U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Science Update

APS March Meeting

March 17, 2016

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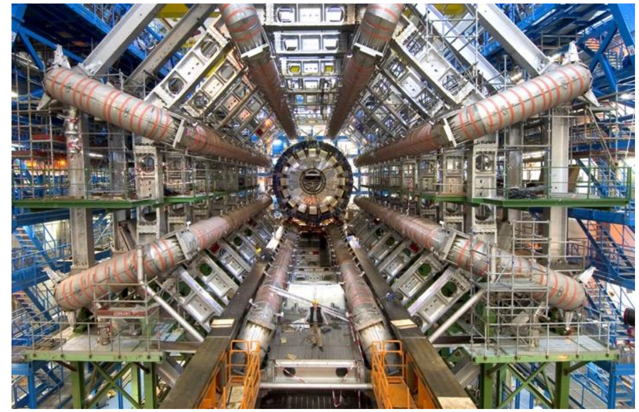
Department of Energy Mission Areas

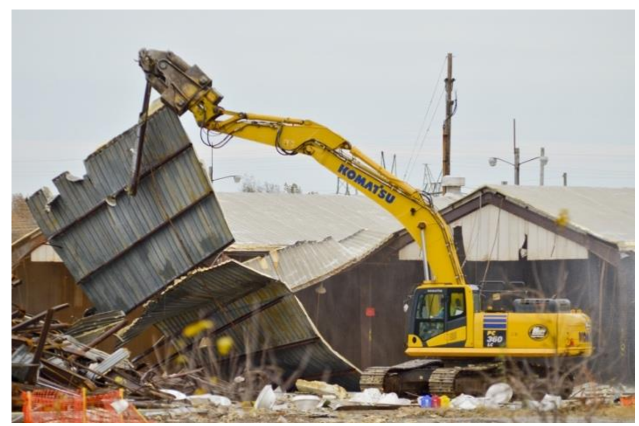
Energy

Science

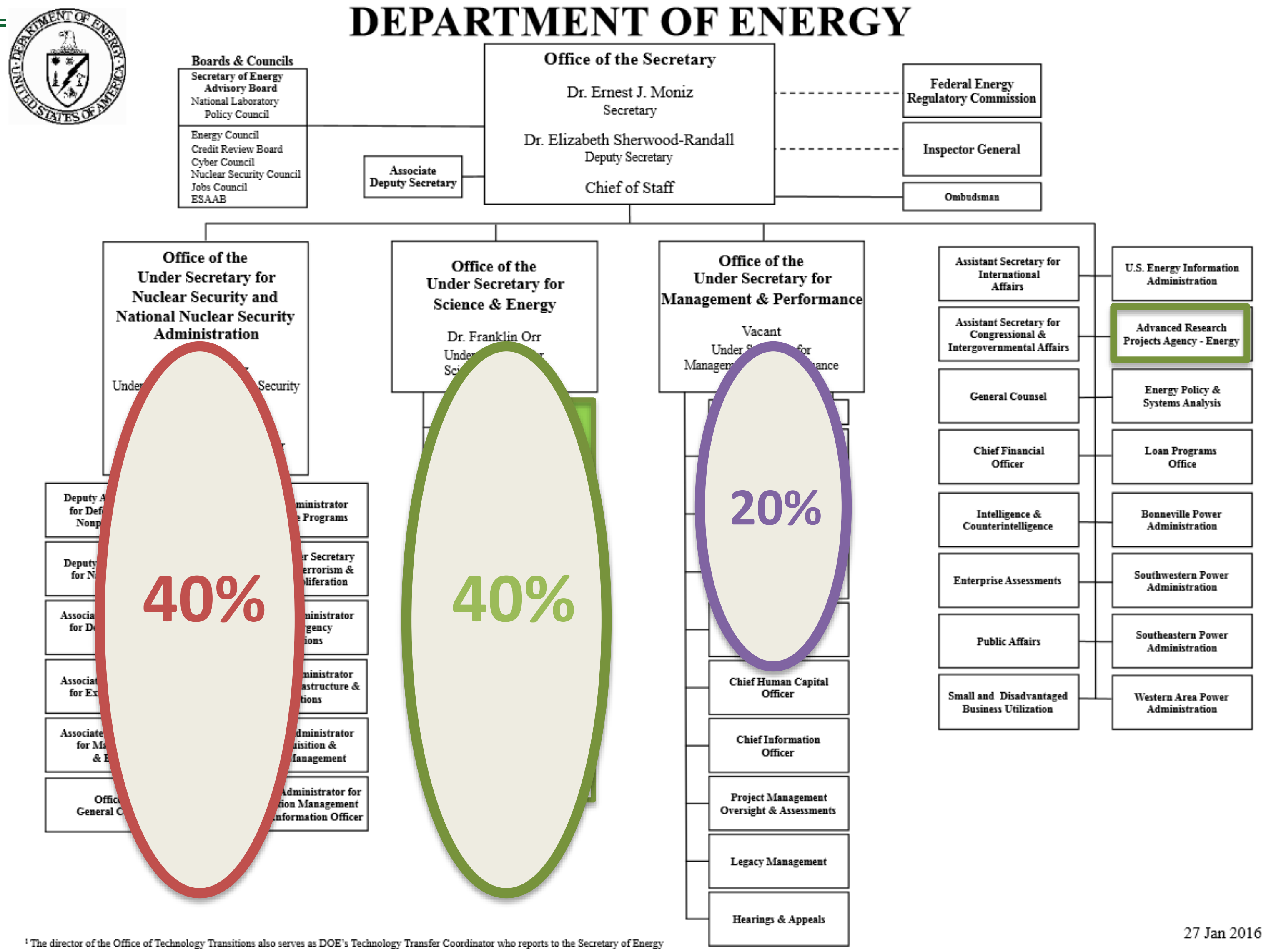


Nuclear Safety and Security

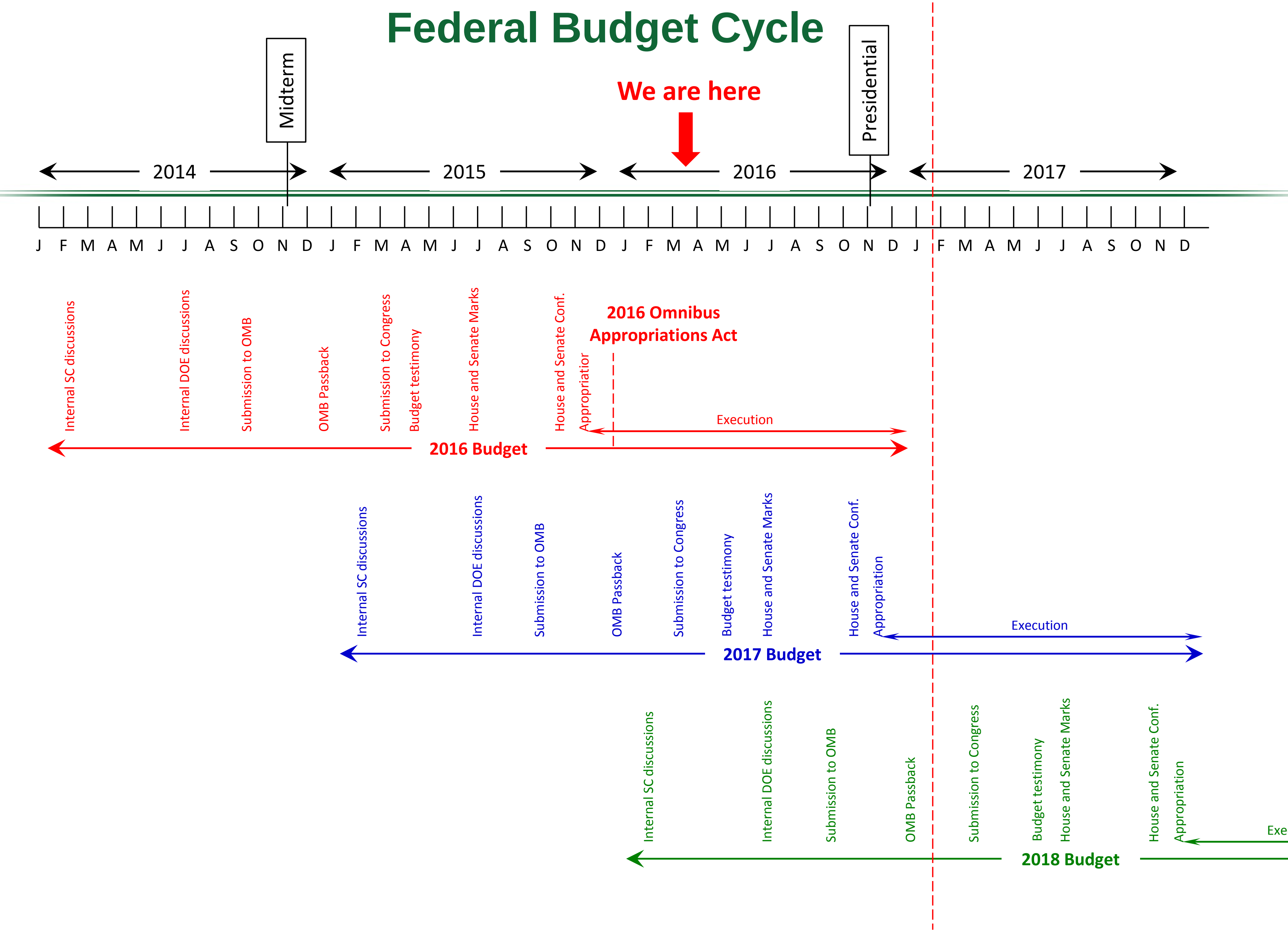
Environmental Cleanup



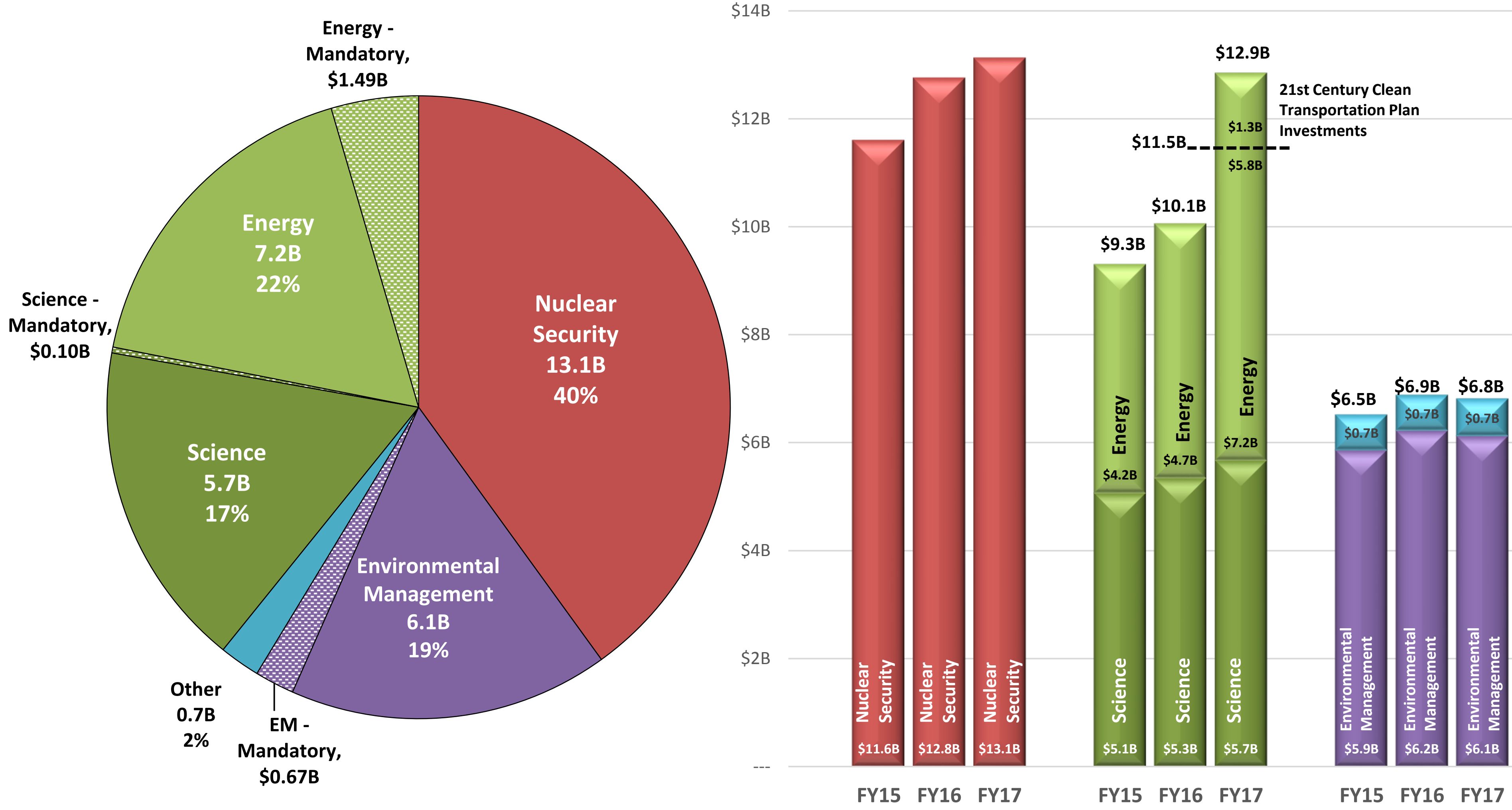
DOE Organization Chart 2016

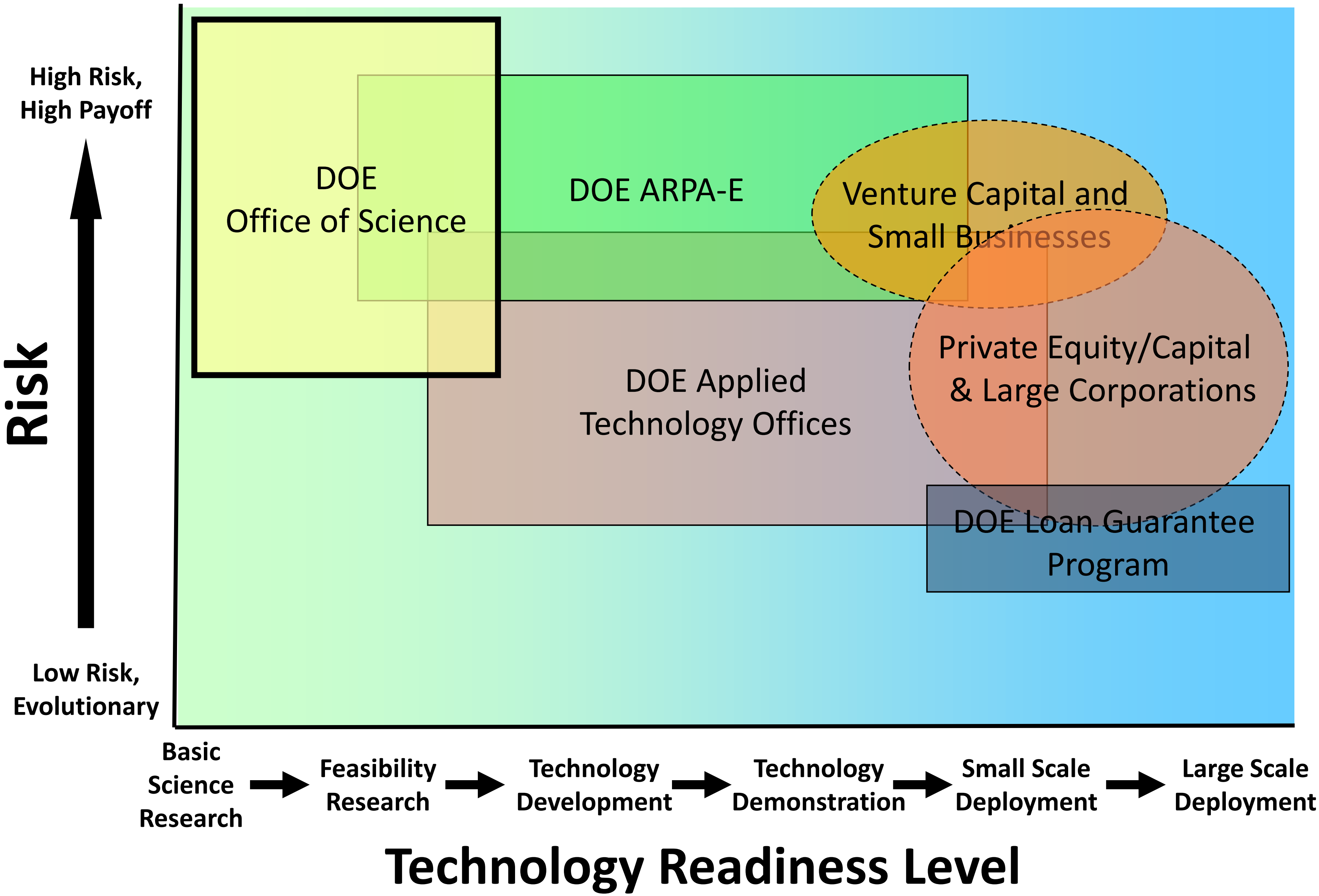


Federal Budget Cycle



President's DOE FY 2017 Proposed Budget




High Risk,
High Payoff
Risk
Low Risk,
Evolutionary
DOE
Office of Science
DOE ARPA-E
Venture Capital and
Small Businesses
DOE Applied
Technology Offices
Private Equity/Capital
& Large Corporations
DOE Loan Guarantee
Program
Basic
Science
Research
Feasibility
Research
Technology
Development
Technology
Demonstration
Small Scale
Deployment
Large Scale
Deployment
Technology Readiness Level

DOE Funding Modalities

Discovery Research | Use-Inspired Basic Research | Applied Research | Technology Maturation & Deployment

Office of Science | ARPA-E* | Applied Programs

Goal: new knowledge / understanding
Focus: phenomena
Metric: knowledge generation

Goal: practical targets
Focus: performance
Metric: milestone achievement

Consortia, Crosscuts

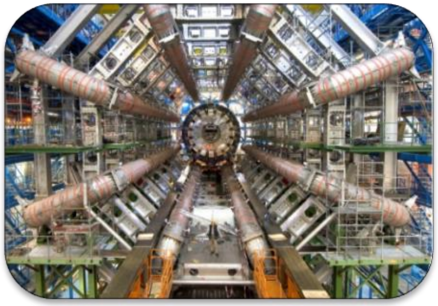
Bioenergy Research Centers, Hubs

Energy Frontier Research Centers

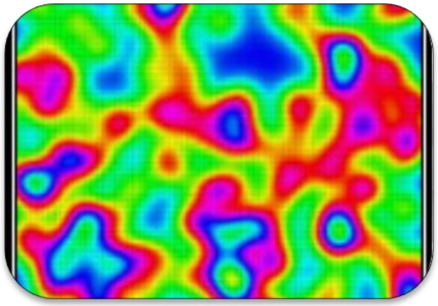
Core Research / Individual PIs

* ARPA-E targets technology gaps, high-risk concepts, aggressive delivery times

Office of Science FY16 - $5.35B

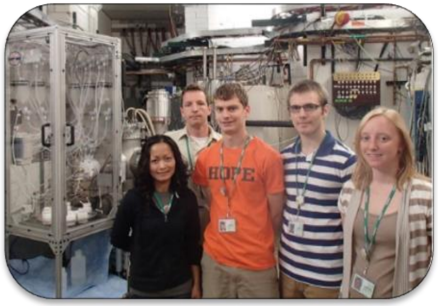


Largest Supporter of Physical Sciences in the U.S.*



Research: 42%, $2.2B

~40% of Research to Universities



> 20,000 Scientists Supported

Funding at >300 Institutions including all 17 DOE Labs

Construction: 13.5%, $723M

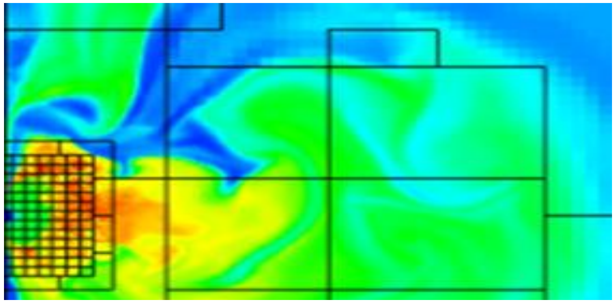
Facility Operations: 38%, $2.02B

>30,000 Scientific Facility Users**

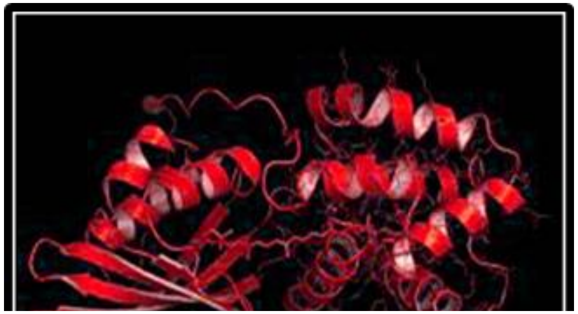
* 43% of all physical sciences, 30% of computer science and math

** from all 50 states and DC

Office of Science Programs

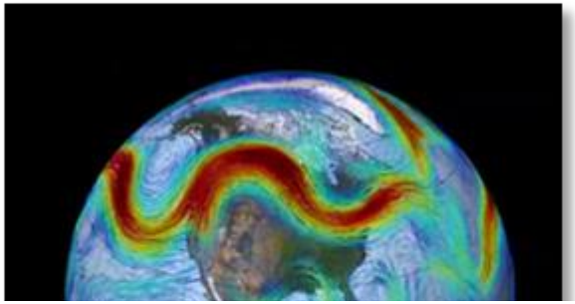


Advanced Scientific Computing Research
FY2016 $621M



Basic Energy Sciences

FY2016 $1849M



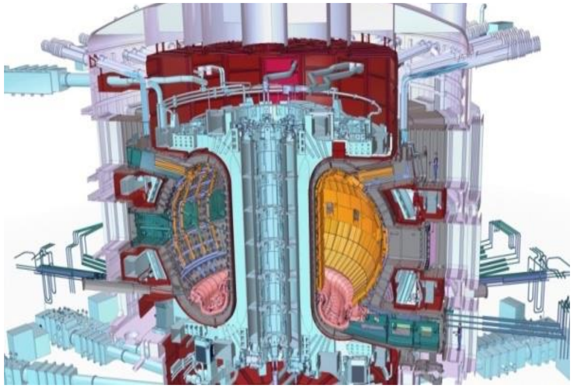
Biological and Environmental Research
FY2016 $609M

High Energy Physics

FY2016 $795M

Fusion Energy Sciences

FY2016 $438M

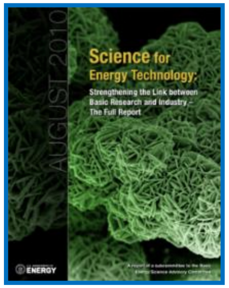


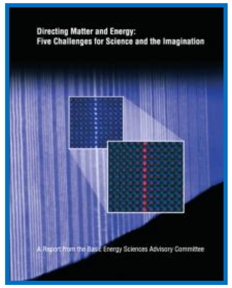
Nuclear Physics

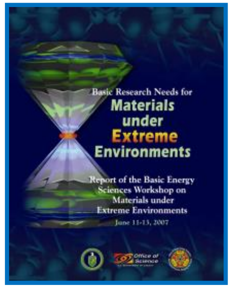
FY2016 $617M

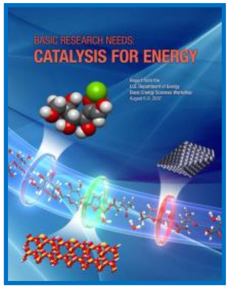
Office of Science Workshops

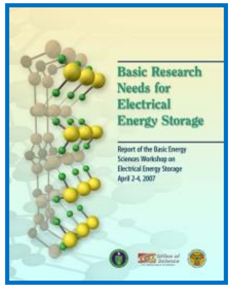
We use workshops, such as the Basic Research Needs Workshops in BES, Federal Advisory Committee Reports and National Academies Studies to engage the scientific community in planning.

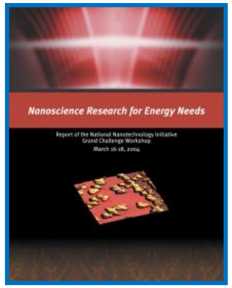


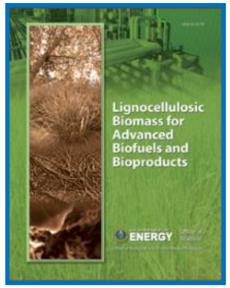


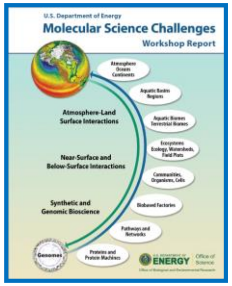


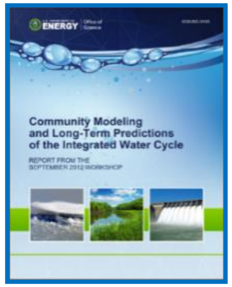


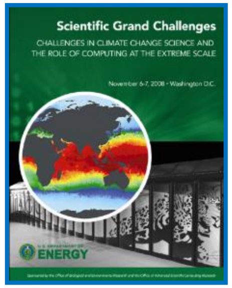


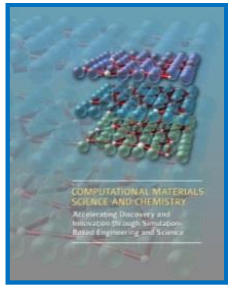




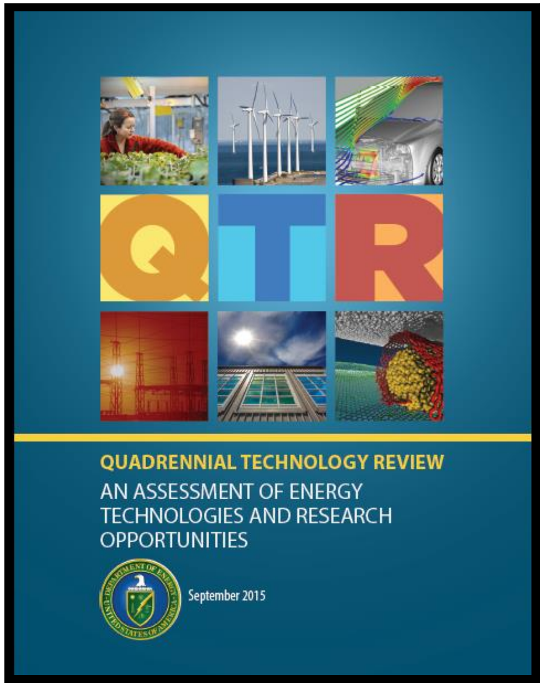




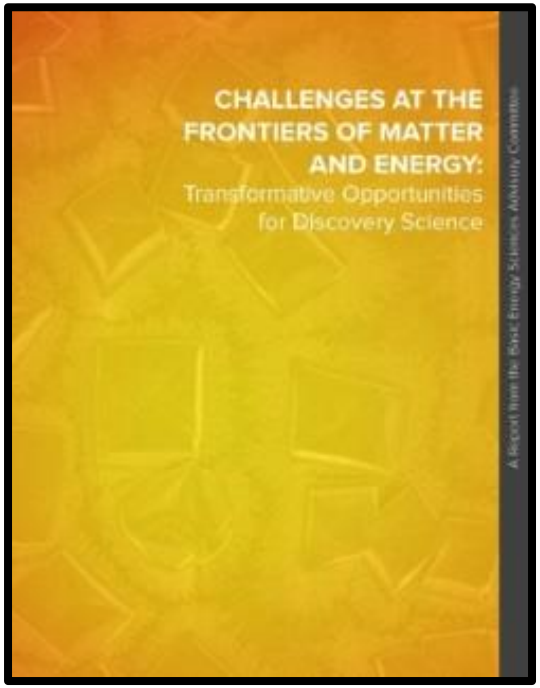




Key Documents Informing BES FY 2017 Budget Request



http://energy.gov/quadrennial-technology-review-2015



http://science.energy.gov/~/media/bes/besac/pdf/Reports/CFME_rpt_print.pdf

DOE Crosscuts:

- Advanced Materials
- Exascale Computing Initiative
- Subsurface Science, Technology, and Engineering

Transformative Opportunities:

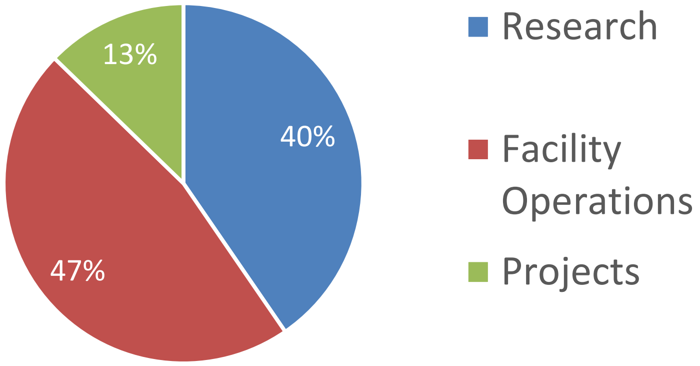
- Hierarchical architectures
- Non-equilibrium matter, non-ideal systems
- Coherence in light and matter
- Modeling and computation
- Imaging across multiple scales

Basic Energy Sciences

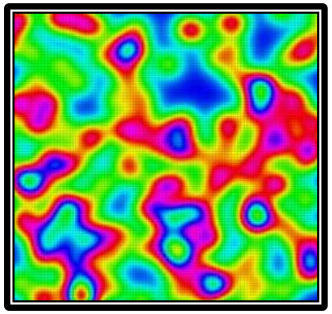
Understanding, predicting, and controlling matter and energy at the electronic, atomic, and molecular levels

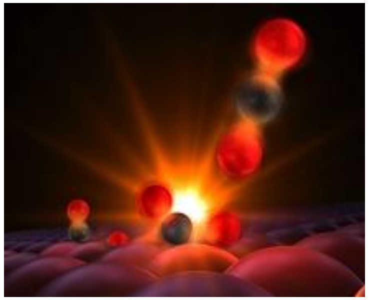
- User facilities: X-ray light sources, neutron sources, and Nanoscience Research Centers.
- Research in materials science, chemistry, and geoscience
- 32 Energy Frontier Research Centers
- 2 Energy Innovations Hubs

FY 16 Omnibus



FY16 BES Total: $1.849B





High Energy Physics

Understanding how the universe works at its most fundamental level

- Particle Physics Project Prioritization Panel (**P5**) report in May 2014 presents an actionable long-term strategy for U.S. particle physics that enables discovery and maintains the U.S. position as a global leader in particle physics.

  - **Five intertwined science drivers**, compelling lines of inquiry that show great promise for discovery:
    - Use the ***Higgs boson*** as a new tool for discovery
    - Pursue the physics associated with ***neutrino mass***
    - Identify the new physics of ***dark matter***
    - Understand ***cosmic acceleration***: dark energy and inflation
    - ***Explore the unknown***: new particles, interactions, and physical principles

	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

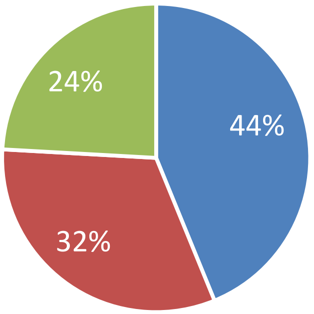
  - Science drivers identify the scientific motivation while the ***Energy, Intensity, and Cosmic Research Frontiers*** provide a useful categorization of experimental techniques

High Energy Physics

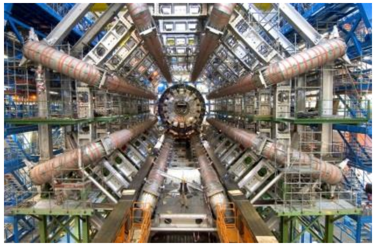
Understanding how the universe works at its most fundamental level, including exploring the elementary constituents of matter and energy, the interactions between them, and the nature of space and time.

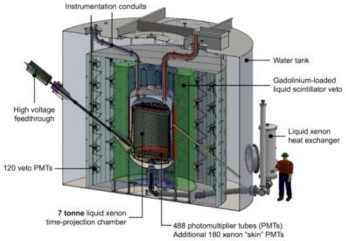
- Research: Science Drivers from P5 Report: Higgs boson, neutrino mass, dark matter, cosmic acceleration, and exploring the unknown.
- User facilities and large-scale collaborative experiments at the energy, intensity, and cosmic frontiers, including the LHC, LBNF/DUNE, and LSST.
- Next-generation of accelerator technology and new application of accelerators for science and industry.

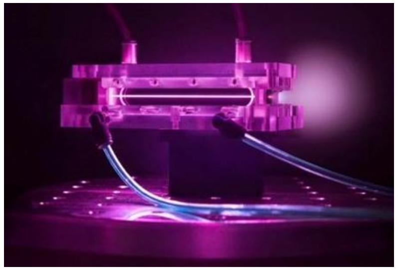
FY 16 Omnibus



FY16 HEP Total: $795M

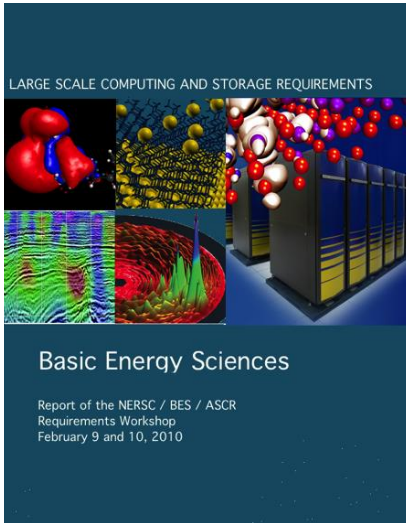


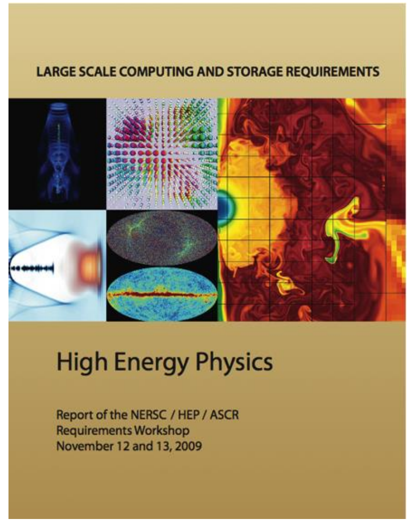


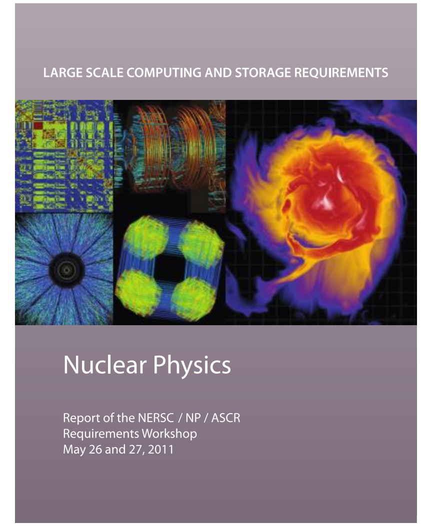


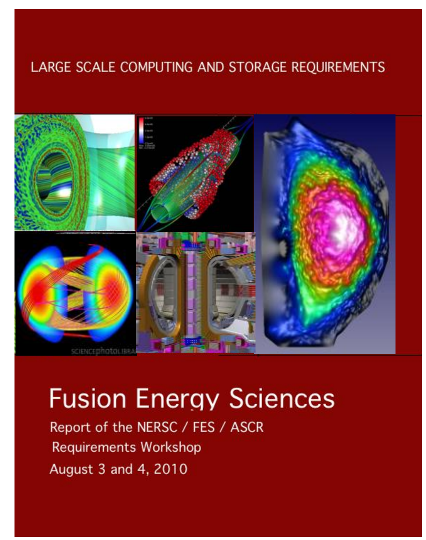
Computational Capacity is Based on Requirements

“Lead with the Science”







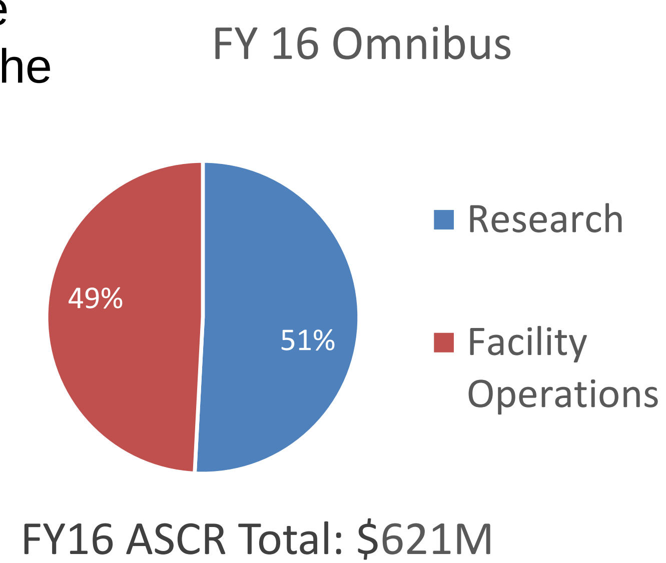


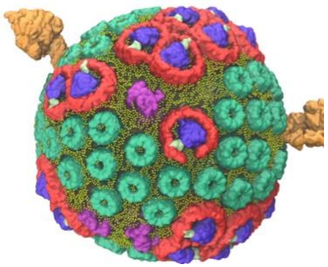
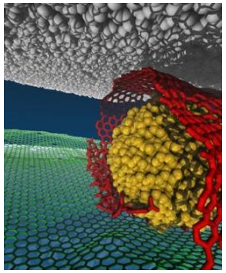
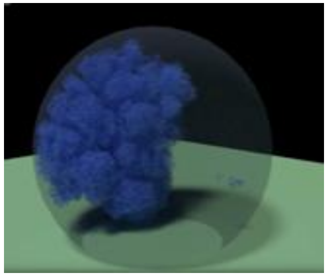
Advanced Scientific Computing Research

Discovering, developing, and deploying computational and networking capabilities for analysis, modeling, simulation, and prediction of complex phenomena

- High performance computing systems at: Oak Ridge and Argonne Leadership Computing Facilities, and the National Energy Research Scientific Computing Center.

- Research: applied math, computer science, high-performance networks (ESNet), and computational partnership (SciDAC) in support of next-generation HPC systems and applications, including exascale computing.

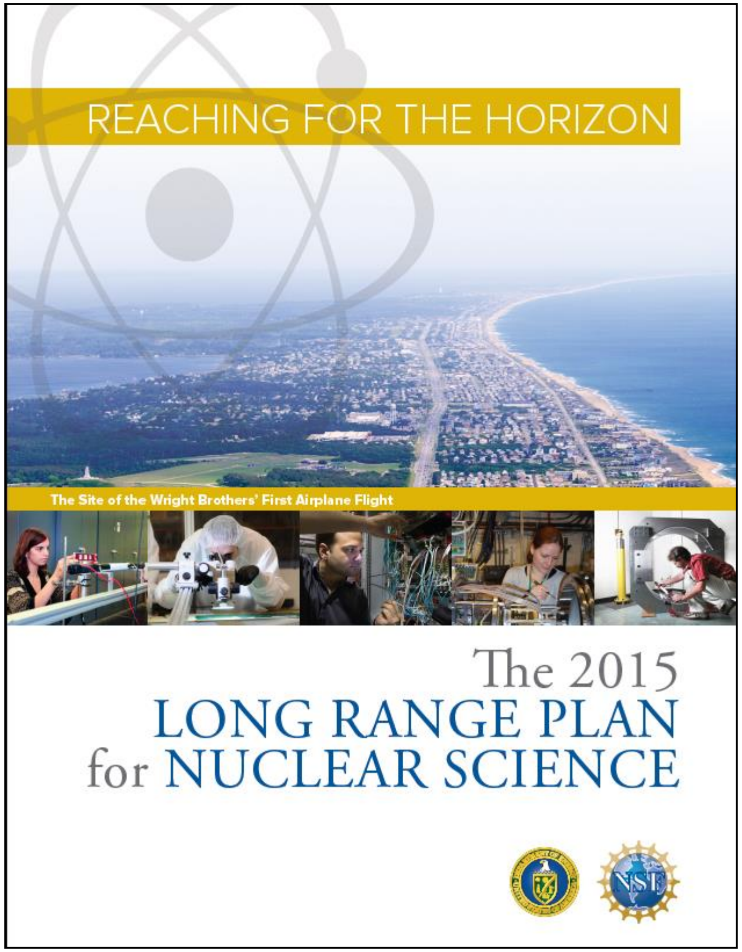


The 2015 Long Range Plan for Nuclear Science

Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.
2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.
3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.
4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

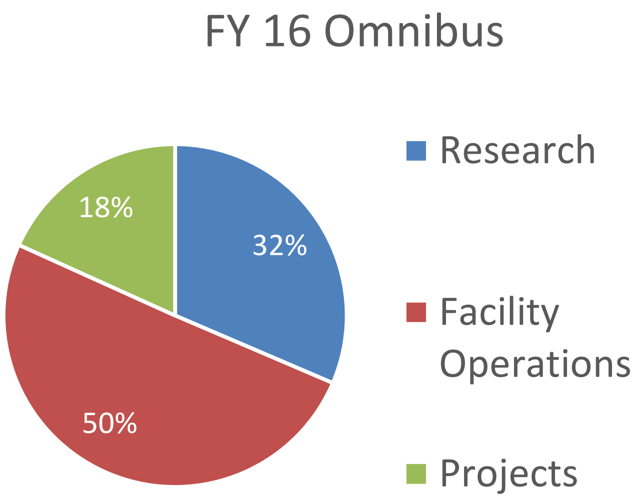


http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf

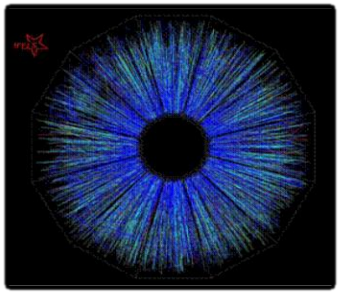
Nuclear Physics

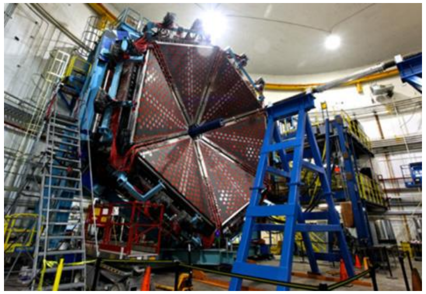
Discovering, exploring, and understanding all forms of matter.

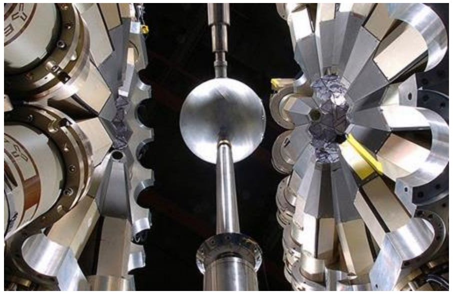
- User facilities in heavy ion, medium energy, and low energy physics: ATLAS, RHIC, CEBAF, and FRIB.
- FRIB will dramatically expand the number of isotopes with known properties and enable research in nuclear structure, nuclear astrophysics, and fundamental symmetries.
- R&D for production of stable and radioactive isotopes crucial to science, technology, medicine, and homeland security.



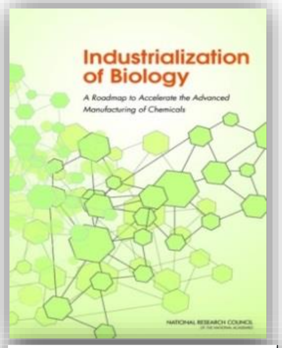
FY16 NP Total: $617M





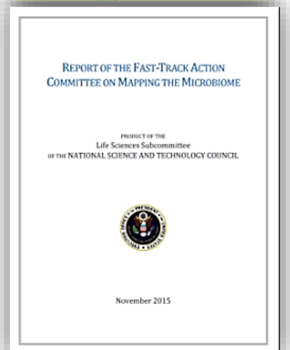


Key Documents Informing the BER FY 2017 Budget Request



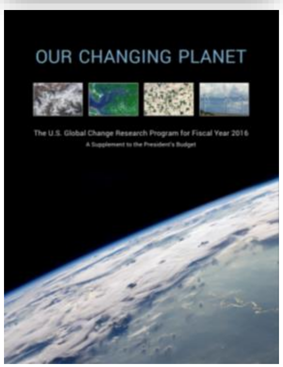
http://www.nap.edu/catalog/19001/industrialization-of-biology-a-roadmap-to-accelerate-the-advanced-manufacturing

Biosystems Design efforts in plants and microbes underpinning development of clean energy



https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/ftac-mm_report_final_112015_0.pdf

The microbiome impacts on plant growth and development, availability of soil nutrients, and carbon cycle processes under changing climate conditions



http://www.globalchange.gov/browse/reports/our-changing-planet-FY-2016

Developing physical, chemical, and biological model components to simulate climate variability and change at regional and global scales.
Supports DOE crosscuts in Exascale Computing and the Energy-Water Nexus

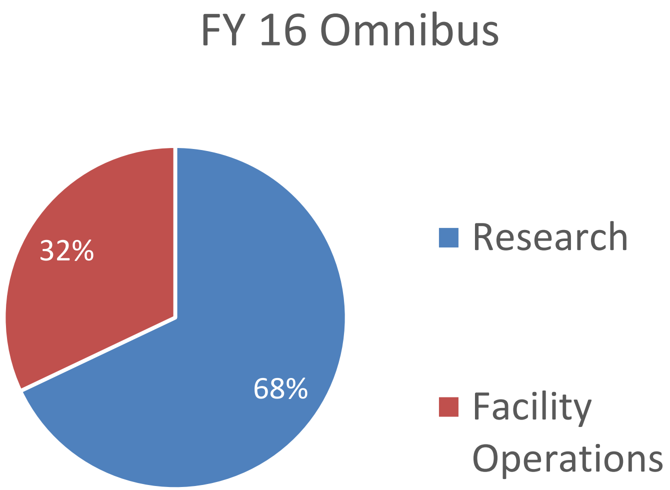
Biological and Environmental Research

Understanding Complex Natural Systems Across Many Spatial and Temporal Scales by Coupling Theory, Observations, Experiments, Models, and Simulations

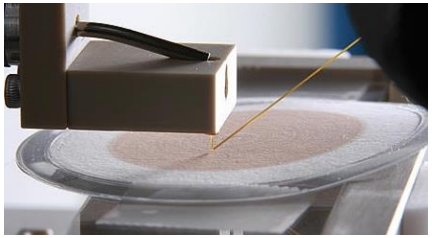
- Research: genomic science for sustainable bioenergy, carbon cycling, and bioremediation, and climate and environmental science to support development of predictive models.

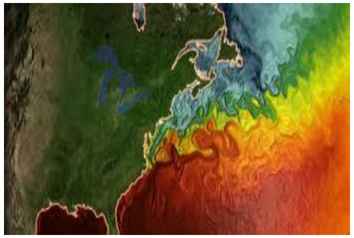
- User facilities: Joint Genome Institute, Environmental Molecular Sciences Laboratory, Atmospheric Radiation Measurement Climate Research Facility

- Three multidisciplinary, multi-institutional Bioenergy Research Centers.



FY16 BER Total: $609M



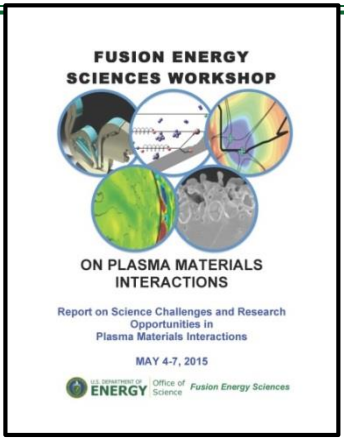


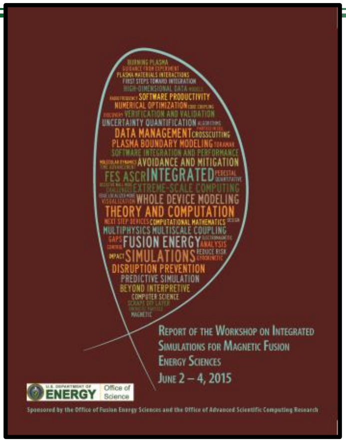
FES Community Engagement Workshops

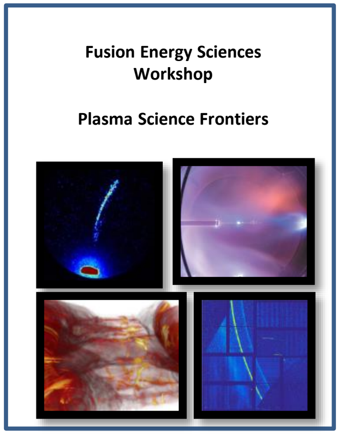
- Following the FESAC *Strategic Planning and Priorities Report* (2014), FES undertook a series of four technical workshops in 2015:
  - Workshop on Integrated Simulations for Magnetic Fusion Energy Sciences
  - Workshop on Transients
  - Workshop on Plasma Science Frontiers
  - Workshop on Plasma-Materials Interaction

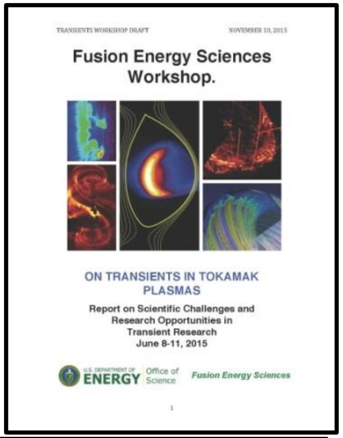
- Each workshop is delivering a report that addresses scientific challenges and potential implementation options.

https://www.burningplasma.org/activities/?article=FES%20Community%20Planning%20Workshops%202015







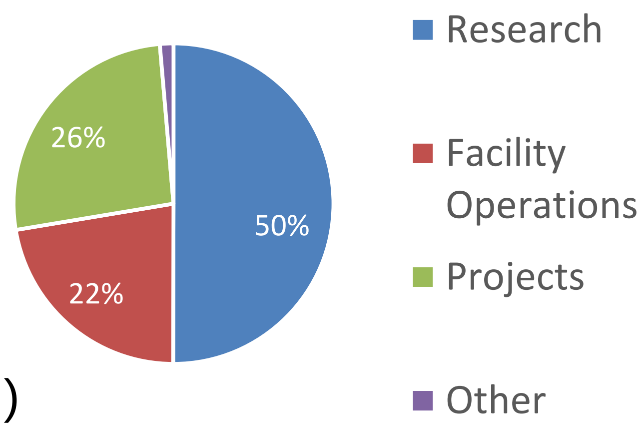


Fusion Energy Sciences

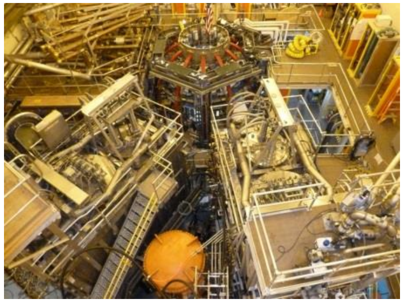
Expanding the fundamental understanding of matter at very high temperatures and densities and building the scientific foundation needed to develop a fusion energy source.

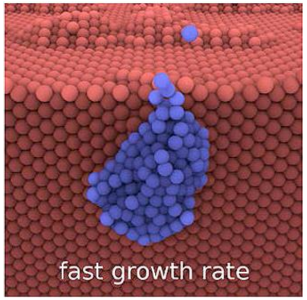
- User facilities: the NSTX–U (PPPL) and DIII-D Tokamak (General Atomics).
- Significant contributions to international fusion experiments, including EAST (China), KSTAR (Korea), W7-X stellerator (Germany).
- Contributions to the science and technology of ITER (EU)
- General plasma science and materials in extreme conditions.

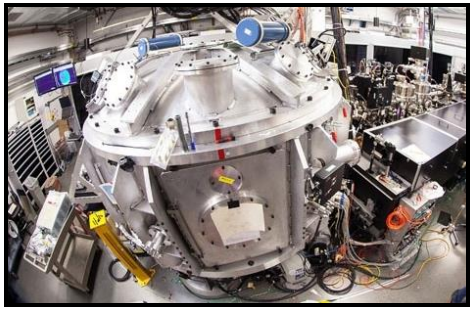
FY 16 Omnibus



FY16 FES Total: $438M







Office of Science Laboratories

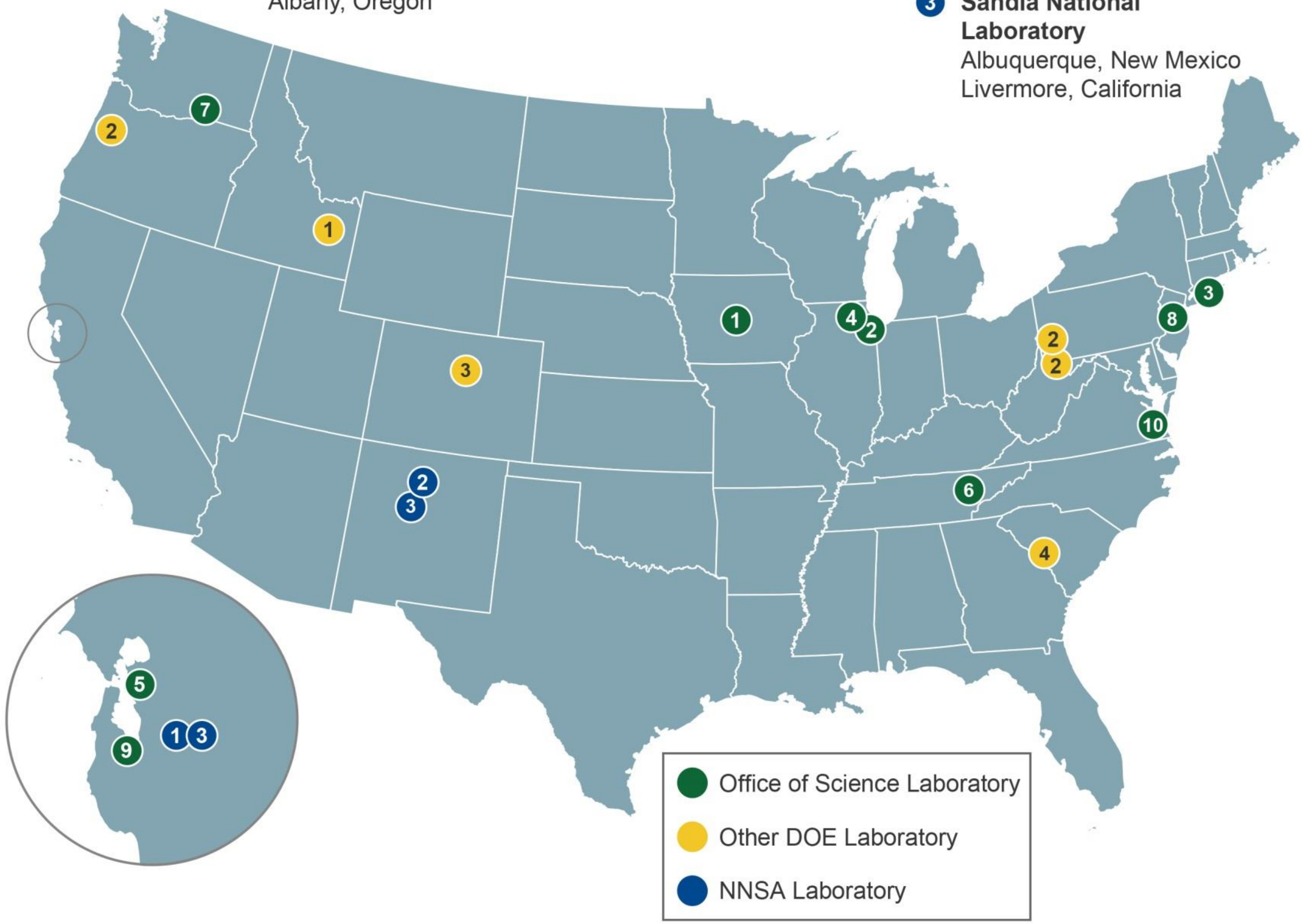
1. **Ames Laboratory**
   Ames, Iowa
2. **Argonne National Laboratory**
   Argonne, Illinois
3. **Brookhaven National Laboratory**
   Upton, New York
4. **Fermi National Accelerator Laboratory**
   Batavia, Illinois
5. **Lawrence Berkeley National Laboratory**
   Berkeley, California
6. **Oak Ridge National Laboratory**
   Oak Ridge, Tennessee
7. **Pacific Northwest National Laboratory**
   Richland, Washington
8. **Princeton Plasma Physics Laboratory**
   Princeton, New Jersey
9. **SLAC National Accelerator Laboratory**
   Menlo Park, California
10. **Thomas Jefferson National Accelerator Facility**
    Newport News, Virginia

Other DOE Laboratories

1. **Idaho National Laboratory**
   Idaho Falls, Idaho
2. **National Energy Technology Laboratory**
   Morgantown, West Virginia
   Pittsburgh, Pennsylvania
   Albany, Oregon
3. **National Renewable Energy Laboratory**
   Golden, Colorado
4. **Savannah River National Laboratory**
   Aiken, South Carolina

NNSA Laboratories

1. **Lawrence Livermore National Laboratory**
   Livermore, California
2. **Los Alamos National Laboratory**
   Los Alamos, New Mexico
3. **Sandia National Laboratory**
   Albuquerque, New Mexico
   Livermore, California



Office of Science Laboratories Total FY15 $5.5B, SC funding $3.4B

Berkeley Lab

Berkeley, California
202 acres and 90 buildings
3,232 FTEs
950 students & postdocs
9,484 facility users
www.lbl.gov

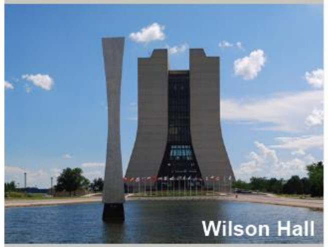
Pacific Northwest National Laboratory

Richland, Washington
346 acres and 20 buildings
4,308 FTEs
628 students & postdocs
2,022 facility users
www.pnnl.gov

The Ames Laboratory

Ames, Iowa
8 acres and 12 buildings
310 FTEs
162 students & postdocs
www.ameslab.gov

Fermilab



Wilson Hall

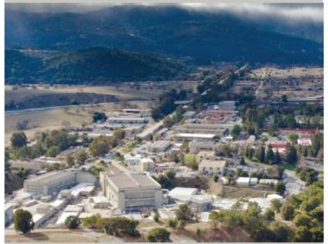
Batavia, Illinois
6,800 acres and 366 buildings
1,760 FTEs
46 students & postdocs
2,340 facility users
www.fnal.gov

Argonne National Laboratory

Advanced Photon Source

Argonne, Illinois
1,517 acres and 100 buildings
3,412 FTEs
620 students & postdocs
7,396 facility users
www.anl.gov

SLAC National Accelerator Laboratory



Menlo Park, California
426 acres and 147 buildings
1,422 FTEs
230 students & postdocs
2,913 facility users
www.slac.stanford.edu

Oak Ridge National Laboratory

Spallation Neutron Source

Oak Ridge, Tennessee
4,421 acres and 195 buildings
4,525 FTEs
1,429 students & postdocs
2,987 facility users
www.ornl.gov

Jefferson Lab

Newport News, Virginia
169 acres and 72 buildings
673 FTEs
62 students & postdocs
1,380 facility users
www.jlab.org

PPPL Princeton Plasma Physics Laboratory

NSTX Spherical Tokamak

Princeton, New Jersey
91 acres and 32 buildings
431 FTEs
59 students & postdocs
290 facility users
www.pppl.gov

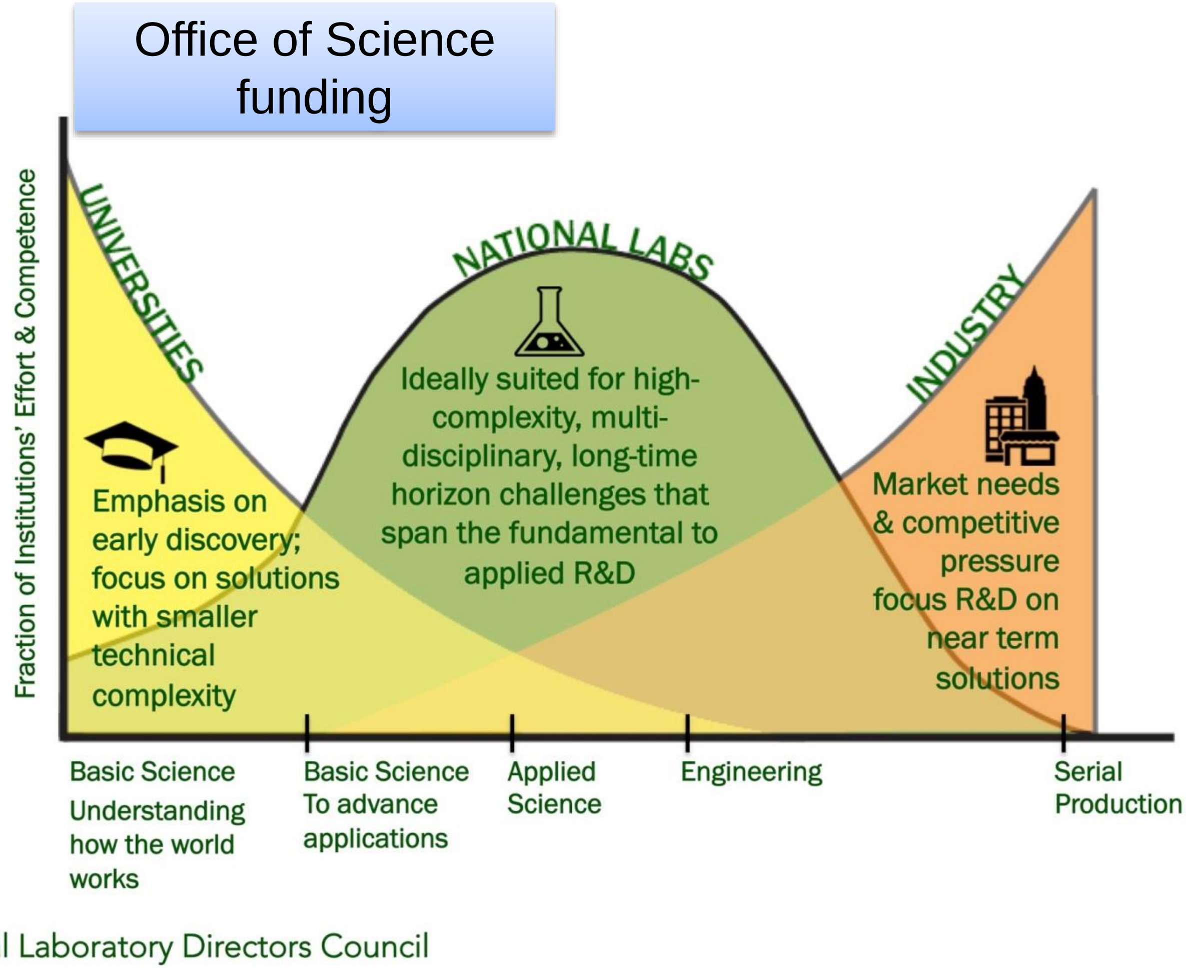
Brookhaven National Laboratory

Relativistic Heavy Ion Collider

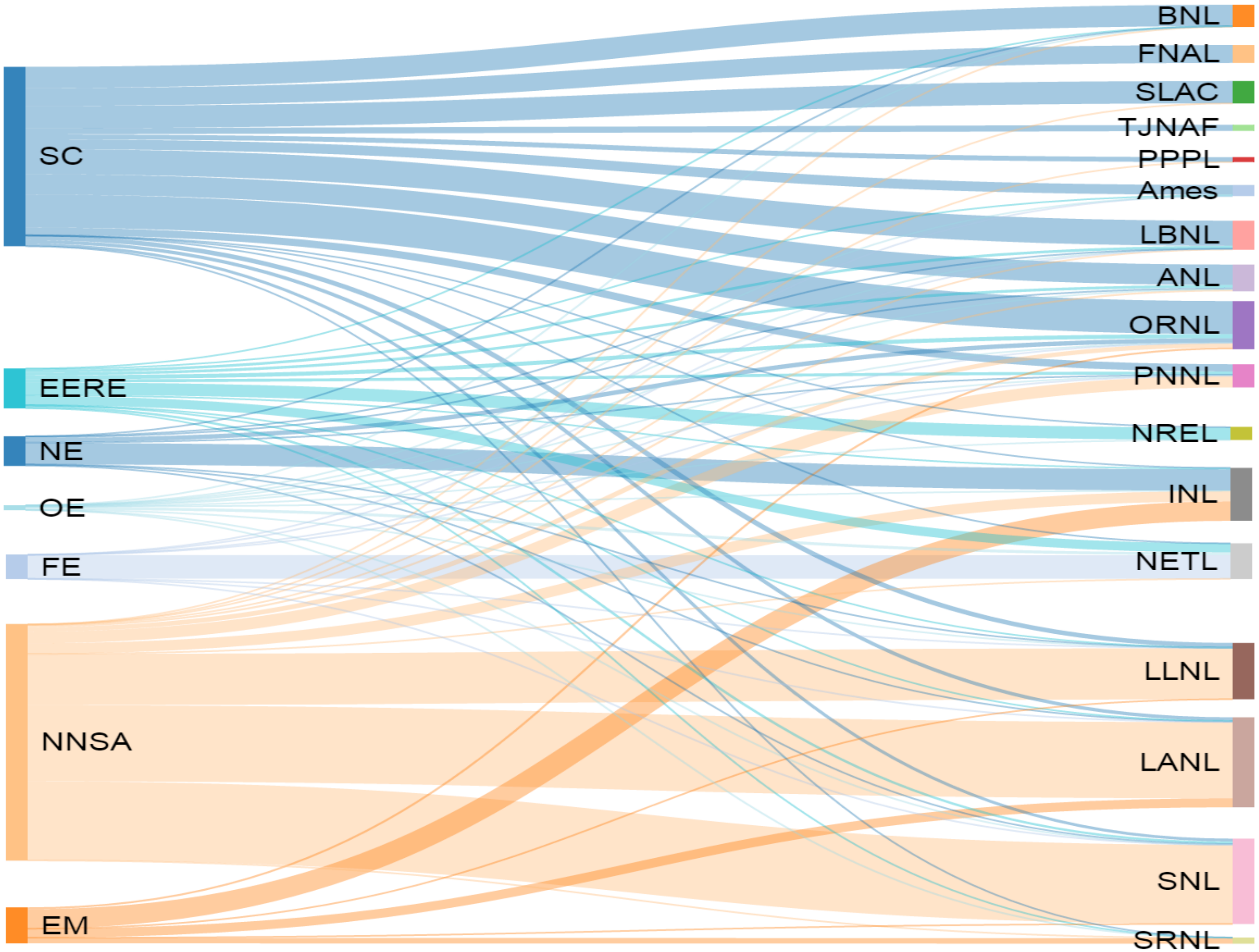
Upton, New York
5,322 acres and 319 buildings
2,788 FTEs
557 students & postdocs
4,090 facility users
www.bnl.gov

National Labs Address Multidisciplinary S&T Challenges

Most of the national labs have broader scope than Office of Science



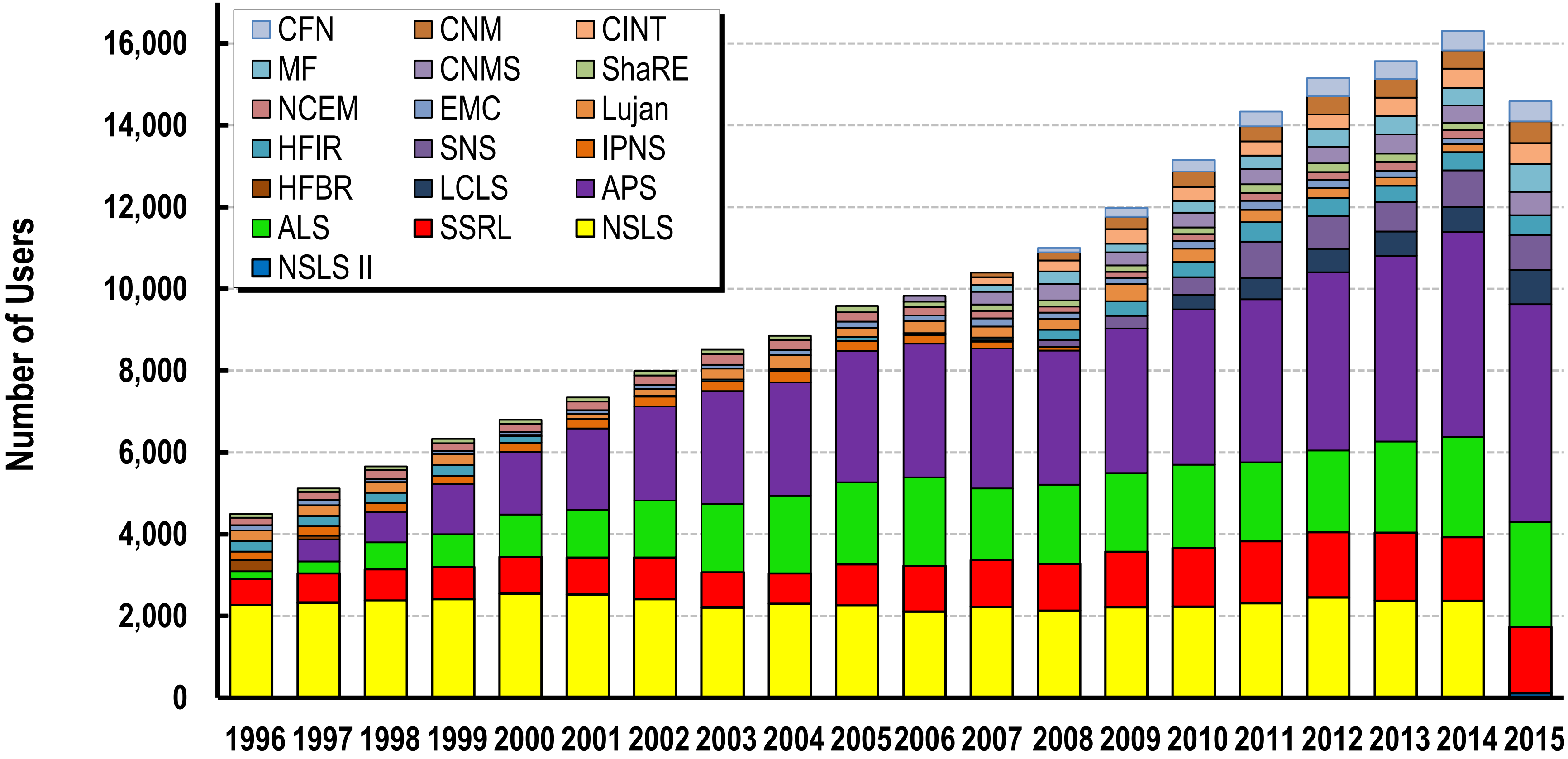
Flow of Funds between DOE Programs to Labs, 2015



FY 2016
28 user facilities

U.S. DEPARTMENT OF
ENERGY
Office of Science

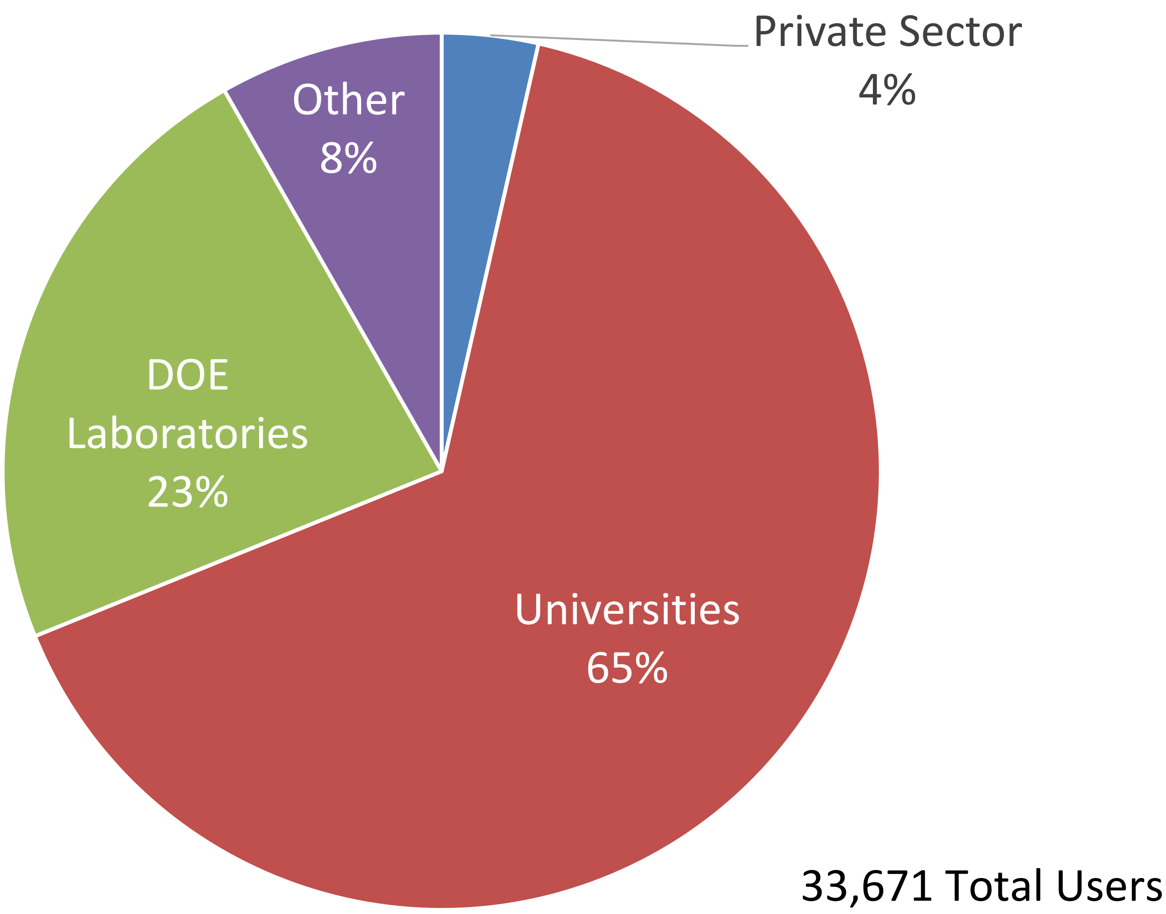
BES User Facilities Hosted Over 14,000 Users in FY 2015



- The newly constructed NSLS-II started early operations in FY 2015 (hosted 110 users).
- The three electron beam microcharacterization centers were merged administratively with their respective neighboring NSRCs in FY 2015.
- The BES operations at the Lujan Neutron Scattering Center ceased operations in FY 2014.

U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Science User Facility Statistics FY14

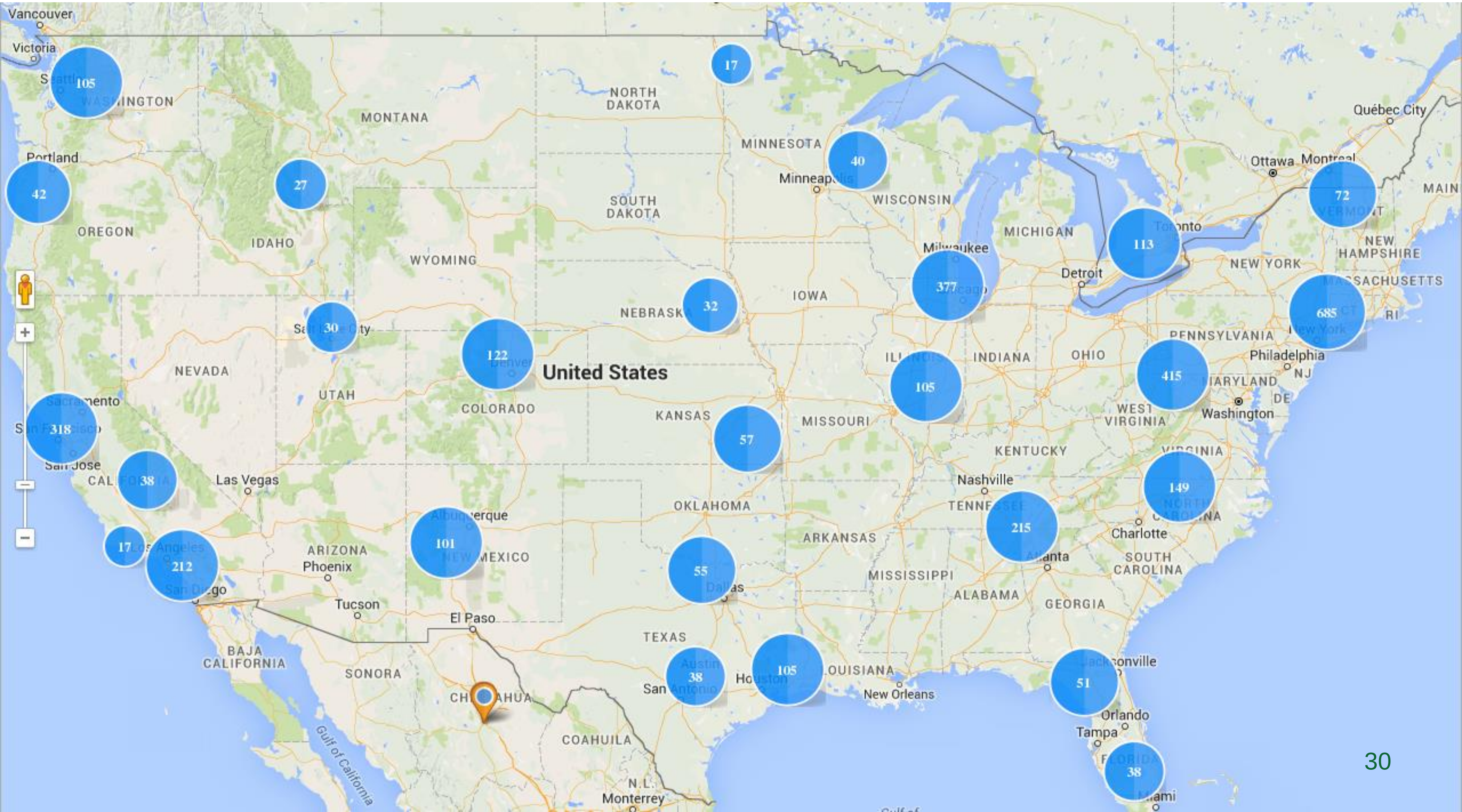


Other includes many institutions, such as: non-DOE labs, federal agencies, research hospitals, K-12 students, and international institutions

Scientific User Facilities – Data on Users Across Country

http://science.energy.gov/universities/interactive-grants-map/

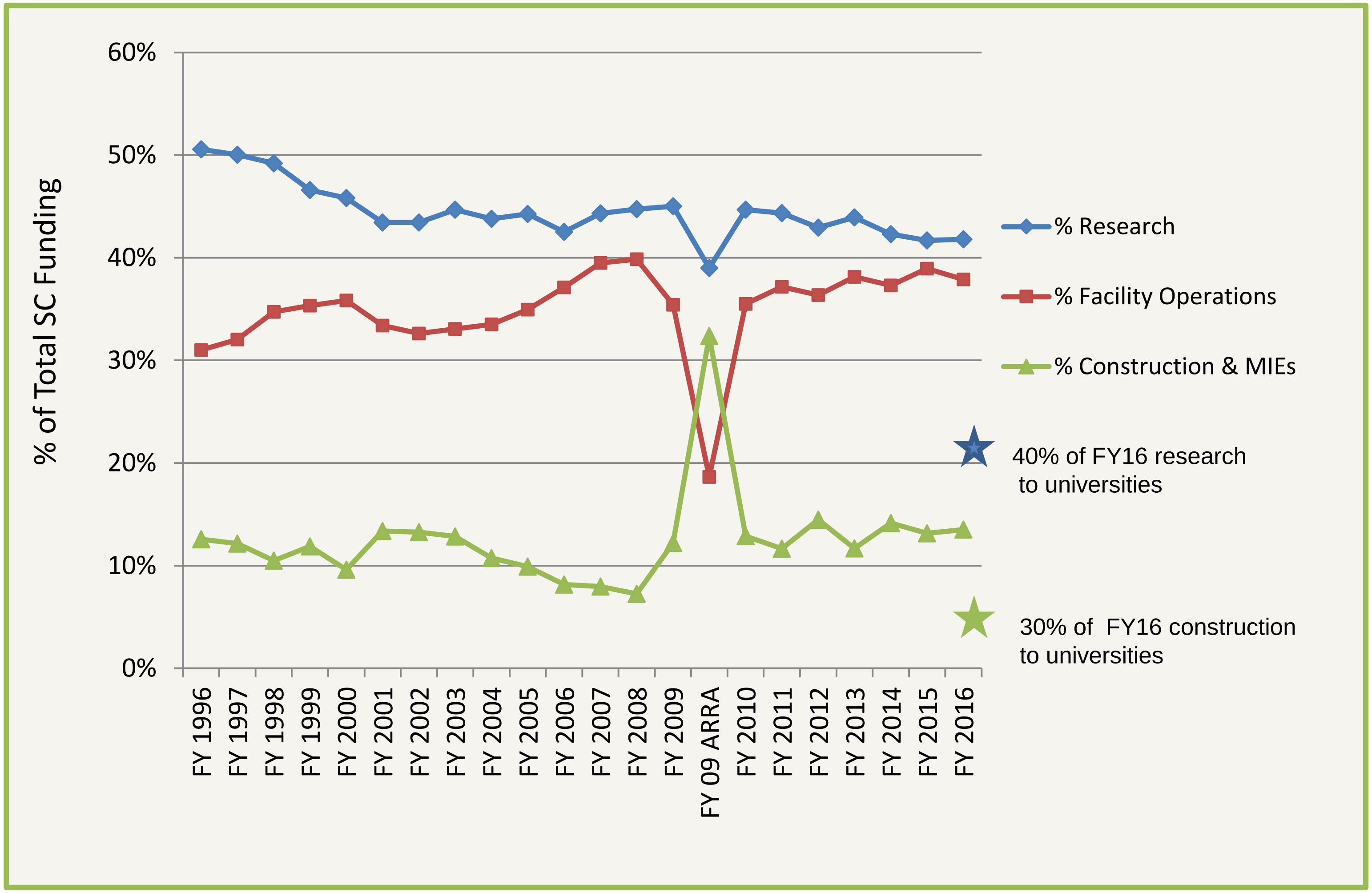
http://science.energy.gov/user-facilities/user-statistics/



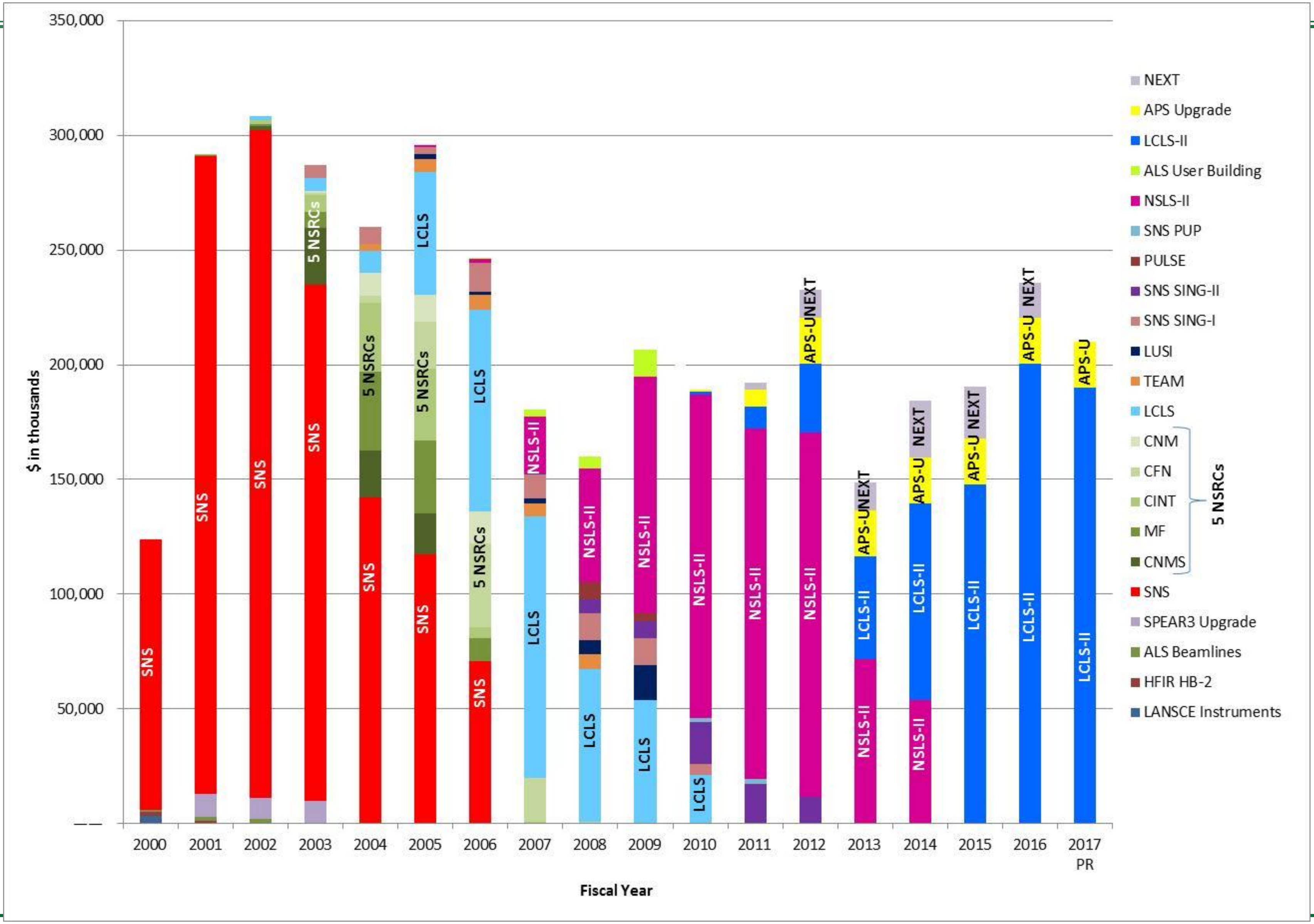
FY2017 Issues and Priorities

- **BALANCE - Research funding vs scientific user facilities construction vs operation**
- BALANCE - Discovery research vs science for clean energy and departmental crosscuts
- Exascale computing Project! National Strategic Computing Initiative
- International partnerships in Big Science
  - Defining moment in fusion sciences
  - LHC CMS, ATLAS upgrades at the same time as LBNF/DUNE
  - BESAC study of 5 proposed user facility upgrades

SC Investments in Research, Facilities, and Construction



BES Construction/MIE Funding Profile 2000 – 2017



Fy2017 Issues and Priorities

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- **BALANCE - Discovery research vs science for clean energy and departmental crosscuts**
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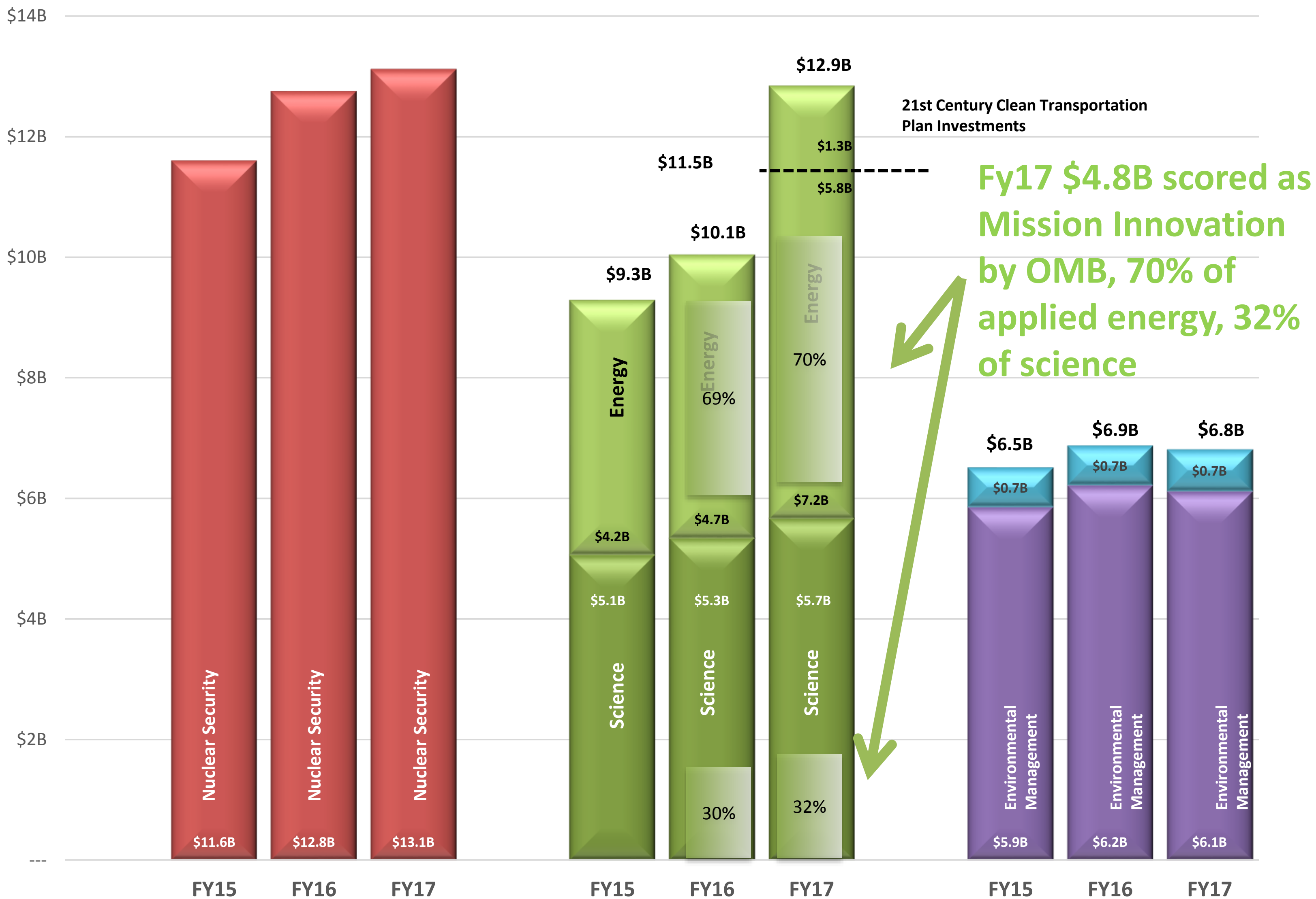
DOE Mission Innovation R&D, FY 16 and 17

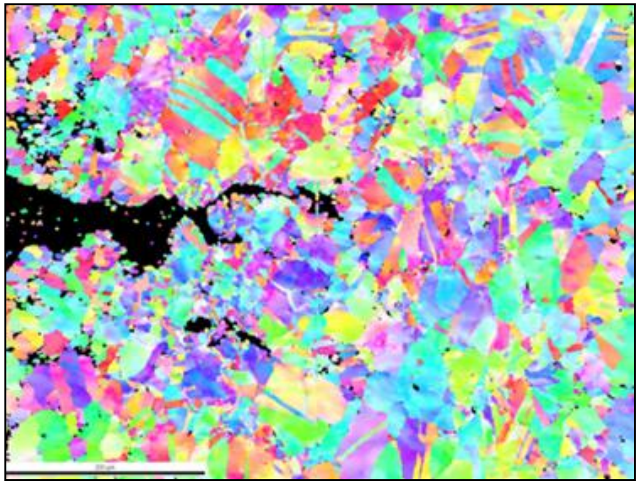


SC Investments for Mission Innovation

$100M in new funding in FY 2017

ASCR (+$10M)

- Computational Partnerships with EFRCs on solar, CO_2 reduction, catalysis, storage, subsurface, and biofuels; possibly new partnerships in wind and nuclear ($10M)



Analysis of cracks at the nanoscale

BES (+$51M)

- Energy Efficiency: Catalysts, modeled after nature's enzymes, that can operate at low-temperature and under ambient conditions; lightweight metallic materials; thermocaloric materials ($34.4M)
- Materials for Clean Energy: Self-healing materials for corrosive and high radiation environments (next-gen corrosive-resistant materials based on experiments and multi-scale modeling; chemistry under harsh or extreme environments) ($16.6M)

BER (+$35M)

- Biosystems design (computationally design and then bio-engineer biosystems) to introduce beneficial traits into plants and microbes for clean energy applications ($20M)
- Bioenergy Research Centers: New investments to translate 10 years of BRC research to industry ($15M, $5M per BRC)

FES (+4M)

- Whole-device fusion modeling and simulation using SciDAC partnerships ($4M)

Fy2017 Issues and Priorities

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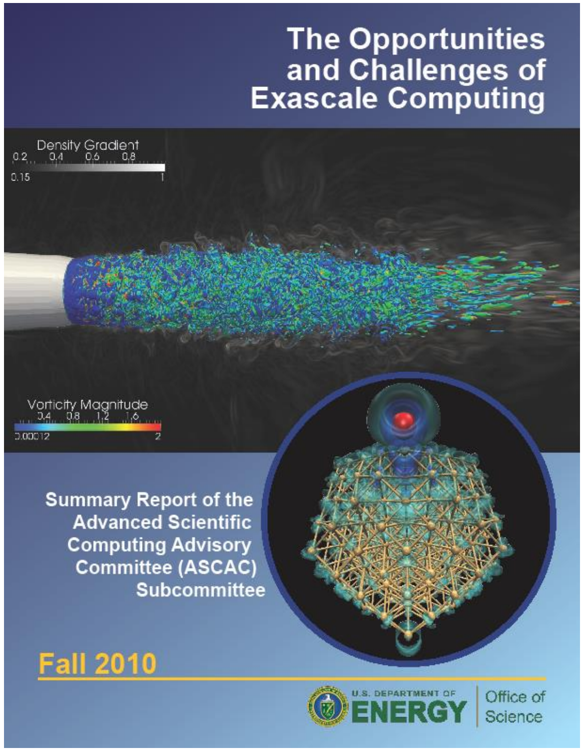
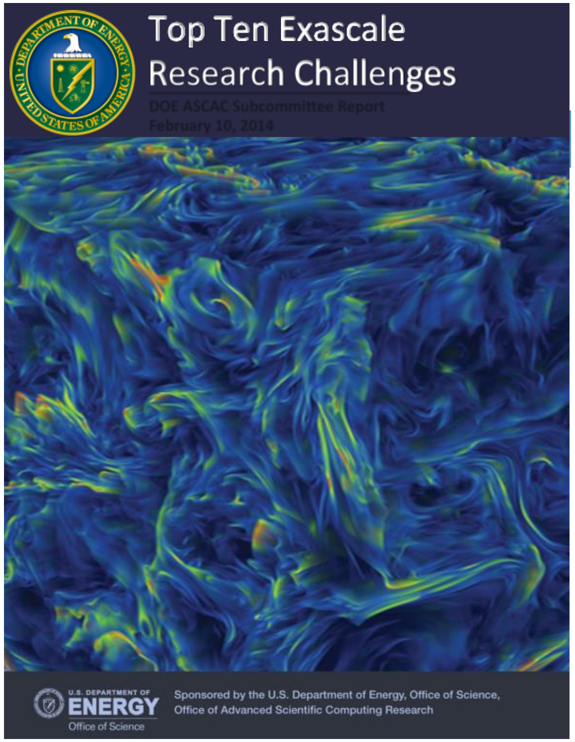
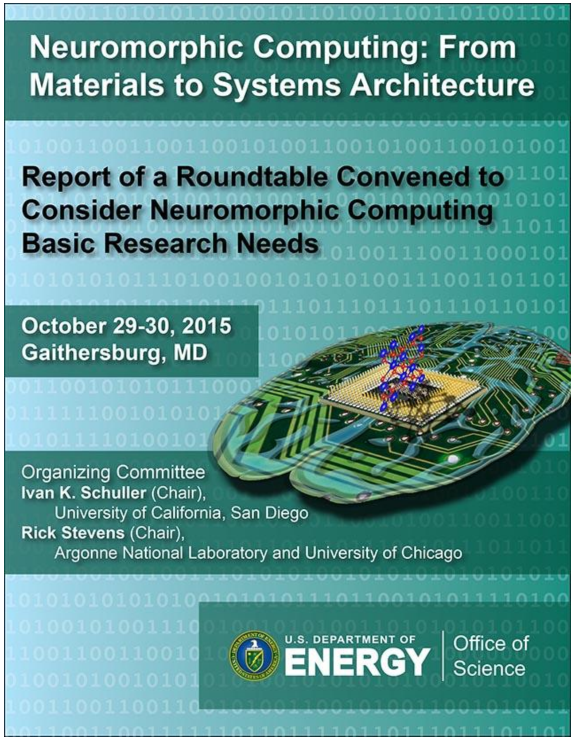






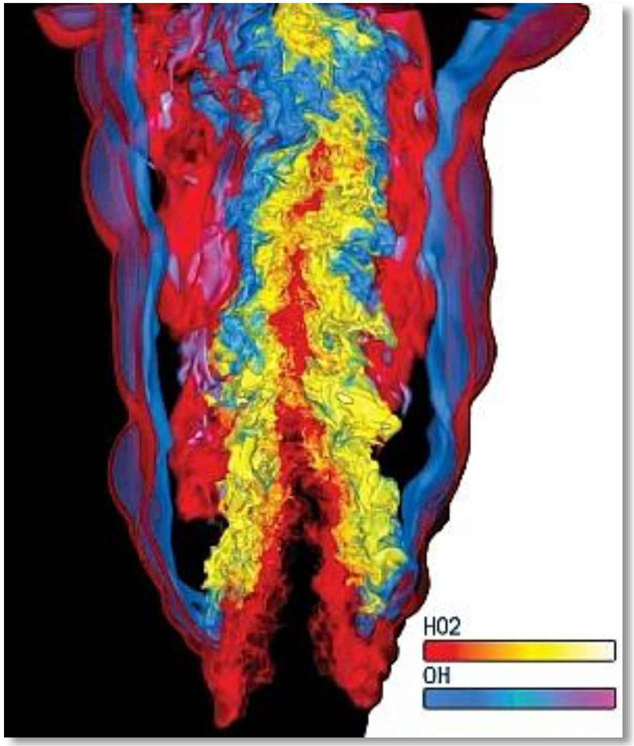
http://science.energy.gov/~/media/ascr/ascac/pdf/reports/Exascale_subcommittee_report.pdf

http://science.energy.gov/~/media/ascr/ascac/pdf/meetings/20140210/Top10reportFEB14.pdf

http://science.energy.gov/bes/community-resources/reports/abstracts/#NCFMtSA

DOE's Exascale Computing Initiative:
Next Generation of Scientific Innovation

- **Departmental Crosscut – In partnership with NNSA**
- **"All-in" approach: hardware, software, applications, large data, underpinning applied math and computer science**
- **Supports DOE's missions in national security and science:**
  - Stockpile stewardship – support annual assessment cycle
  - Discovery science – **next-generation materials; chemical sciences**
  - Mission-focused basic science in energy – next-generation **climate software**
  - Use current Leadership Computing approach for users
- **The next generation of advancements will require Extreme Scale Computing**
  - 100-1,000X capabilities of today's computers with a similar physical size and power footprint
  - Significant challenges are power consumption, high parallelism, reliability
- **Extreme Scale Computing, cannot be achieved by a "business-as-usual," evolutionary approach**
  - Initiate partnerships with U.S. computer vendors to perform the required engineering, research and development for system architectures for capable exascale computing
  - Exascale systems will be based on marketable technology – Not a "one off" system
  - Productive system – Usable by scientists and engineers



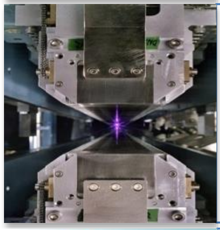
Extreme-Scale Science Data Explosion

Genomics

Data Volume increases to 10 PB in FY21

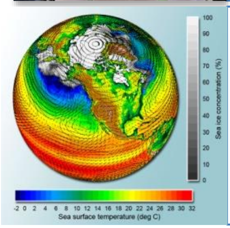
High Energy Physics (Large Hadron Collider)

15 PB of data/year



Light Sources

Approximately 300 TB/day



Climate

Data expected to be hundreds of 100 EB

Driven by exponential technology advances

Data sources

- Scientific Instruments
- Scientific Computing Facilities
- Simulation Results
- Observational data

Big Data and Big Compute

- Analyzing Big Data requires processing (e.g., search, transform, analyze, …)
- Extreme scale computing will enable timely and more complex processing of increasingly large Big Data sets

Fy2017 Issues and Priorities

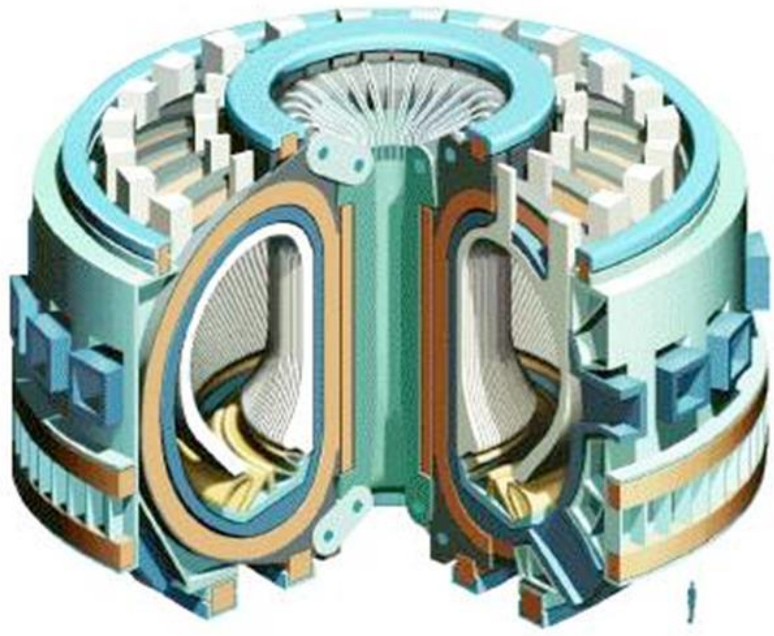
- BALANCE - Research funding vs scientific user facilities construction vs operation

- BALANCE - Discovery research vs science for clean energy and departmental crosscuts

- Exascale computing Project! National Strategic Computing Initiative

- **International partnerships in Big Science**
  - **Defining moment in fusion sciences**
  - **LHC CMS, ATLAS upgrades at the same time as LBNF/DUNE**
  - **BESAC study of 5 proposed user facility upgrades – international competitiveness**

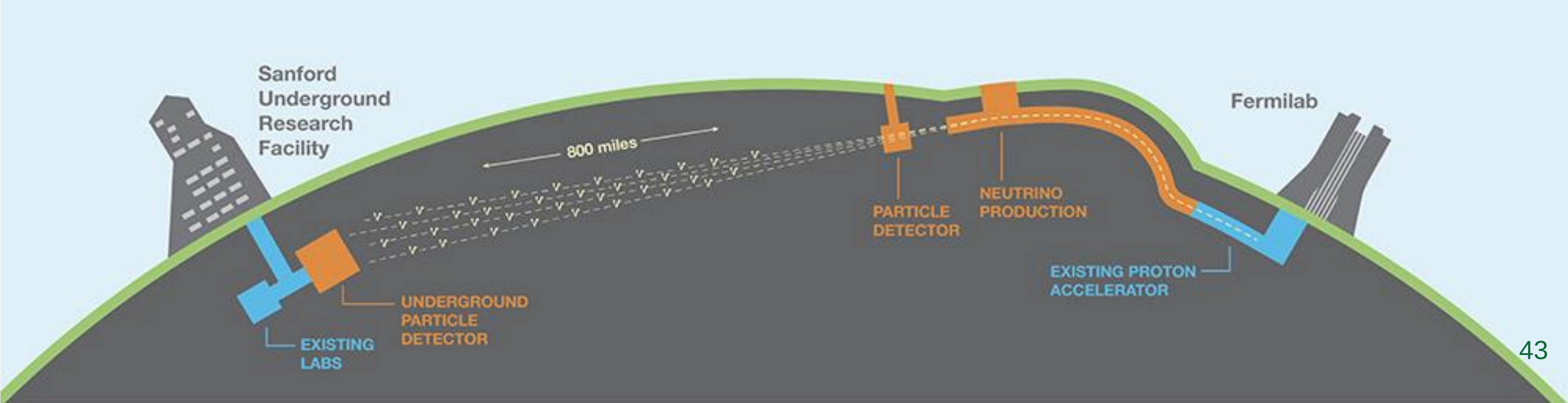
ITER Congressional Report



"…not later than May 2, 2016, the Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress a report recommending either that the United States remain a partner in the ITER project after October 2017 or terminate participation, which shall include, as applicable, an estimate of either the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance of ITER or the cost of termination."

Long Baseline Neutrino Facility

- **P5 recommended LBNF as the centerpiece of a U.S.-hosted world-leading neutrino program**
  - P5 recognized LBNF as the highest-priority large project in its timeframe
- **The world's most intense neutrino beam will be produced at Fermilab and directed 800 miles through the earth to Lead, South Dakota**
  - Fermilab will lead this effort with a few international partners, most notably CERN
- **A very large (40 kiloton) liquid argon neutrino detector will be placed in the Homestake Mine in Lead, SD**
  - An international collaboration has been established for the Deep Underground Neutrino Experiment (DUNE)
  - The U.S. will contribute to the detector as part of the LBNF project



BESAC New Charge on Prioritization of Facility Upgrades

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

December 21, 2015

Professor John C. Hemminger
Chair, Basic Energy Sciences Advisory Committee
Professor of Chemistry
Aldrich Hall 160
University of California, Irvine
Irvine, California 92697

Dear Professor Hemminger:

Thank you very much for your continuing service to the Office of Science and the scientific communities that it serves as the Chair of the Basic Energy Sciences Advisory Committee (BESAC). In particular, thank you for your recent outstanding work on the BESAC report, *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*. This report provides crucial advice to BES on the breakthrough potential of current and prospective energy science frontiers toward transformative impacts for science and society. As the new report notes, enabling success in seizing the transformative opportunities and in meeting the grand challenges will require targeted investments from BES in areas that include instrumentation and tools, and specifically in the world-leading large-scale user facilities that BES supports. I need your help now in this connection.

I am writing to present a new charge to BESAC, related to the prioritization of upgrades of existing user facilities and major construction projects for new user facilities. This charge is directed by the 2016 Omnibus appropriation for BES that stated:

> *Since the February 2013 and the July 2013 Basic Energy Sciences Advisory Committee (BESAC) studies of BES facilities, the mix and status of ongoing and prospective BES major facility upgrades and construction projects have changed. Therefore the BESAC is directed to update its assessment of the proposed upgrades to x-ray scattering facilities (both free-electron laser-based sources and ring-based sources) and to the Spallation Neutron Source using the same criteria that were used in prior studies-the ability of a proposed upgrade or construction project to contribute to world leading science and the readiness of the upgrade or construction project to proceed to construction-and the same rating system. The assessment shall include a prioritization of the next three to five projects and be submitted to the Committees on Appropriations of both Houses of Congress not later than 180 days after the enactment of this Act.*

2

The following are the two criteria to be considered in your evaluation:

1. The ability of a proposed facility or upgrade to contribute to world-leading science, noting in particular the relevance to the 2015 BESAC report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." Activities will be placed in one of three categories:(a) absolutely central; (b) important; and (c) don't know enough yet.
2. The readiness to proceed to construction, noting whether the concept has been thoroughly studied, the R&D performed to date is sufficient, the technical challenges can be met, and the extent to which the cost to build and operate the facility is understood. Concepts will be placed in one of three categories: (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; and (c) mission and technical requirements not yet fully defined.

Three categories of facilities are to be considered in the prioritization:

- **Free electron laser based x-ray light sources**
  1. SLAC LCLS-II High Energy Upgrade (LCLS-II-HE) (i.e., additional cryomodules in existing tunnel)
- **Ring-based x-ray light sources**
  1. ANL Advanced Photon Source Upgrade (APS-U)
  2. LBNL Advanced Light Source Upgrade (ALS-U)
- **Spallation based neutron scattering sources**
  1. ORNL Spallation Neutron Source Proton Power Upgrade (SNS PPU)
  2. ORNL Spallation Neutron Source Second Target Station (SNS STS)

I would appreciate receiving a written report by June 30, 2016.

Sincerely,

C. A. Murray
Director, Office of Science

From: Dr. Cherry A. Murray (Director, Office of Science)

I am writing to present a new charge to BESAC, related to the prioritization of upgrades of existing user facilities and major construction projects for new user facilities.

The following are the two criteria to be considered in your evaluation:

1. The ability of a proposed facility or upgrade to contribute to world-leading science, noting in particular the relevance to the 2015 BESAC report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." Activities will be placed in one of three categories:(a) absolutely central; (b) important; and (c) don't know enough yet.

2. The readiness to proceed to construction, noting whether the concept has been thoroughly studied, the R&D performed to date is sufficient, the technical challenges can be met, and the extent to which the cost to build and operate the facility is understood. Concepts will be placed in one of three categories: (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; and (c) mission and technical requirements not yet fully defined.