diagnostics



NSTX-U TF bundle delamination

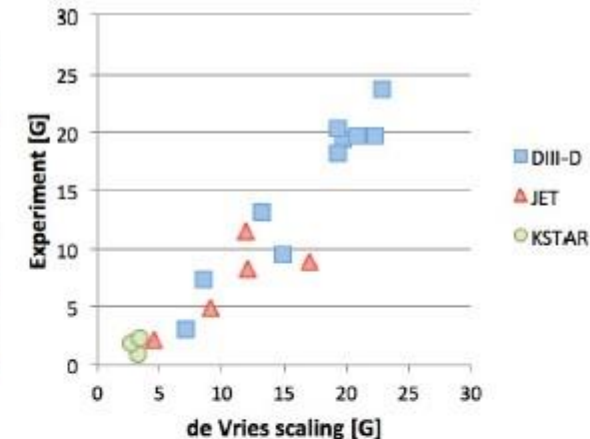
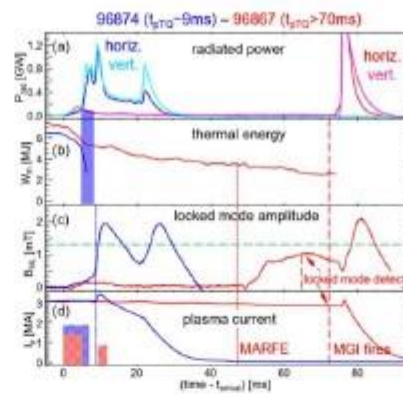


ST40 results

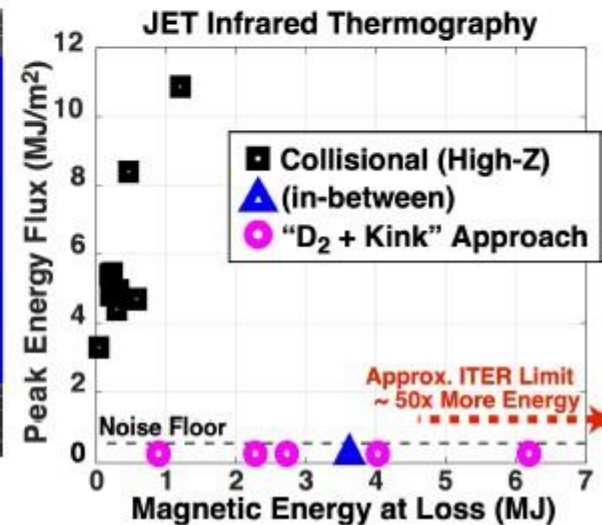
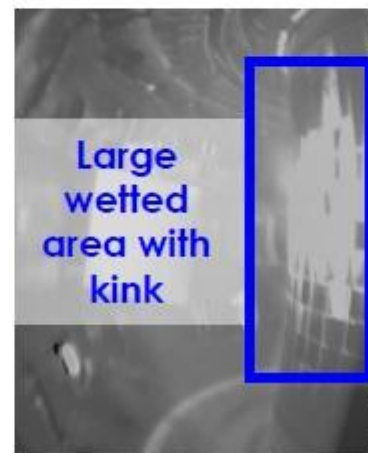
FY 2021 Joint Research Target: Shattered Pellet Injection for Disruption Mitigation on ITER

Final Report Identifies Areas of Consensus Across DIII-D, JET, and KSTAR SPI Research

- Assimilation of hydrogenic pellets is limited, with typical injection quantities leading to delayed disruption determined by subsequent MHD growth
 - Radial transport limits assimilation, MHD limit observed in all three devices



- Global MHD instabilities in mature runaway electron (RE) beams with a recombined background enables benign termination of the beam
 - Instability broadly disperses REs, in DIII-D and JET



JRT team led by Daisuke Shiraki (ORNL)



<https://science.osti.gov/fes/Community-Resources>

Other FES new facility projects

Material Plasma Exposure Experiment

Test materials exposed to high-heat-flux plasma

ORNL

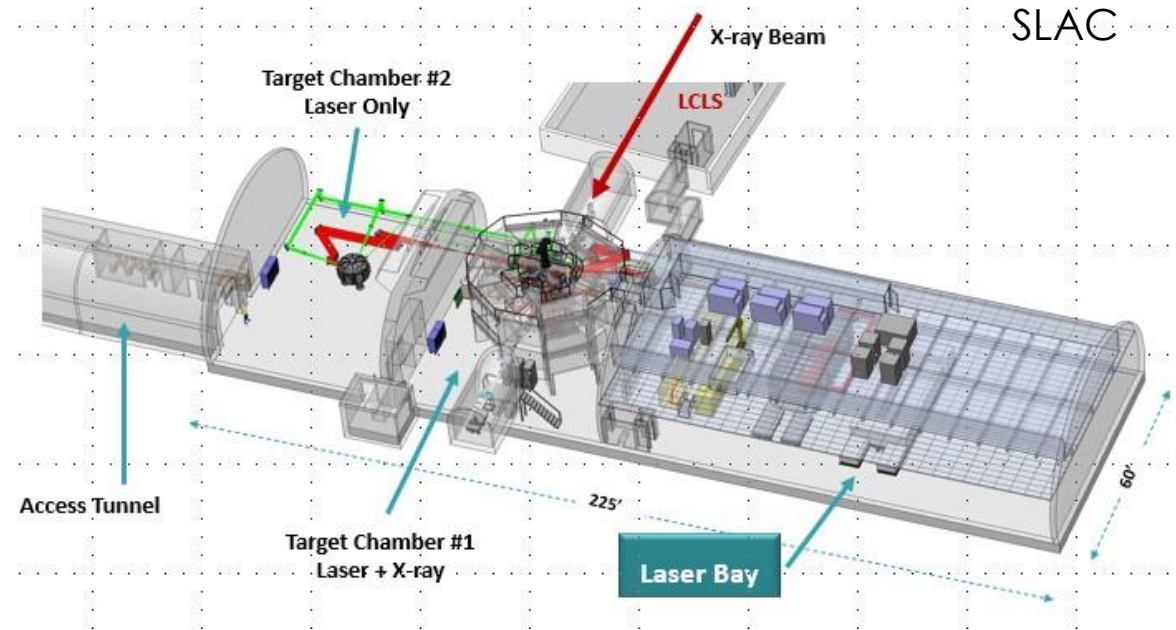


- CD-1 (Alternative Selection & Cost Range): January 2020
- CD-3A (Long-lead Procurement \$43M): Oct 2020
- Planned CD-2/3 ESAAB: September 2022
- CD-4: January 2028
- Estimated total project cost: \$183M

Matter in Extreme Conditions – Upgrade

Upgrade lasers that create high-energy-density plasma, to be probed with LCLS-II/HE hard x-rays

SLAC



- CD-1 (Alternative Selection & Cost Range): Oct 2021
- Estimated total project cost range: \$264M - \$461M
- CD-4 estimated: Q4 FY 2029

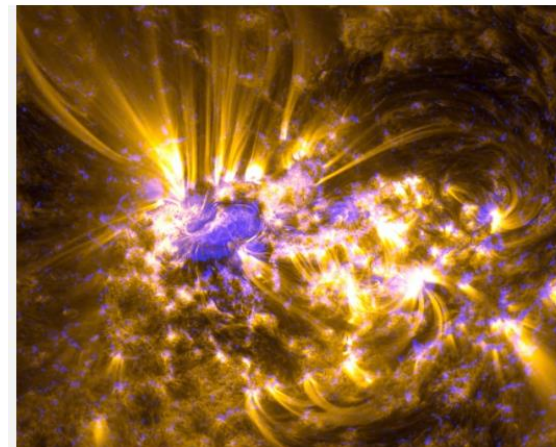
Innovation Network for Fusion Energy (INFUSE)

- INFUSE is now in its fourth year
- In FY 2021: Two Request for Assistance Calls, with approximately \$4.0M in research awards
- To date, 47 awards totaling \$9.3M have been made, enabling 9 DOE national labs to collaborate with 17 fusion companies
- A pilot program for University participation was launched in FY 2022
- The 3rd Annual INFUSE Workshop was held virtually December 16, 2021, and included discussion of this pilot program
- The FY 2022 First Round Request for Assistance Call has closed, and selections will be announced shortly

<https://infuse.ornl.gov/>



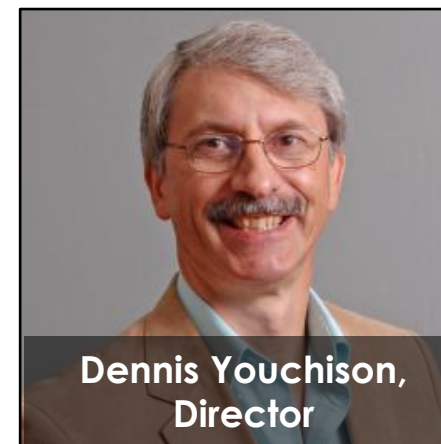
What Is INFUSE? Topic Areas ▾ Meetings ▾ Library Submission ▾



Innovation Network for Fusion Energy

The INFUSE program will accelerate fusion energy development in the private sector by reducing impediments to collaboration involving the expertise and unique resources available at DOE laboratories. This will ensure the nation's energy, environmental and security needs by resolving technical, cost, and safety issues for industry.

Read More



Dennis Youchison,
Director



Ahmed Diallo,
Deputy Director



STEP Program in the UK

Spherical Tokamak for Energy Production – STEP

- Predictable net electricity production
- Lower capital cost than other fusion power plant designs
- £220M investment for concept design by 2024

- Already a national endeavour with 290 companies involved in delivery and 20+ universities

Talk by Dr. Ian Chapman



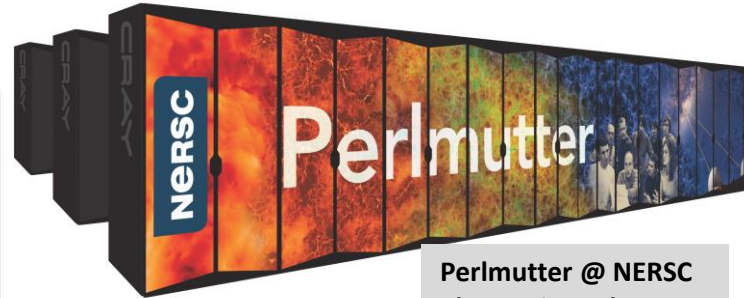
40th anniversary of US-Japan fusion cooperation was celebrated in a recent report

- Report was presented at the US-JA Coordinating Committee on Fusion Energy Annual Meeting (April 12, 2022)
- Similar format to 20th and 30th anniversary reports
- Report summarizes progress during 2011-2020
- Over 180 US and Japanese contributors provided 88 summaries covering fusion science, technology, theory and simulation, and joint projects (120 pages)
- 277 joint publications were collected
- Report to be posted on FES web site:
science.osti.gov/fes/community-resources

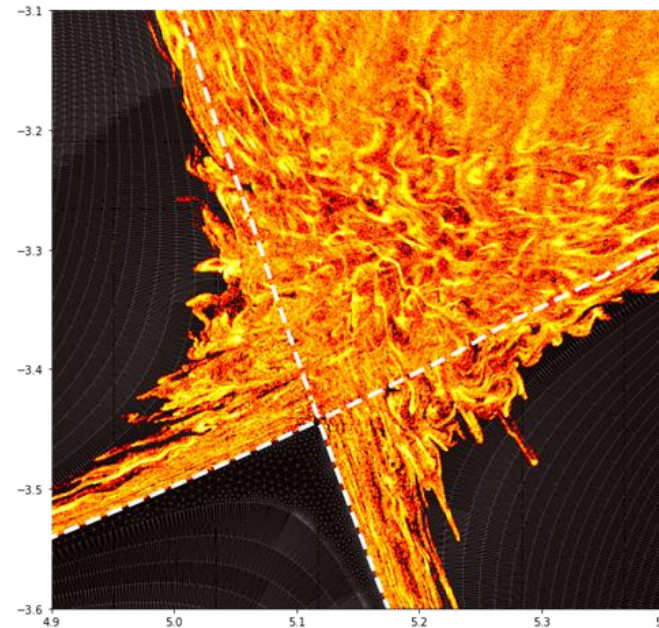


Theory and Simulation

- The 9 FES multi-institutional SciDAC partnerships are being extended for a sixth year
- The portfolio will be re-competed in FY 2023
 - Expand from WDM to whole facility modeling to provide integrated high-fidelity tools for FPP studies
- The FES Theory program continues to address gaps in burning plasma science



Perlmutter @ NERSC
Phase 2 in early FY23



Microturbulence driven, fluctuating
homoclinic tangles in ITER edge
(4,096 Summit nodes)



SUMMIT @ ORNL



FRONTIER Exascale Computer @ ORNL
(due in 2022)



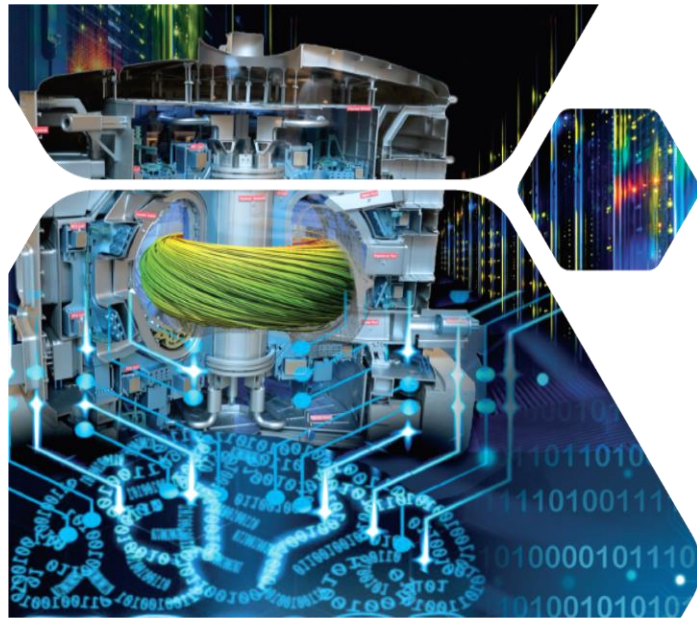
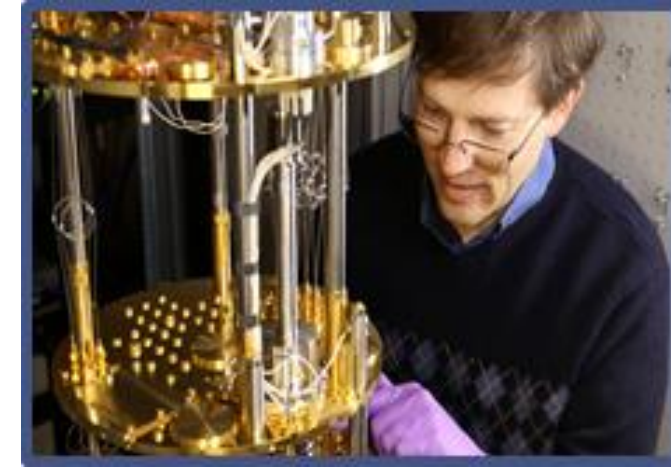
AURORA Exascale Computer @ ANL
(due in 2022-2023)

QIS and AI/ML research activities

New Quantum Algorithms Finally Crack Nonlinear Equations

- ▶ Fusion plasmas are highly non-linear, and there is a need for quantum information science (QIS) algorithms to advance FES mission
- ▶ An MIT-led team has developed an algorithm that mimics nonlinear phenomenon on a quantum computer, using Bose-Einstein condensate to connect nonlinearity and linearity.

Talk by Dr. Andrew Houck



FES-supported AI & ML

- New ML descriptors improved the accuracy of atomistic materials simulations
- Six one-year pilot studies supported in: randomized methods, plasma pulse design, stellarator optimization, detached divertor models, inertial confinement fusion, and physics-informed neural networks for disruption prediction.

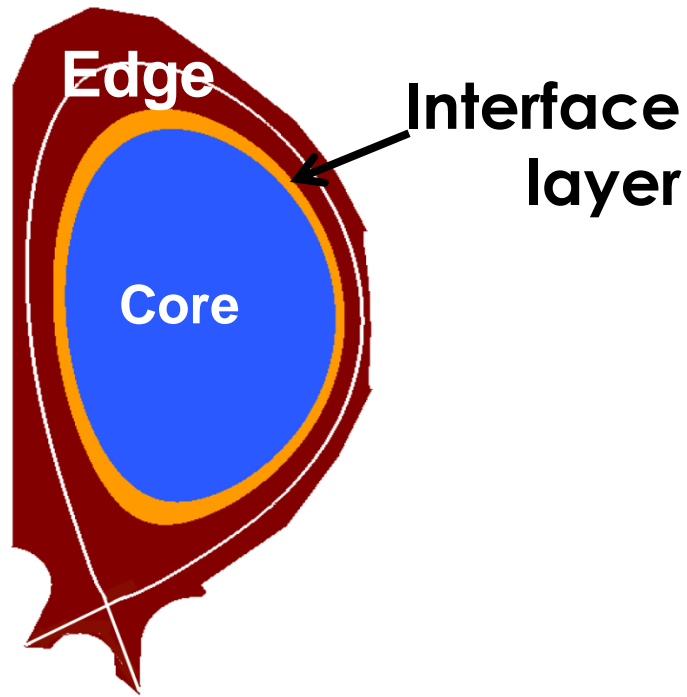
FY 2022 Plans

- Final year of three-year award cycle
- Consideration of AI/ML data center

FY 2023 Plans

- Start of a new three-year award cycle

Exascale Computing Project



Principal goals of WDMapp (Whole Device Modeling)

- Demonstration and assessment of WDM **gyrokinetic physics** on experimental transport time-scale in a challenge problem for pedestal formation
- **Figure of Merit (FOM) of >50** for coupled code on exascale platforms, accomplished through algorithmic advancement, performance engineering and hardware improvement
- Completion of **extensible integration framework** EFFIS 2.0 (End-to-End Framework for Fusion Integrated Simulations 2.0) and demonstration on exascale platform

Talk by Dr. Doug Kothe

ESnet networking requirement review for FES

Energy Science Network (ESnet) conducted a FES Network Requirements Review during 2021 to comprehensively survey FES stakeholders' plans and processes in networking and data



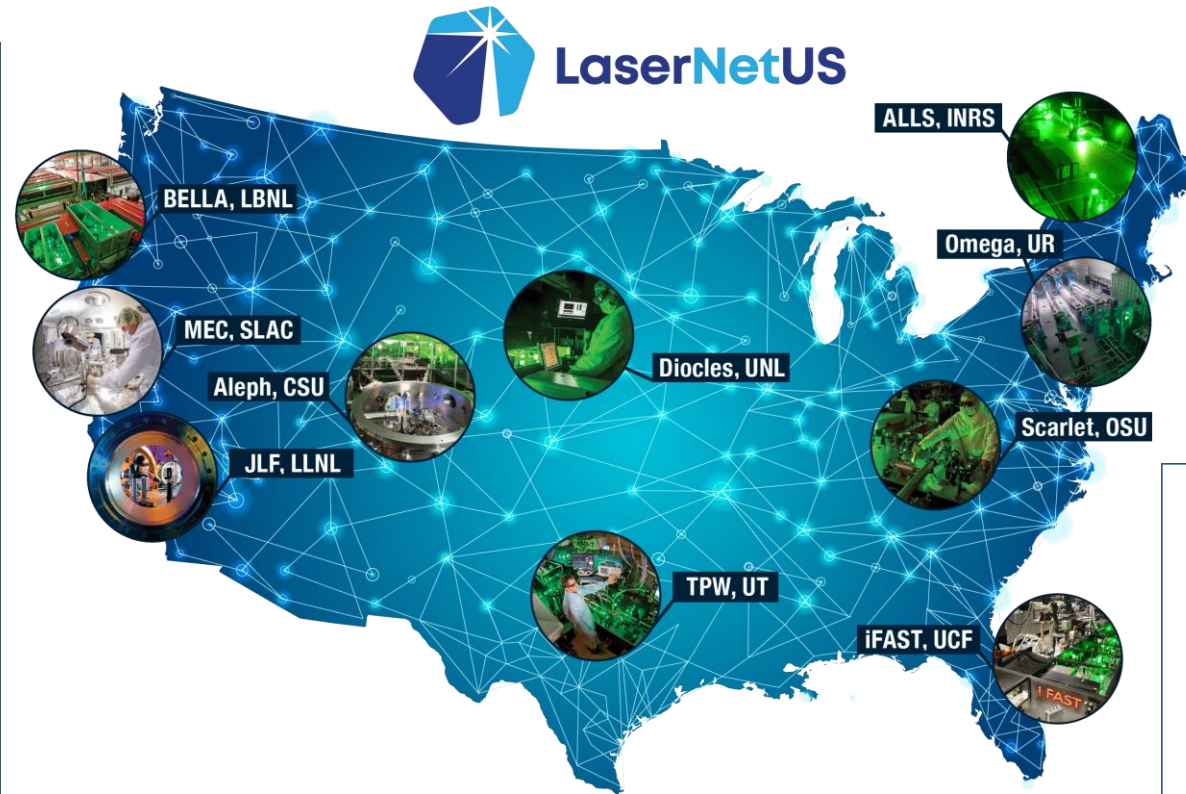
Final report expected imminently

REVIEW OUTPUT: COMMON THEMES

- Scientific Data Management: Storage, Dissemination, Mobility, and Volume
- ITER Challenges and Opportunities
- Remote Collaboration Requirements and Use Cases
- Multi-Facility Computational Workflows and Use Cases
- International and Transoceanic Networking
- Domestic Networking for Local and Wide-Area Uses Cases
- Software Infrastructure Requirements and Improvements
- Cybersecurity

LaserNetUS updates

- 3rd LaserNetUS Users Meeting (August 16-18, 2022, Fort Collins)
- iFAST laser (Univ. of Central Florida) joined LaserNetUS
- LaserNetUS usage:
 - 1,200+ members
 - More than 130 students
 - 123 institutions (88 US)
 - 70 user experiments
- New website: <https://lasernetus.org>
- Pursuing MOU with LaserLab EU



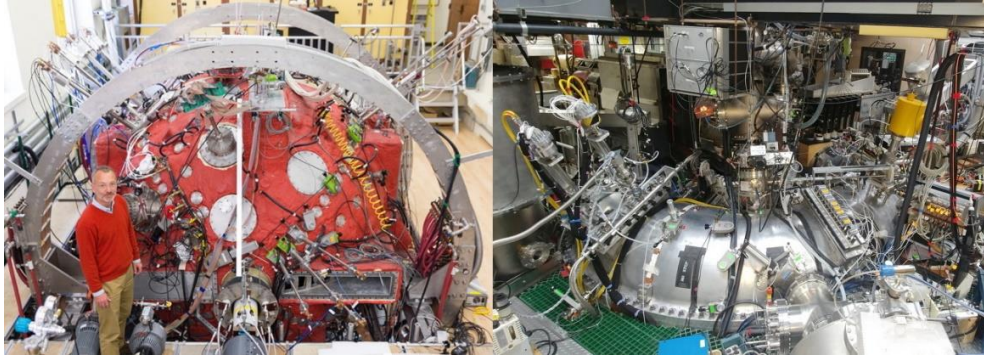
10 facilities

60 experiments performed

1239 members

Other research networks

MagNetUS



- Network of magnetized plasma experimental facilities for basic plasma science
- Formed in 2021, following FESAC Long Range Plan recommendation
- 2nd MagNetUS Annual Users Meeting June 7-10, College of William & Mary

<http://MagNetUS.net/>

ZNetUS



- Consortium from universities, labs, and industry for pulsed power Z-pinch science and technology research
- Formed in 2020; recommended in FESAC Long Range Plan
- 2nd ZNetUS Workshop, April 21-22, 2022, UCSD

<https://znetus.eng.ucsd.edu/>

FY 2022 FES Basic Research Needs Workshops

Inertial Fusion Energy (June 21-23, 2022)



Dr. Tammy Ma (LLNL), Chair, and Prof. Riccardo Betti (UR-LLE), Co-Chair

US ITER Research (July 2022)



Dr. Charles Greenfield (GA), Chair, and Dr. Cami Collins (ORNL), Co-Chair

Plasma Science for Microelectronics Fabrication (August 8-9, 2022)



Co-Chairs: Prof. David Graves (PPPL), Dr. Catherine Labelle (Intel), and Prof. Mark Kushner (Michigan)

- To seek community engagement on microelectronics R&D in the fields of plasma science and associated materials and surface sciences
- To provide FES with prioritized research opportunities to inform future research efforts in plasma-associated semiconductor nanofabrication science and build a community of next-generation researchers
- Pending DOE approval

Peaceful Uses Initiative 2-year position at IAEA

- The International Atomic Energy Agency (IAEA) Department of Nuclear Energy seeks a senior nuclear expert in fusion technology to support the Department's Nuclear Power Technology Development Section (NPTDS) in the Division of Nuclear Power (NENP). Duty station is Vienna, Austria.
- The expert would lead activities in the area of fusion reactor technology and coordinate collaborative projects within and outside of the UN system.
- The Department of Energy's Office of Science is prepared to support an allocation of U.S. funding already provided to the IAEA under the Peaceful Uses Initiative (PUI) totaling €526,000 (approximately \$600,000) for an initial two-year assignment of a P-5 Cost Free Expert (CFE).
- The position was posted in mid-May and can be found here:
[https://international.anl.gov/Staffing/docs/2022/CFE/NE202203-P5-0%20Senior%20Nuclear%20Expert%20\(Fusion%20Technology\).pdf](https://international.anl.gov/Staffing/docs/2022/CFE/NE202203-P5-0%20Senior%20Nuclear%20Expert%20(Fusion%20Technology).pdf)
- Information about how to apply can be found here:
<https://anl.app.box.com/v/HowToApply-CFE>

2022 Young Women's Conference in STEM

- PPPL's 2022 Young Women's Conference in science, technology, engineering and mathematics (STEM), held May 6, was a national bicoastal virtual event this year.
- The Young Women's Conference brought together about 300 seventh to tenth-grade students for the 21st such event sponsored by PPPL.
- Similar to last year, the conference took place in a virtual meeting place designed by Oak Ridge Associated Universities (ORAU) that featured an auditorium, a lobby, and exhibit hall with virtual booths.

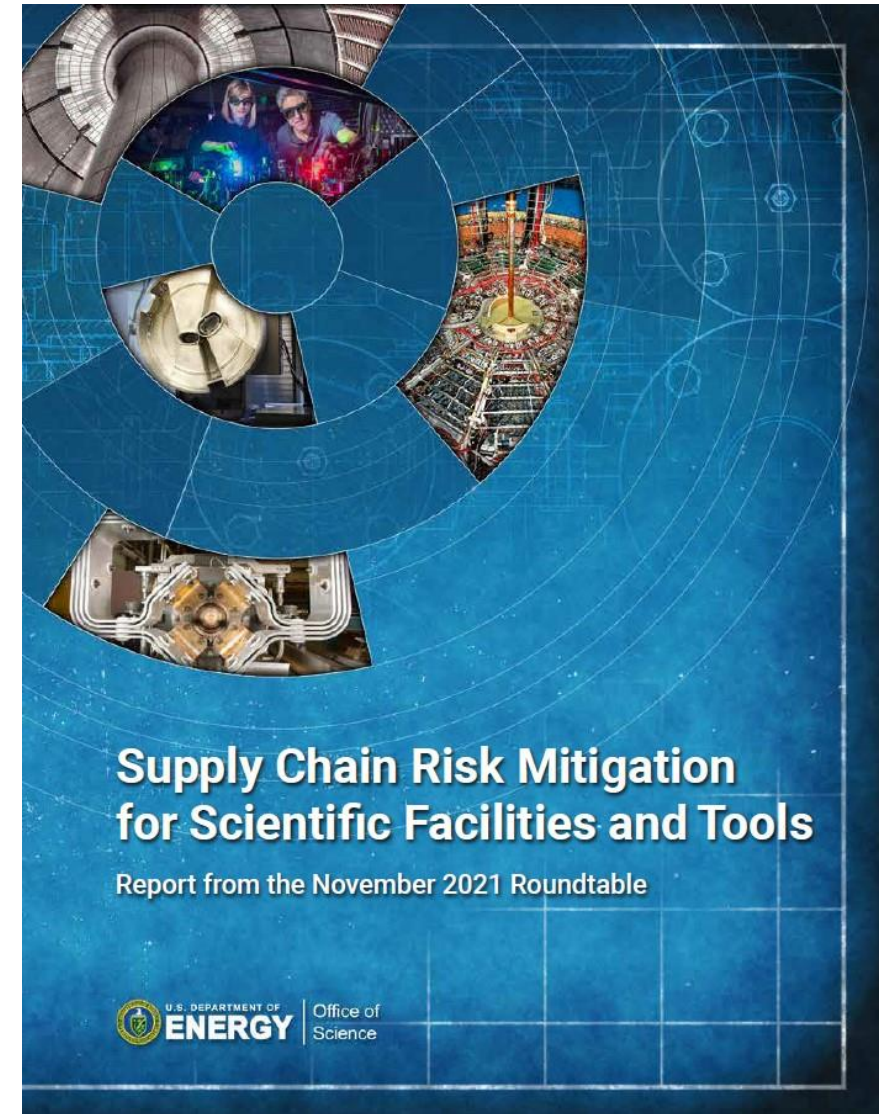


PPPL and Princeton University participants in the Young Women's Conference, clockwise from left: Deedee Ortiz, Science Education program manager; Hekima Qualls, head of Procurement; Carol Ann Austin, administrative manager in the director's office; Kathryn Wagner, a lecture demonstrator and outreach director in chemistry in Princeton University's Chemistry Department; and Shannon Swilley Greco, Science Education senior program leader.

Office of Science report on supply chain issues

- SC roundtable report “Supply Chain Risk Mitigation for Scientific Facilities and Tools” has been posted
- The roundtable (November 2021) was timely amid an increased federal government emphasis on strengthening domestic supply chains to help U.S. businesses compete in strategic industries and help America’s workers thrive
- Executive Order (EO) 14005, “Ensuring the Future is Made in All of America by All of America’s Workers” (January 2021)
- Roundtable participants identified several opportunities that could yield near-, mid-, and long-term benefits

<https://science.osti.gov/fes/Community-Resources>



US Fusion Energy website

- Organized and designed by the US fusion community
 - Fusion Outreach Team
- Aligns with the FESAC Long-Range Plan
- Provides the community and the general public:
 - Introduction and general education on Fusion and Plasma Science
 - Current fusion and plasma science news
 - Fusion and plasma science events
 - Fusion and plasma sciences support in government and industry
 - Student engagement and research opportunities



<https://usfusionenergy.org/>

DOE leadership update



Dr. Geraldine Richmond

Under Secretary for Science and Innovation

- Sworn in on November 9, 2021
- Presidential Chair in Science and Professor of Chemistry at the University of Oregon
- Member, NASEM and AAAS
- Honors: National Medal of Science (2016), the Priestley Medal from the American Chemical Society (2018), and the Linus Pauling Medal Award (2018)



Dr. Asmeret Berhe

Director of the Office of Science

- Sworn in on May 19, 2022
- Professor of Soil Biogeochemistry in the Department of Life and Environmental Sciences, Ted and Jan Falasco Chair in Earth Sciences and Geology, and Interim Associate Dean for Graduate Education, University of California, Merced
- Fellow, AGU and GSA; Chair, NASEM US National Committee on Soil Science; founding investigator of the ADVANCEGeo Partnership

International Benchmarking Charge for FESAC

Please address the following questions:

- Since the last time FESAC assessed the opportunities afforded to U.S. scientists by international fusion facilities with unique capabilities, a number of new facilities have come online, and existing facilities have undergone significant upgrades. In what areas of research and on which facilities are there compelling opportunities for U.S. researchers over the next 10 years?
- What is the potential of these facilities to help U.S. scientists address priorities and recommendations in the Long Range Plan and the National Academies report on “Bringing Fusion to the U.S. Grid”, contribute to the Administration’s bold decadal vision for commercial fusion, and increase the U.S. readiness for ITER operation? In addition, please assess whether the existing modes of collaboration are adequate for maximizing the impact of international collaborations on the U.S. fusion program and objectives.
- How can the U.S. take advantage of its considerable and growing fusion private sector in international engagements, and how can we cooperate with overseas public-private partnership programs that focus on accelerating the development of commercial fusion?
- Within the FES-supported research areas and facility capabilities for fusion energy science and discovery plasma science, what are the areas where the U.S. is leading, the areas where U.S. leadership is threatened in the near- and long-term, and the areas in which U.S. is not leading at present but where investing resources could offer significant opportunities for leadership that would be beneficial to the U.S. goals and objectives?
- How can the U.S. ensure the availability of a highly trained and internationally competitive workforce in fusion science and technology and related areas , including the recruitment of talent from traditionally underrepresented groups within the U.S.?