FEDERAL INVESTMENTS IN COAL AS PART OF A CLEAN ENERGY INNOVATION PORTFOLIO

The Administration's FY 2017 budget supports a comprehensive strategy for coal, with the primary objectives of:

- Spurring innovation in coal utilization technologies to enable coal to compete in a future clean energy economy;
- Targeting economic and community development assistance to communities distressed by declining domestic coal production;
- Providing training and job assistance to displaced coal industry workers; and
- Supporting pensions and health benefits for coal mining retirees.

These objectives are supported across nine Federal departments and agencies, with the Department of Energy (DOE) having principal responsibility for coal technology innovation. The total Federal investment in coal is summarized below and discussed further in the pages that follow.

FY 2017 FEDERAL BUDGET INVESTMENTS IN COAL

Program	($ millions)	Page
DOE Coal Technology Research and Development Programs		
Fossil Energy Research and Development	$600	3
Science	$56.5	5
Advanced Research Projects Agency—Energy	$63	7
R&D Crosscutting Initiatives	$504.2	8
International Cooperation through Domestic Investments	$37.5	12
Coal Technology Demonstration and Deployment Activities		
CCUS Demonstration Projects	$1,422	13
Loan Guarantee Program (Loan authority)	$8,500	15
CCUS Deployment Incentives (tax credits)	~$5,000	15
Targeted Economic and Workforce Development[1]		
Interagency POWER Initiative	$75	17
Small Business Administration	$0.45	19
Office of Surface Mining Reclamation & Enforcement	~$1,072	20
DOL Employment & Training Administration	$19	20

[1] In addition to the funding shown in the table below, coal-related economic and workforce development projects are eligible for competition for funding within other national and regional programs. A summary of these can be found in the Economic and Workforce Development Section beginning on Page 16.

The DOE FY 2017 budget request explicitly recognizes that coal technology innovation challenges require an increasingly multi-disciplinary, as well as multi-program research and innovation strategy. The FY 2017 DOE budget includes funding not only in the Fossil Energy R&D account, but in five separate appropriation accounts, spanning the entire innovation spectrum from research to deployment. In addition, meeting the critical technological challenges requires crosscutting research and development programs such as high efficiency conversion, subsurface engineering, advanced materials, and energy water interdependencies.

Federal investment in coal R&D is a key element of DOE's Mission Innovation budget. DOE's FY 2017 budget proposal takes a significant first step toward fulfilling the U.S. pledge as part of Mission Innovation, to seek to double Federal clean energy technology research and development[2] investments government-wide over the next five years. Mission Innovation was launched by the U.S. and 19 other countries to accelerate widespread clean energy technology innovation and cost reduction. The DOE Fossil Energy R&D FY 2017 budget proposal of $600 million includes $564 million to support Mission Innovation, an increase of $31 million from the Enacted FY 2016 budget of $533 million. These investments will drive innovation essential for economic growth, provide clean, affordable and reliable energy, and advance energy security.

[2] Clean energy technology in this case can be defined as any process, product or system of products and processes, that can be applied at any stage of the energy cycle from production to consumption, whose application will reduce net greenhouse gas emissions, and can meet one or more of the following characteristics: reduced demand for water resources; reduced waste; reduced emissions of other air pollutants; or reduced concentrations of contaminants in wastewater discharges.

Clean Coal Research and Development

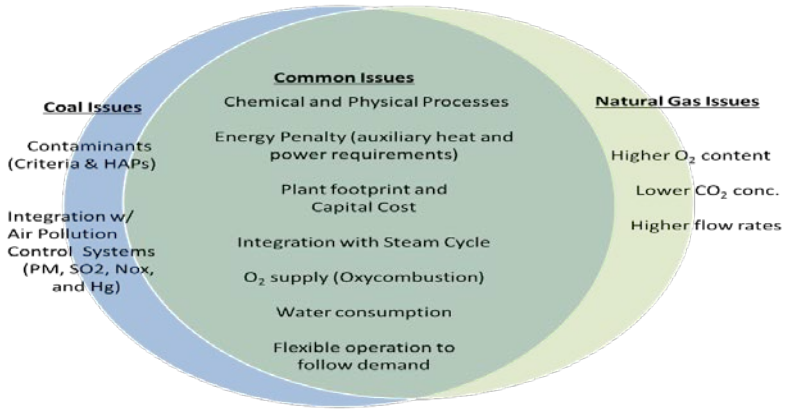
Fossil Energy Research and Development (FER&D) ($600 million)

The FY 2017 budget proposal includes $600 million for FER&D to advance the role of coal in a future clean energy economy.

The FY 2017 budget proposal proposes to restructure the FER&D budget to streamline the structure, align subprograms that support related technology efforts under the same program, and provide a more comprehensive view of the costs associated with National Energy Technology Laboratory (NETL). The key motivation for the structural change is to align sub-programs by commonality among technologies and fossil energy applications rather than by fuel source. Additional information on the restructuring can be found in Appendix 1.

***Carbon Capture and Storage and Advanced Power Systems ($368.4 million)*:** The FY 2017 budget proposes a new structure that consolidates R&D in Carbon Capture and Storage (CCS) and Advanced Power Systems technology because much of the R&D addresses science and technology challenges common to both coal-based and natural gas power generation applications. CCS and Advanced Power Systems supports secure, affordable, and environmentally acceptable near-zero emission fossil energy through RD&D to improve the performance of advanced Carbon Capture and Storage (CCS) technologies and improve the efficiency of advanced power generation systems with CCS technologies. $337.4 million of the $368.4 million requested in FY 2017 in CCS and Advanced Power Systems is focused on coal-based R&D. The remaining $31 million is for natural gas carbon capture applications. However, as illustrated in Figure 1, even a portion of the R&D conducted under the Natural Gas Carbon Capture line will address issues common to both coal and natural gas.

Figure 1: Common and Distinct Issues for Carbon Capture Technology for Coal and Natural Gas-fired Power Systems



The FY 2017 budget proposal includes $170.4 million, 30 percent above FY 2016 enacted, to continue R&D on carbon capture technologies. This includes $101 million to support

construction of four large (10 MWe scale) post-combustion capture pilot plants, three for coal-fired power plants and one optimized to capture CO_2 from a natural gas power system. Funding also supports front-end engineering and design (FEED) studies for two large scale pilot plants (10+MWe) to test advanced low-carbon combustion systems, such as chemical looping and pressurized oxy-combustion. Furthermore, this funding includes work on a number of innovative technological approaches to carbon capture. These pilot projects will be critical to reducing costs and increasing energy efficiency to make low-carbon fossil energy market competitive. The FY 2017 budget proposal for carbon storage decreased relative to the FY 2016 enacted level, largely because the Regional Carbon Sequestration Partnerships are transitioning from injection to post-injection monitoring.

Crosscutting Research and Analysis: The FY 2017 budget proposal includes $59.4 million for Crosscutting Research and Analysis (CRA)—17 percent above the FY 2016 Enacted level. CRA serves as a bridge between basic and applied research by targeting concepts that offer potential transformational breakthroughs and step change benefits in the way fossil energy systems are designed, constructed, and operated. The program is focused on the development of new materials, catalysts, instrumentation, sensors, and advanced computer systems for future power plants and energy systems. This research includes $15.8 million for water management R&D, minimizing the thermoelectric cooling dependence on freshwater and improving efficiency of water systems. This research also includes $23.2 million for Extreme Environment Materials to develop new materials, conduct component testing and develop new modeling for applications that require high-temperature component parts needed for a directly fired-supercritical carbon dioxide turbine. This will enable high-efficiency coal-based electric power generation with a much smaller physical footprint than current plants. It also includes an Energy-Water Crosscut that will involve a field test of promising technologies and processes for treating water produced by injection of carbon dioxide in deep saline aquifers.

Advanced Energy Systems: The FY 2017 budget proposal enables the Advanced Energy Systems (AES) subprogram to develop a new generation of fossil-fueled energy conversion systems integrated with CCS that may be capable of producing competitively priced electric power. The Supercritical Transformational Electric Power (STEP) initiative, which is proposed as an activity under AES as part of the FY 2017 restructuring, supports the Department's Supercritical CO2 (sCO2) crosscut, which is focused on technology development for supercritical carbon dioxide-based power conversion cycles. In coordination with the sCO2 crosscut team, the FY 2017 budget also includes $24.3 million, a 62 percent increase from FY 2016 Enacted, to support a 10 MW supercritical CO_2 pilot scale facility. This is a key step in proving out supercritical CO_2 technologies, which have the potential to greatly increase the efficiency of coal-fired power plants. This project is supported as a crosscutting activity because supercritical carbon dioxide-based power conversion cycles can be applied to most heat sources, including fossil, nuclear, solar and geothermal, offering significant improvements in efficiency, cost, footprint, and water use. The Office of Fossil Energy co-leads this cross-cutting effort within the Department, and is coordinating this project with the Offices of Nuclear Energy and Energy Efficiency and Renewable Energy.

National Energy Technology Laboratory: The FY 2017 budget proposal also provides $76.1 million for the new NETL Research and Operations line and $68.1 million in the NETL Infrastructure line. NETL Research and Operations funding includes $53 million support for NETL in-house coal R&D.

NETL infrastructure funding includes $16.5 million to upgrade Joule, the NETL supercomputer. This upgrade is expected to increase the system's speed ten-fold to advance visualizations and simulations that broadly support fossil energy R&D and help overcome technical development barriers quickly, reliably, and cost-effectively. Joule currently is an integral component of how NETL performs research. It is utilized by more than 90 researchers in the following areas: carbon capture materials and processes, sensor materials, combustion dynamics for MHD and pulsed combustion, and reactive flow for chemical looping. The upgraded computing power is required to support a number of NETL research efforts, to include advanced alloys for advanced power systems, Carbon Capture Simulation Initiative (CCSI2), National Risk Assessment Partnership (NRAP), Radically Engineered Modular Systems (REMS), uncertainty quantification, and development of code suitable for exascale computing.

Science ($56.5 million)

The DOE Office of Science supports basic science research and scientific user facilities to enable breakthroughs in coal and carbon capture, utilization, and storage (CCUS) related technologies. These activities include research on advanced materials and efficient gas separations that could advance ultra-supercritical plants, which have the potential to substantially increase the efficiency of coal-fired powered plants and reduce the cost of carbon capture technologies.

Basic Energy Sciences: Within the Office of Science, the Basic Energy Sciences program supports research to better understand the science underpinning novel technological approaches to deep underground carbon sequestration. Research directions include: understanding geochemical processes relevant to the dimensions of subsurface sequestration sites; development of critical geophysical measurement techniques to enable remote probing and tracking of important chemical and physical processes within rock formations at depth; and development and application of fluid-flow measurement approaches and simulation tools that can link, and explicitly couple, chemical and physical processes at multiple scales. The development of new materials and methods for the effective and efficient separation and capture of CO_2 from post-combustion gas streams and oxygen separation from air prior to oxy-combustion are also being explored.

$000

	FY 2016 Enacted	FY 2017 Pres Request	FY 2017 vs FY 2016
BES Core Research	5,650	8,150	+2,500

Energy Frontier Research Centers: The Office of Science also supports a group of Energy Frontier Research Centers (EFRCs)—grants to integrated, multidisciplinary research teams to advance the science underpinning breakthrough energy technologies.

- In the first round of funding awards (2009-2014), three EFRCs focused on carbon capture and storage research were selected – one in CO_2 capture and two in CO_2 storage. The three centers are conducting a wide range of scientific research activities, including the development of new materials for CO_2 capture, improving the nano-scale physics and chemistry of CO_2 storage reservoirs, and understanding emergent behavior arising from coupled physics and chemistry in subsurface materials. In 2014, these three centers were renewed.

- Also in 2014 two new EFRCs were selected to undertake research related to CO_2 capture and storage. The new centers are focused on additional scientific issues such as characterization, prediction, and control of acid-gas interactions with a broad class of materials; and development of new conceptual, mathematical, and computational models applicable to geologic storage systems, based on uncertainty and limitations observed in field pilots, CO_2 injection demonstration projects, and laboratory experiments.

$000

	FY 2016 Enacted	FY 2017 Pres Request	FY 2017 vs FY 2016
EFRCs	14,500	48,300	+33,800

The FY 2017 budget includes an increase of $33 million to fully fund up to five new EFRCs in subsurface science relevant to CCUS. The new EFRCs will support multidisciplinary teams to address the grand science challenge identified in 2015 strategic planning activities related to advanced imaging of geophysical and geochemical signals in the subsurface.

National Laboratory User Facilities: In addition to direct research support, DOE Office of Science budget includes approximately $2 billion annually to support the operation of major scientific user facilities at DOE National Laboratories. The user facilities provide a broad range of experimental platforms, including x-ray light sources, neutron sources, and nanoscience facilities. These facilities support a variety of experimental efforts relevant to coal-based technologies, such as 3D mapping and volume construction of rocks that store CO_2, interrogating the structure and performance of high-temperature alloys, and development and testing of environmental monitoring tools (e.g., electromagnetic induction methods). The user facilities have the scientific tools to support micro- and nano-scale material characterization, combustion physics experiments and development of subsurface tracers.

In addition, coal researchers are provided access to the Department's world-leading supercomputers to conduct modeling and simulation of combustion and combustion engines, advanced fossil fuel power systems, CO_2 capture and compression technologies, and characterization of subsurface CO_2 storage sites and fossil reservoirs. Over the past three years, projects in these areas have been given over a billion hours of computing time on Department supercomputers for projects that ranged from academic basic research to industrial

commercialization efforts by both Fortune 500 companies and small businesses. Examples include:

- The Lawrence Berkeley National Laboratory National Energy Research Scientific Computing Center (NERSC) employed computer models to predict the long-term behavior of CO_2 injected into the subsurface. The key to the success of the modeling effort – and the reason massive computation is required – is its ability to simultaneously represent both movements and chemical reactions that take place at microscopic levels as the CO_2 migrates through porous rock structures. These models are generating data that closely match the quality of images taken from experiments at the Energy Frontier Research Center for Nanoscale Control of Geologic Carbon. The ability to capture subsurface behavior in a computer model is also relevant to other fossil energy efforts, such as hydrocarbon recovery.

- The National Energy Technology Laboratory utilized the Leadership Computing Facilities (LCF) to improve high fidelity coal gasifier simulations, for the ongoing design and optimization of advanced fossil fuel plants. Researchers explicitly addressed the issue of technology scale-up by studying the effect of various operating conditions on the performance of a commercial scale transport gasifier. The calibrated gasifier model is now being used to support the design of commercial- scale systems.

- The University of Utah Carbon-Capture Multidisciplinary Simulation Center (CCMSC) is using the LCF to more rapidly deploy a new technology for providing low cost, low emission electric power generation from coal. They are using a hierarchal validation approach to obtain simultaneous consistency between a set of selected experiments at different scales embodying the key physics components (large eddy simulations, multiphase flow, particle combustion and radiation) to predict performance in a 350MWe oxygen-fired clean coal boiler.

Advanced Research Projects Agency—Energy ($63 million)

ARPA-E complements the DOE Fossil Energy R&D program by investing funds in advanced high-potential, high-impact carbon capture and use technologies that are too early for private-sector investment.

ARPA-E invested a total of $53.3 million of prior year funds in carbon capture projects from its first OPEN solicitation in 2009 and through its Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT) program. These projects were aimed at the innovative technologies for existing coal-fired power plants that have the potential to dramatically lower the cost of carbon capture. IMPACCT focused on minimizing the cost of removing CO_2 from coal-fired power plant emissions by developing materials and processes that have never before been considered for this application. IMPACCT projects aim to enable

cost effective adoption of carbon capture to help reduce greenhouse gas emissions at existing power plants.

ARPA-E has subsequently invested an additional $10 million of prior year funds in additional carbon capture and utilization projects through its second OPEN solicitation in 2012. These projects include electrochemical approaches to the capture and conversion of CO_2 to useful chemical products and the use of advanced thickeners to improve the utility of CO_2 for enhanced oil and gas recovery.

Of the 14 projects funded through the IMPACCT program, ten were completed by 2015. A brief description of the four remaining projects, which are being overseen by NETL/FE follow:

- Alliant Techsystems Inc. (ATK) uses aerospace wind-tunnel technologies to turn CO_2 into a condensed solid for collection and capture. Its technology is mechanically simple and generates no chemical waste, reducing the cost of carbon capture to less than $45 per ton. It is also readily scalable and can be integrated into existing facilities.

- General Electric (GE) is advancing a unique CO_2 capture process that is more efficient than other solvent-based processes because it turns solid when reacting with CO_2, so that the separation process requires little energy input. This ultimately leads to a CO_2 capture cost of less than $40 per ton, lowering the additional cost to produce electricity at coal-fired power plants.

- Lawrence Livermore National Laboratory (LLNL) is developing a new CO_2 capture process using microcapsules filled with an advanced solvent. This solvent requires less energy for regeneration, but in bulk form reacts slowly with CO_2. Placing the liquid in LLNL's microcapsules increases the capture rate by ten times compared to the solvent by itself, opening the possibility for a new capture process that is 30-50% less expensive.

- RTI International is advancing novel non-aqueous solvent systems that remove the CO_2 from flue gas by lower-energy reaction pathways and thus can be regenerated at lower temperatures. The technology has the potential to substantially reduce the parasitic power load associated with solvent regeneration and reduce the capital cost of CO_2 capture. The process is now being prepared for pilot-scale testing in an actual combustion facility.

Finally, ARPA-E is defining programs for 2016 and 2017 solicitations, which could lead to further projects in carbon capture and utilization.

DOE R&D Crosscutting Initiatives ($504.2 million)

DOE supports crosscutting initiatives to integrate the expertise in multiple programs and the National Laboratories to address common scientific and technical challenges. Within the FY 2017 budget proposal, four of these initiatives can directly benefit coal power generation.

These activities are embedded in the various DOE program office budgets, some of which are described above.

Supercritical CO_2 Technology ($36.3 million; includes $30.3 million of FER&D funding): The FY 2017 budget proposal includes $36.3 million, $4 million above FY 2016, to continue a Supercritical CO_2 crosscutting initiative to accelerate the development of a technology with the potential to significantly improve the efficiency and economics of low-carbon power from several thermal energy sources—including coal-fired plants. In addition to continued R&D on supercritical CO_2 technologies, the FY 2017 request builds on industry outreach and focused R&D efforts in FY 2015, and the development in FY 2016 of more detailed conceptual plans, technical approach, cost and schedule estimates relevant to a 10 MWe pilot test facility.

These inputs will inform the development of the Supercritical Transformational Electric Power (STEP) solicitation, to be issued and awarded in FY 2016, for the design, construction and operation of a 10 MWe pilot test facility. Initiation of design and construction of the STEP facility would begin in early FY 2017.

Subsurface Science, Technology and Engineering RD&D ($258.3 million; includes $97.9 million of FER&D funding, of which $90.9 million is Coal R&D): The FY 2017 Request includes $258.3 million for the Subsurface Science, Technology and Engineering RD&D crosscutting initiative, $51.1 million above the FY 2016 Enacted level, including funding across five programs to identify and coordinate strategic subsurface research, development, and demonstration (RD&D) projects and policies. Of the $97.9 million of FE R&D funding, $90.9 million is for CCS and Advanced Power Systems, and $7 million is for Fuel Supply Impact Mitigation.

The subsurface environment is critical to the U.S. for energy production, energy and CO_2 storage, remediation of existing legacy waste, and ultimate disposal of future energy wastes. Work includes common scientific and technical challenges around the theme of Adaptive Control of Subsurface Fractures and Fluid Flow—issues that are important to CO_2 subsurface sequestration.

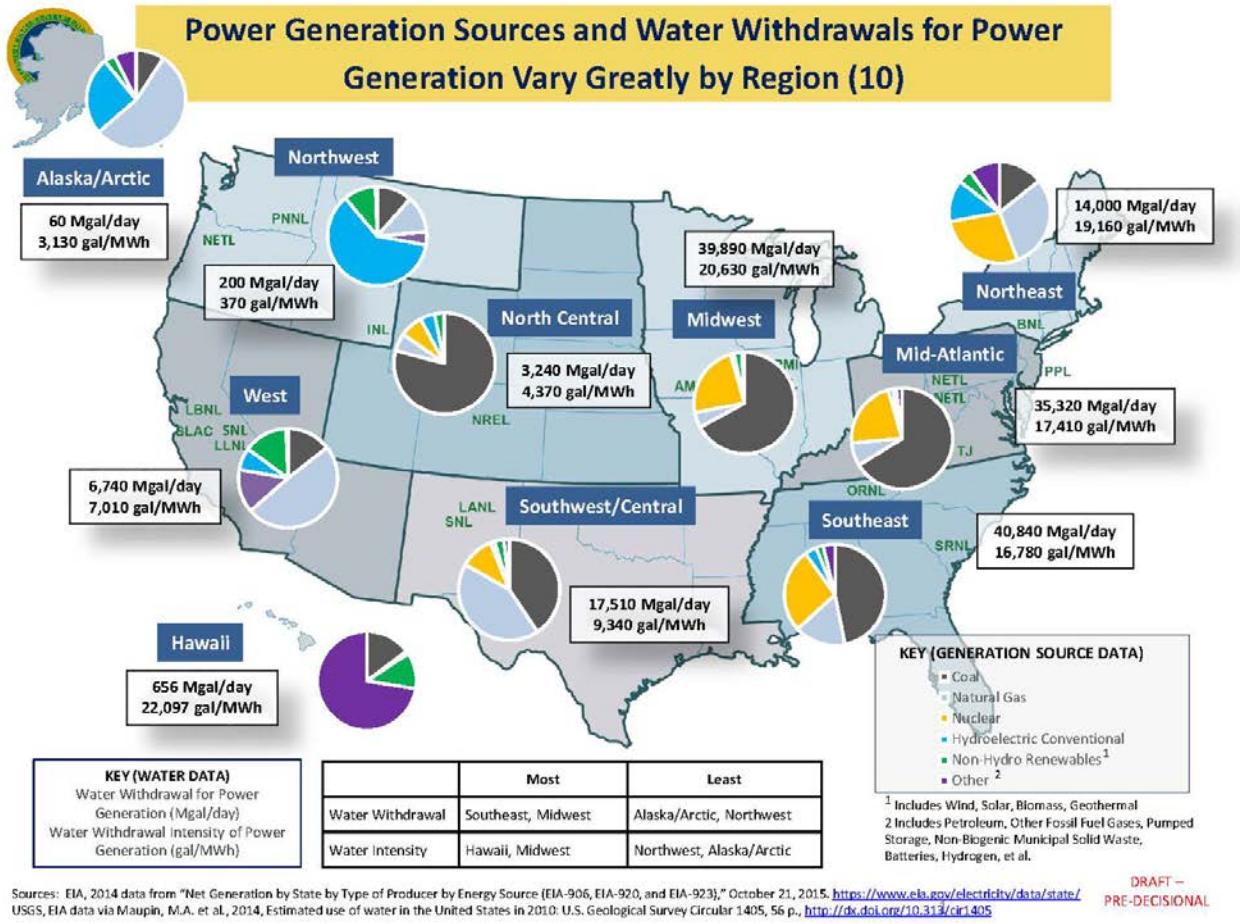
The Subsurface crosscut will address identified challenges in the subsurface through highly focused and coordinated research in Wellbore Integrity, Subsurface Stress State and Induced Seismicity, Permeability Manipulation, and New Subsurface Signals to enhance renewable energy supply, ensure material impact on climate change via CO_2 storage, and significantly mitigate environmental impacts from energy-related subsurface activities and operations. In addition, in FY 2017 the Subsurface Crosscut team will pursue R&D on a grand challenge topic on “Advanced imaging of geophysical and geochemical signals in the subsurface,” and support investments in Risk Assessment Tools and Methodologies.

Energy-Water Nexus ($96.1 million; includes $15.8 million of FER&D funding): The FY 2017 budget proposal also proposes $96.1 million for the Energy-Water Nexus crosscutting initiative. This initiative seeks to address water-energy challenges through transformative science and technology solutions. Water is used in all phases of electricity generation and energy

production, accounting for over 40% of total water withdrawals and over 5% of total water consumption, while the water system accounts for 3% of total electricity consumption. In just one example, when severe drought affected more than a third of the United States in 2012, limited water availability constrained operation of some power plants and other energy production activities. The Energy-Water Nexus crosscutting initiative seeks to address water-energy challenges through transformative science and technology solutions. The application of state-of-the-art (SOTA) CCS technologies on a 550 MW Super Critical Pulverized Coal (SCPC) power plant increases the demand for water by approximately 80 percent. Technologies under development, including advanced solvents, sorbents, and membranes can reduce that additional water demand by ~20 percent and 60 percent, respectively. The FE R&D program is also working to scale up transformational carbon capture technologies such as molten carbonate fuel cells (MCFC) that can actually produce water and supplement the water demand for base plant operation.

In the area of coal-powered generation, this initiative will explore production of water from carbon capture and storage, water-efficient cooling for electricity generation, and data, modeling, and analysis (DMA) activities focused on water availability on a regional/state level.

The following chart highlights the differences of water consumption for power generation across the country by region.



Advanced Materials for Energy Innovation ($113.5 million; includes $23.2 million of FER&D funding): The FY 2017 budget proposal includes $113.5 million for the crosscutting initiative on Advanced Materials development, including materials for extreme environments, such as those needed for Super Critical (sCO_2) and Advanced Ultra-Super Critical (AUSC) power cycles. New materials discoveries have the potential to revolutionize whole industries, but only a small fraction of these materials make it to widespread market deployment. The uncertainties and risks associated with scale-up and production, as well as the real or perceived liabilities associated with material failures in service, significantly slow the development and deployment cycles. This crosscut focuses on a subset of materials R&D that will involve close coordination among the participating offices to form a cohesive network with the following capabilities: (1)

predictive tools, (2) functional (applied) design validation, (3) process scale-up, (4) qualification, and (5) digital data and informatics.

Computational techniques will continue to be developed to design materials, decreasing the time and cost of high temperature materials for directly-heated sCO_2 and advanced ultra-supercritical high steam environments.

International Cooperation through Domestic Investments ($37.5 million)

In November 2014, President Obama and President Xi announced in Beijing the U.S. and China's respective post-2020 greenhouse gas reduction targets, sending a clear signal about the commitment of the two largest economies to a low carbon future and creating a huge market for investment and innovation in clean energy technologies and services. As part of the November announcement, both sides will extend and expand the successful U.S.-China Clean Energy Research Center (CERC) from 2016-2020. The CERC, established in 2009, leverages resources of both countries and aims to accelerate the development and deployment of clean energy technologies, a benefit to both countries. The resulting increased demand for new and advanced products can boost America's exports, create American jobs, and help our country remain at the forefront of technology innovation.

Under the new announcement, CERC's joint research activities will be organized into five technical tracks, including advanced coal technology with CCUS and energy and water. Under each track, U.S. and Chinese scientists and engineers, with industrial partners in both countries, have mutually agreed to pursue collaborative research in specific topic areas. For each research track, DOE will contribute $2.5 million per year over five years, funded within the respective program office budgets. These DOE contributions are matched by $2.5 million per year by U.S. entities and $5 million per year by partners in China. U.S. funds will be used exclusively to support work conducted by U.S. institutions and individuals only, and Chinese funds will support work conducted by Chinese institutions and researchers.

Since 2010, DOE has invested $12.5 million in the U.S. Advanced Coal Technology Consortium (ACTC) within the CERC. Led by West Virginia University, this consortium has received over $12.5 million of matching funds from industry to perform power-plant systems analysis, work with U.S. companies doing business in China, and undertake bench-top research to foster partnership between China and the U.S. The ACTC program has also received additional funding from the U.S. State Department to focus on issues of Intellectual Property (IP), and the CERC created one of the first and best models for IP protection in the energy sector. It is hard to overstate the importance of this effort – senior leaders in China have cited CERC as the premier platform for U.S.-China collaboration, and many U.S. companies have received access, technical support, and IP protection through the CERC. All DOE funding resources support exclusively U.S. research performers.

Presidents Xi and Obama not only committed to continue the CERC but to expand its activities to cover energy-water nexus research and partnerships. This solicitation was issued on March

6, 2015, and is expected to commence in FY 2016. Much of this work, including alternative cooling technologies and practice, water recovery from coal-fired power plants, and development of unconventional water supplies, directly benefit the RD&D within FE's Office of Clean Coal and Carbon Management.

Coal Technology Demonstration and Deployment

DOE Carbon Capture Utilization and Storage (CCUS) Demonstration Projects ($1.42 billion)

While the DOE R&D portfolio supports innovation for the next generation of low-carbon coal technologies, clean coal plants that use coal and emit less carbon pollution are already in operation or being built today. As shown in Appendix 2, there are 50 CCUS projects currently in operation or under development outside the United States.

Today, CCUS technology is available from commercial vendors with a performance guarantee and a warranty. In the absence of a price on carbon, CCUS technology is not yet competitive with other electricity generation options. However, the experience gained from these commercial demonstration facilities, combined with current R&D efforts, will decrease the cost of these technologies. CCUS tax incentives (described further below) will provide the necessary incentives for the initial round of commercial CCUS projects to bridge the cost competitiveness gap.

Technology Foundations: The Southern Company Plant Barry project successfully demonstrated the performance of post-combustion carbon capture and sequestration from a coal-fired power plant. This work, funded under the DOE Regional Carbon Sequestration Partnership program, provided foundational information for other large demonstrations, including the commercial scale Boundary Dam project in Canada. The Dakota Gasification Company Great Plains Synfuels Plant in Bismarck, North Dakota, initially supported with a DOE loan guarantee, has also been capturing CO_2 from a coal gasification plant and selling it for enhanced oil recovery (EOR) in the Weyburn-Midale oil field for over ten years. It remains an important model for technical success in a large-scale demonstration project.

Active Industrial CCUS Demonstration Projects ($425 million): Two commercial-scale industrial CCUS demonstration projects have been supported with prior year DOE cost-sharing.

- Air Products & Chemicals, Inc. partnered with Denbury Onshore LLC to capture and sequester 1 million tons of CO_2 per year from existing steam-methane reformers in Port Arthur, Texas. Air Products is transporting the captured gas to oil fields in eastern Texas by pipeline, where it is being used for enhanced oil recovery. This $431 million project, supported by a DOE investment of $284 million, began operations in December 2012 and has successfully captured and stored over 2.5 million metric tons of CO_2 as of December 2015.

- The Archer Daniels Midland Company's project will capture and sequester 1 million tons of CO_2 per year from an existing ethanol plant in Illinois into Mt. Simon Sandstone, a well-characterized saline reservoir located about one mile from the plant. This $208 million project is currently under construction and is supported by $141 million in DOE funding. Start of commercial operations is expected in 2016.

Active Power Generation CCUS Demonstration Projects ($597 million): Two large scale power generation demonstration projects are currently in development, supported with prior year DOE funds.

- DOE is providing $407 million (including $137 million as a result of Section 313 of the FY 2016 omnibus appropriation, described further below) in cost sharing for the Southern Company Kemper County Energy Facility, a 582 MW integrated gasification combined cycle (IGCC) power plant. The project has nearly completed construction in Kemper County, Mississippi and is undergoing testing. The plant features a CCS system designed to capture approximately 65 percent of the produced CO_2. The project is expected to be fully operational in the second half of 2016.

- DOE is investing $190 million (including $23 million as a result of Section 313 of the FY 2016 omnibus appropriation) in cost sharing for the NRG/PetraNova Project, near Houston, Texas. This project will capture and store over 1 million tons of CO_2 from an existing boiler using post-combustion retrofit technology. The project commenced construction in September 2014, and is scheduled for commissioning at the end of 2016.

Inactive and Terminated CCUS Demonstration Projects ($400 million): Three large-scale demonstration projects – FutureGen, HECA, and Summit – received prior year DOE cost sharing, but have not been implemented. Section 313 of the Consolidated Appropriations Act, 2016, directed DOE to reallocate funds previously obligated to projects selected under solicitations for the Clean Coal Power Initiative (CCPI) and FutureGen programs. Specifically, the law required that not less than $160 million be transferred from projects that did not secure funding to commence construction by January 17, 2016, to projects that had secured construction funding by that date. As described above, two CCPI projects met the criteria of having secured funding to commence construction: Southern Company's Kemper County Energy Facility, and NRG Energy's PetraNova project. The Department identified funding previously obligated to the Hydrogen Energy California (HECA), FutureGen Restart, and FutureGen 2.0 projects for reallocation to the Kemper and Petra Nova projects.

The FY 2017 FER&D budget also proposes to reallocate $240 million in prior year unobligated balances from funds appropriated in prior year Acts under the headings "Fossil Energy Research and Development" and "Clean Coal Technology" for prior year solicitations under the CCPI from projects selected under such solicitations that have not reached financial close. Two projects, HECA and Summit, have not yet reached financial close; FutureGen has been closed out.

DOE Title XVII Loan Guarantee Program ($8.5 billion loan guarantee authority)

The DOE Loan Programs Office (LPO) has $8.5 billion in Congressionally-approved authority from prior year appropriations acts to issue loan guarantees to innovative fossil energy projects. Loan guarantees will help provide critical financing to support innovative advanced fossil energy projects and facilities—such as advanced resource development, carbon capture, low-carbon power systems, and efficiency improvements—that also reduce, avoid, or sequester greenhouse gas emissions.

The DOE LPO is currently accepting applications for this loan guarantee authority under its Advanced Fossil Energy Projects solicitation. The solicitation includes rolling deadlines for Part I through July 2016 for the basic eligibility determination of a project. Part II rolling deadlines currently run through October 2016, and are the part of the application process where confirmatory due diligence begins. Additional deadlines for Part I and Part II may be announced in a supplement to the Advanced Fossil Energy Projects solicitation.

DOE has identified four technology areas of interest under this solicitation.

- Resource development and extraction processes;

- Carbon capture for fossil-based energy systems. This includes both natural gas and coal-based systems for both power generation and industrial applications, which account for over half of the United States' annual greenhouse gas emissions;

- Innovative combustion technologies that can produce CO_2 exhaust gas systems more amenable to carbon capture; and

- Higher efficiency fossil fuel conversion processes that can result in reduced emissions-per-product and better fuel utilization.

LPO has seen increased industry interest and a steady uptick in applications to the Title XVII program, and anticipates that the market will continue to respond to the Advanced Fossil Solicitation and other Title XVII solicitations with an increasing volume of applications. To date, projects applying under the Advanced Fossil Solicitation include projects developing natural gas chemicals projects, carbon capture and utilization, natural gas-to-liquids, and petroleum coke gasification, among others. LPO continues to expeditiously process these applications.

Department of Treasury, CCUS Deployment Tax Incentives ($5+ billion)

The FY 2017 budget re-proposes $5 billion in two tax incentives that will complement each other in making the deployment of CCUS technologies cost competitive, which in turn will enable additional technology improvements and drive down the costs of follow-on CCUS deployment.

New Investment Tax Credit: The FY 2017 budget proposes $2 billion in refundable investment tax credits for projects that capture and permanently sequester CO_2. Credits would be available to new and retrofitted electric generating units. Projects must capture and store at least one million metric tons of CO_2 per year. Projects that treat the entire flue gas stream from an electric generating unit or set of units must sequester at least 50 percent of the CO_2 in the stream. Projects that treat only a portion of the flue gas stream must capture at least 80 percent of the CO_2 in the stream. No more than $800 million of the credits would be allowed to flow to projects that capture and store less than 80 percent of their CO_2 emissions. A minimum of 70 percent of the credits would be required to flow to projects fueled by greater than 75 percent coal. The credits would be available for 30 percent of the installed cost of eligible property, which also includes CO_2 transportation and storage infrastructure. Eligible property would include carbon capture equipment and other tangible property used as an integral part of the project and CO_2 transportation and storage infrastructure, including pipelines, wells, and monitoring systems. Eligible property includes only property that is part of a new project or retrofit placed in service after December 31, 2015.

Expanded Sequestration Tax Credit: The FY 2017 budget provides $2 billion in refundable investment tax credits to new and retrofitted electric generating units (EGUs) that deploy carbon capture technology. Projects must capture and store at least one million metric tons of CO_2 per year. Projects that treat the entire flue gas stream from an electric generating unit or set of units must sequester at least 50 percent of the CO_2 in the stream. Projects that treat only a portion of the flue gas stream must capture at least 80 percent of the CO_2 in the stream. No more than $800 million of the credits would be allowed to flow to projects that capture and store less than 80 percent of their CO_2 emissions. A minimum of 70 percent of the credits must go to projects fueled by greater than 75 percent coal. The credits would be available for 30 percent of the installed cost of eligible property, which would include CO_2 transportation and storage infrastructure in addition to EGUs. Eligible property includes only property that is part of a new project or retrofit placed in service after December 31, 2015. The FY 2017 budget proposal also provides a refundable sequestration tax credit for qualified investments at a rate of: (a) $50 per metric ton of CO_2 permanently sequestered and not beneficially reused; or (b) $10 per metric ton for CO_2 that is permanently sequestered and beneficially reused (e.g. for enhanced oil recovery EOR). The credit would be allowed for a maximum of 20 years of production. The Department of Treasury estimates the value of this sequestration tax credit at $3 billion over a 10-year period, but it is possible the total financial support would be higher. Projects may utilize both the investment and sequestration tax credits. Under current law, tax credits are available at $10 per metric ton for EOR and $20 per metric ton for storage. The expanded tax credit also reduces the amount of injected CO_2 needed to qualify.

Economic and Workforce Development

The U. S. has been undergoing a rapid energy transformation, particularly in the power sector. Increased production of natural gas at lower prices, declining costs for renewable energy, increases in energy efficiency, flattening electricity demand, and updated clean air standards are changing the way electricity is generated and used across the country. At the same time, this transformation is impacting workers and communities that have relied on the coal industry as a source of good jobs and economic prosperity. The impacts are particularly significant in the Appalachian coal producing areas.

***Interagency POWER Initiative ($75 million)*:** The FY 2017 budget provides $75 million for the implementation of the POWER (Partnerships for Opportunity and Workforce and Economic Revitalization) initiative, a set of targeted economic and workforce development strategies across a number of Federal programs. POWER was initiated in FY 2015 and supported in the FY 2016 Omnibus appropriations bill. The FY 2017 budget will continue efforts to help communities to: diversify their economies; create good jobs in existing or new industries; attract new sources of job-creating investment; and provide reemployment services and job training to dislocated workers in order to connect them to high-quality, in-demand jobs. The three principal components of the FY 2017 budget for the POWER initiative include:

- ***Appalachian Research Commission (ARC) ($50 million)*:** The FY 2017 budget requests $120 million for the ARC, $25 million above the FY 2016 enacted level. Of this total, $50 million will be targeted specifically to those Appalachian communities most affected by coal economy transition. ARC is a regional development agency created to assist economic growth in Appalachian communities. Funds are awarded through a cooperative process with the governors of the 13 states that make up Appalachia. The funds will support a range of economic development planning and implementation activities, including developing entrepreneurial ecosystems, facilitating access to capital investments and new markets, and addressing barriers related to adequate water, sewer, and telecommunication infrastructure.

  The FY 2017 budget of $25 million builds upon the $45 million currently allocated in FY 2016 to the POWER 2016 Federal Funding Opportunity (FFO). This FFO will include up to $1.2 million in technical assistance to help communities develop partnerships, refine strategic investment plans, and craft compelling applications for POWER 2016; and offering additional capacity-building assistance to communities that need help identifying enduring economic development strategies. ARC will also work closely with Local Development Districts, community investors, and other public and private partners to leverage additional investments in Appalachia's coal-impacted communities.

- **Environmental Protection Agency (EPA) Brownfields Program ($5 million):** The FY 2017 budget proposal provides up to $5 million exclusively for Area-Wide Planning

(AWP) grants targeted to communities that are developing comprehensive strategies as part of assessing and cleaning up brownfield sites related to the coal economy. AWP grants may involve developing market studies, analyzing approaches for securing implementation resources, defining viable new end uses, prioritizing sites, and engaging a range of community stakeholders. In addition, EPA will initiate a Brownfield Area-Wide Planning (AWP) competition in 2016 (which will be funded in early 2017), that will specifically include areas impacted by closed or closing coal-fired power plants or other facilities involved in the coal economy. Under AWP, EPA will support communities to develop comprehensive strategies and area-wide plans to assess and clean up brownfields sites related to the coal economy. Coal economy facilities will be considered as an "other factor" that the applicant can cite as part of the competitive process, giving the proposal priority consideration as projects are selected.

- **Department of Labor, Dislocated Workers National Reserve ($20 million):** Using National Reserve funds, DOL provides grants to States that have recently experienced a significant dislocation event, such as a mass layoff or plant closing. These funds supplement job training formula grants to temporarily expand the capacity of States and local communities to provide reemployment services, job training, subsidized employment, and supportive services to help unemployed workers get back on the job. The Budget provides $20 million specifically to support workers dislocated from the coal economy. This will allow States and local areas to provide reemployment, training, and supportive services to these transitioning coal economy workers to help them get back to work in good jobs and careers.

Department of Interior, Office of Surface Mining Reclamation and Enforcement (OSMRE), Mine Reclamation and Redevelopment **($539 million – mandatory; $158 million – discretionary):** OSMRE regulates coal production and reclaims abandoned mines, or authorizes States and Tribes upon approval of their regulatory and reclamation programs to perform these responsibilities. With this authority, States and Tribes regulate approximately 97% of the nation's coal production and complete over 90% of the abandoned mine lands abatement work. The FY 2017 OSMRE budget request contains both mandatory and discretionary funding to achieve their goals. The FY 2017 budget provides $539 million in mandatory funding ($339.0 million in for reclamation grants to States and Tribes, and $200 million to accelerate reclamation of Abandoned Mine Land (AML) sites and revitalize coal country communities ($1B total over 5 years). The FY 2017 budget also provides $158 million in discretionary funding for a variety of efforts, including ensuring that coal mine surface activities are operated in a manner that protects communities and the environment, restoration of lands to beneficial use following mining, and pursuing reclamation of abandoned coal mines. OSMRE will work with AML state and tribal programs and POWER grantees to identify and leverage linkages between AML coal mine reclamation projects and the planning and implementation of their economic development strategies.

***Department of Commerce, Economic Development Administration (EDA) ($215 million)*:** The FY 2017 budget requests a total of $215 million. Within this total budget, EDA will help advance and coordinate the POWER Initiative and other place-based economic development initiatives that support job and opportunity creation through implementation of locally-driven strategic plans in communities across the country. EDA is currently implementing funding specifically targeted to coal-related projects in the FY 2015 appropriation for POWER grants and the FY 2016 appropriation for "Assistance to Coal Communities" grants. Specifically:

- In FY 2015, EDA made a total of $15.5 million in grant funds available for POWER-eligible grants, including:
    - $12.5 million for implementation project grants; and
    - $3 million for POWER-specific economic strategic planning grants.
- In FY 2016, EDA is making a total of $19.6 million available for additional POWER grants, including:
    - $15 million in FY 16 Assistance to Coal Communities appropriations; and
    - $4.6 million unobligated balance of FY 15 POWER implementation funds.

***Small Business Administration (SBA) ($0.45 million)*:** In FY 2016, the SBA, through its Small Business Development Center (SBDC) program, plans to provide up to three $100,000 Portable Assistance grants to SBDCs in coal-impacted communities to conduct additional, concerted technical assistance and counseling to existing and aspiring small businesses in these areas. In addition, the SBA Office of Native American Affairs (ONAA) plans to provide up to three $50,000 7(j) technical assistance grant awards to provide training and counseling to aspiring small business owners in Native American communities impacted by changes in the coal economy. ONAA also will provide education and training to tribal leaders in coal-impacted Native American communities through an executive education program developed in partnership with The New School. Through its Regional Innovation Cluster program, SBA intends to award preference points to applicants serving coal-impacted communities if the agency issues a new Regional Innovation Cluster solicitation.

***Department of Commerce, SelectUSA ($20 million)*:** The FY 2017 budget includes $20 million for the SelectUSA program, which provides an information portal on Federal programs for entities seeking to invest in establishing new business activities in the U.S. Recipients of POWER grants are eligible to seek assistance from SelectUSA including: (1) counseling on best practices related to foreign direct investment (FDI) attraction; (2) support through overseas investment missions; and (3) advocacy services to help retain or attract firms engaged in global location competitions (in a geographically neutral manner with respect to locations within the U.S.).

***Department of Commerce, NIST-Manufacturing Extension Partnerships (MEP) ($142 million)*:** The FY 2017 budget includes a total of $142 million for the MEP program, a Federal-state-industry partnership that provides U.S. manufacturers with access to technologies, resources, and industry experts. The program consists of 58 MEP Centers that work directly with their

local manufacturing communities to strengthen the competitiveness of our nation's domestic manufacturing base. Manufacturers in the coal power plant and coal mining supply chains are eligible to seek technical assistance services, including strategies related to diversification, risk mitigation, market research, and entry into new and export markets. NIST MEP Centers in coal impacted regions will be available to collaborate with applicants for POWER funds. NIST MEP Centers also will conduct enhanced outreach to manufacturers that supply to the coal economy as part of their market penetration; explore ways to capture impacts from MEP Center work with manufacturers that supply to the coal economy; and promote the POWER Initiative and the needs of the coal communities via various communication forums.

Department of Interior, Office of Surface Mining Reclamation and Enforcement, Retiree Health Care and Pension Plan Contributions ($375.4 million mandatory): The FY 2017 budget includes $375.4 million to strengthen the health care and pension plans that provide for the health and retirement security of over 100,000 retired coal miners and their families. Currently, the OSMRE makes annual transfers to three health care plans administered by the UMWA Health and Retirement Funds to provide benefits for retired coal miners and their families whose employers no longer contribute to their plans. The UMWA Health and Retirement Funds collectively pay about $1 billion per year in health and retirement benefits to health care providers and families in all 50 states, with the majority of benefits flowing to Appalachian states where coal mining job loss has been most severe.

The FY 2017 budget proposal revises the formula for transfers of funds to the UMWA 1993 Health Benefit Plan by taking into account all beneficiaries enrolled in that health care plan as of this proposal's enactment. This builds on the FY 2016 Budget which accounted for those retirees whose health benefits were denied or reduced as the result of a bituminous coal industry bankruptcy proceeding which commenced in 2012. The proposal would transfer funds to the Pension Benefit Guaranty Corporation for the purpose of protecting the long-term solvency of the 1974 UMWA Pension Plan and Trust (1974 Pension Plan), which is significantly underfunded and approaching insolvency. Transfers would continue until the Plan is fully funded.

Department of Labor (DOL) Employment & Training Administration (ETA) ($19 million)**:** ETA will make an additional $19 million available during Program Year 2016 (between July 1, 2016 and June 30, 2017) to provide new grants, or increase the award amounts for existing POWER Dislocated Worker Grants (DWG), capped at $2 million per award to state workforce development agencies on behalf of eligible coal-impacted communities. ETA has awarded four POWER DWGs totaling just under $8 million to date. ETA also intends to provide technical assistance to state and local workforce development agencies and partners, focusing primarily on use of existing resources, including state Rapid Response funds, to conduct layoff aversion activities to minimize the impacts of downturns in the coal industry on downstream industries and sectors.

DOE Office of Energy Jobs Development**:** The Department will provide energy-related technical assistance resources to POWER grant recipients and applicants from DOE offices and National

Labs, and access to investment in a range of energy technology and manufacturing projects through its Loan Program Office. Additional technical assistance programs include integrating combined heat and power in existing energy systems, designing energy efficiency strategies to create jobs and energy savings, deploying carbon capture, utilization and storage technologies for existing power plants, the reuse of energy and mining land sites, and expanding renewable energy deployment and jobs.

USDA-Rural Business Cooperative Service (RBS): The RBS will use its portfolio of economic development programs to support POWER grantees. USDA Rural Development State Directors and the RBS Administrator will assign priority through discretionary points for applications from POWER grantees and other coal-impacted communities for RBS loans or grants and will focus outreach to such communities. Additionally, State Directors will make POWER Initiative awardees outreach a priority for their Community Economic Development (CED) staff. Specifically, CED staff will connect POWER grantees with Rural Development set aside funding opportunities designed to promote regional economic development planning. POWER activities will be implemented in FY 2016 and FY 2017 with currently available funds.

Department of Treasury, Community Development Financial Institutions (CDFI) Fund**:** The CDFI Fund will (1) participate in meetings targeting CDFIs and Community Development Entities (CDEs) that currently invest, or are well positioned to invest, in coal-impacted communities with low or no CDFI/CDE investment; (2) provide training as requested on CDFI Fund programs to state/regional staff of participating federal agencies; and (3) include investment in POWER partnership communities as a targeted investment option in the 2016 New Market Tax Credit (NMTC) Program application.

Corporation for National and Community Service (CNCS)**:** CNCS will encourage its AmeriCorps grantees to support POWER grant recipients. Additionally, CNCS will connect coal-impacted communities with CNCS State Offices to assess capacity needs and potential collaboration with AmeriCorps VISTA. Additionally, CNCS is available to explore opportunities with prospective POWER 2016 applicants to consider the inclusion of AmeriCorps grantees and members in their applications.

Contribution of Fossil Energy R&D to the Mission Innovation Clean Energy R&D Portfolio

In November, the U.S. and 19 other countries launched Mission Innovation, a landmark commitment to dramatically accelerate the pace of clean energy technology innovation. The 20 countries representing 80 percent of global clean energy research and development are committing to seek to double their respective clean energy R&D budgets over five years.

Increased government investment will significantly expand opportunities for private sector investment in new technologies needed to support economic growth and competitiveness,

strengthen energy security, increase access to clean and affordable energy, and enable the global community to meet shared climate goals.

The Breakthrough Energy Coalition, an independent initiative launched simultaneously with Mission Innovation and spearheaded by Bill Gates, is a global group of private investors that will provide investments to take early stage innovative technologies from the laboratory into the marketplace. These investments will be targeted to Mission Innovation partner countries.

The DOE Mission Innovation clean energy R&D strategy supports a robust, all-of-the-above program portfolio across the major DOE applied energy organizations, including the Office of Fossil Energy, the Office of Nuclear Energy, the Office of Energy Efficiency and Renewable Energy, the Office of Electricity Delivery and Energy Reliability, and ARPA-E.

Figure 2: FY2016 Budget Estimates for DOE Applied Energy Program Organizations *(excludes program direction and EERE corporate support)*

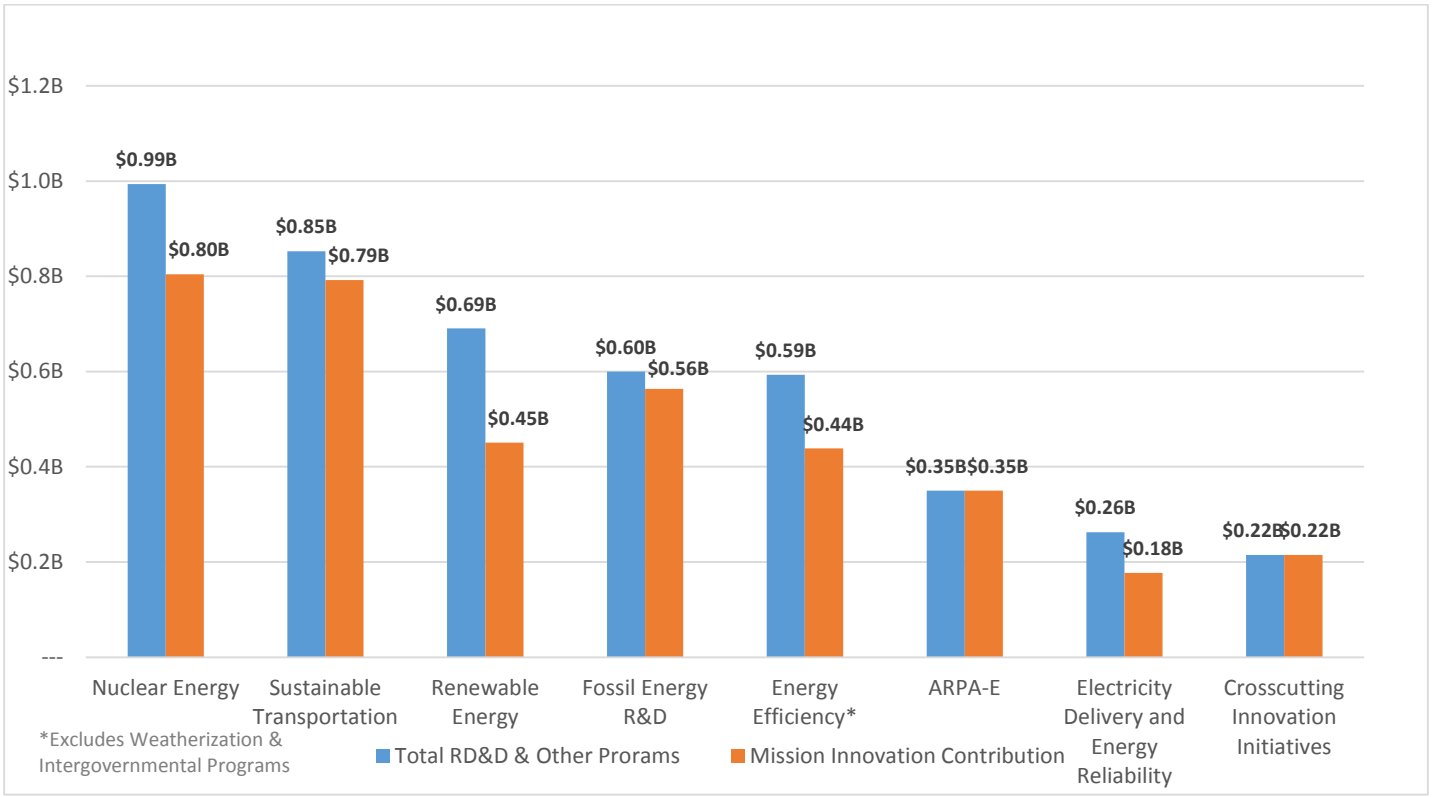


Figure 2 above shows the comparison of the FY 2017 budget proposal across the major DOE applied energy program organizations. The comparison shows that total funding for the Office of Fossil Energy, while below NE and EERE's Sustainable Transportation program area, is comparable to the energy efficiency and renewable energy R&D program portfolios.

The comparison includes only new funding proposed in the President's FY 2017 budget. The estimates exclude the significant amount of prior year appropriations for coal-based CCUS

demonstration projects, whereas the FY 2017 budgets for Energy Efficiency, Renewable Energy and Sustainable Transportation programs include both R&D and demonstration projects and deployment incentive programs. Including prior year investments in coal and CCUS demonstration project activities would be additive to the estimates presented in Figure 2.

Finally, it is important to recognize that R&D and demonstration programs funded in the energy efficiency and transportation programs benefit coal and other fossil fuels. The energy efficiency programs address all forms of end use energy efficiency including coal-based electricity and natural gas use for power generation, space heating and industrial processes. The transportation programs address the efficient use of petroleum-based fuels; the use of natural gas as a vehicle fuel; and innovation in electric drivetrain technology and deployment of plug-in electric hybrid vehicles fueled by electricity, where coal currently comprises about 50 percent of electricity generation.

Conclusion

Federal activities support coal technologies and coal country communities through a full spectrum of programs across at least nine Federal agencies. This broad suite of ongoing and proposed programs aims to advance and deploy coal technologies while helping coal country communities adapt to the changing energy landscape.

Within DOE alone, the coal portfolio spans more than six program offices to enable coal as a low-carbon marketplace contributor. In this effort, DOE brings to bear the full spectrum of its research and development programs, demonstration projects, science and user facilities, and National Laboratories to advance coal technologies. DOE continues to support an all-of-the-above energy strategy that includes a commitment to coal in parallel with support for renewable energy, energy efficiency, advanced transportation technologies, nuclear energy, power grid, ARPA-E, and Crosscutting Innovation Initiatives.

Glossary

Carbon Capture, Utilization, and Storage: The process of capturing and permanently storing underground or re-using carbon dioxide (CO^2) from fossil fuel plants and industrial sources. It is one part of a wider portfolio strategy that many scientists and nations favor for achieving significant cuts in atmospheric CO_2 emissions.

Chemical Looping: Process in which coal is mixed with some carrier material, typically iron or calcium based, that releases a stream of oxygen for coal combustion. The carrier material flows into a separate chamber where it mixes with air, which causes it to reoxidize. The carrier material is then "looped" back into the fuel chamber in a continuously repeating cycle. Chemical looping produces a pure stream of CO_2 that can be compressed and permanently stored underground.

Gasification: Process in which carbon-containing material is converted into synthesis gas, composed primarily of carbon monoxide and hydrogen (referred to as syngas). Syngas can be used as a fuel to generate electricity or steam, as a basic chemical building block for a large number of uses in the petrochemical and refining industries, and for the production of hydrogen.

Enhanced Oil and Gas Recovery: Process in which heat, chemicals or gases such as CO_2 are injected into depleted oil and gas formations to recover those resources that would otherwise be difficult to reach. Gas injection accounts for nearly 60 percent of enhanced oil recovery production in the United States.

INCITE: The Innovative Novel and Computational Impact on Theory and Experiment (INCITE) program is the program under which allocations on Advanced Scientific Computing Research leadership computing systems are provided. INCITE is open to national and international researchers, including industry; not constrained by existing DOE or Office of Science funding or topic areas; and is based on rigorous peer and computational reviews.

Leadership Computing Facilities: As defined by P.L. 108-423 the Department of Energy Revitalization Act of 2004, “Leadership System” is a high-end computing system that is among the most advanced in the world in terms of performance in solving scientific and engineering problems. The Advanced Scientific Computing Research program in the Office of Science operates two leadership computing facilities at Argonne and Oak Ridge National Laboratories.

Nano-Scale Science: Nanoscale science is the science of understanding and controlling matter at extremely tiny dimensions spanning 1 to 100 nanometers (nm). For comparison, a fingernail grows about 1 nm in a second, and there are 25.4 million nm in an inch. Matter such as gases, liquids, and solids can exhibit unusual physical, chemical, and biological properties at the nanoscale, differing in important ways from the same material in bulk. These enhanced properties include increased strength, lighter weight, more control of the

light spectrum, and greater chemical sensitivity. Such phenomena result both from quantum effects, which rule particle behavior and properties at the nanoscale, and from the larger surface areas of nanomaterials. This increased surface area per mass allows more of the material to come into contact with surrounding materials. Many important chemical and electrical reactions occur only at surfaces and are sensitive to surface shape, texture, and chemical composition. Also, many nanoscale materials can spontaneously assemble into ordered structures, enabling atom-by-atom design of materials for specific purposes.

Oxycombustion: A process in which coal is burned in oxygen instead of in air, with the resulting exhaust containing only CO_2 and water vapor. Because it yields an almost 100 percent CO_2 stream that is readily transportable, the process has strong potential but is extremely energy-intensive.

Post-Combustion Capture: A carbon capture process in which the CO_2 is captured from flue gases (gases that are emitted as exhaust) after the fossil fuel has been burned. It is used mainly for conventional coal-fired power generation, but can also apply to combustion turbines and other combustion systems fired by natural gas.

Regional Carbon Sequestration Partnerships: A DOE-established network of seven regional partnerships to help develop the technology, infrastructure, and regulations to implement large-scale CO_2 storage (also called carbon sequestration) in different regions and geologic formations within the U.S. The Partnerships are comprised of more than 400 diverse organizations covering 43 states and four Canadian provinces.

Supercritical Carbon Dioxide: Supercritical Carbon Dioxide-based (sCO_2) power cycles, which utilize carbon dioxide, rather than steam, as a working fluid in a supercritical fluid state, have emerged as a technology capable of achieving significant improvements in electric power generation. sCO_2-based power cycles have shown the potential for increased heat-to-electricity conversion efficiencies, high power density, reduced size, and simplicity of operation compared to existing steam-based power cycles. In addition, sCO_2-based power cycles can be configured for a wide range of energy sources, making them applicable to several technologies and resources, including nuclear, fossil and solar-power based systems.

Ultra-Supercritical: Technology used in some coal-fired power plants to generate steam at a much higher pressure and temperature (more than 1,100 degrees F) than in conventional plants. The result is higher plant efficiencies, lower water use and reduced operating costs.

Appendices

Appendix 1: Fossil Energy R&D Budget Restructure Proposal

FOSSIL ENERGY R&D RESTRUCTURING

FY 2016 Structure	FY 2017 Structure	Changes in FY 2017
Fossil Energy R&D Coal CCS and Power Systems	**Fossil Energy R&D** CCS and Advanced Power Systems	Expanded to combine coal and natural gas technology applications.
Carbon Capture	Carbon Capture	* Advanced Combustion Systems moved from AES to Carbon Capture. * Natural Gas Carbon Capture subprogram added.
Carbon Storage	Carbon Storage	* Storage Infrastructure renamed from Storage Field Management. * Sub-disciplinary Storage R&D renamed Risk and Integration Tools.
Advanced Energy Systems (AES)	Advanced Energy Systems (AES)	* Advanced Combustion Systems moved from AES to Carbon Capture. * STEP moved under AES.
Cross Cutting Research	Crosscutting Research and Analysis	* Special Recruitment moved under Education and Outreach. * Several subprogram/activity consolidations.
STEP (Supercritical CO_2)		Moved under AES.
NETL Coal Research & Development		* R&D funds (including Rare Earth Elements funding) moved to new NETL Research and Operations line and consolidated with associated program direction. * Infrastructure projects moved to NETL Infrastructure line.
Natural Gas Technologies	Fuel Supply Impact Mitigation	* Emissions Mitigation from Midstream Infrastructure and Emissions Quantification from Natural Gas Infrastructure combined into Emissions Mitigation and Quantification subprogram.
Unconventional Fossil Energy Technologies	Unconventional Fossil Energy Technologies	No change.
*New Program	NETL Research and Operations	Combines NETL Coal Research and Development programs, but not infrastructure and associated Program Direction costs.
*New Program	NETL Infrastructure	Includes Supercomputer, Plant & Capital Equipment, Fossil Energy Environmental Restoration, and consolidates associated Program Direction costs.
Program Direction	Program Direction	Some funding moved to NETL Infrastructure and NETL Research and Operations.
Plant and Capital Equipment		Moved to NETL Infrastructure.
Fossil Energy Environmental Restoration		* Vast majority of funding moved to NETL Infrastructure. * Small portion of funding moved to Washington HQ Program Direction.
Supercomputer		Moved to NETL Infrastructure.
Special Recruitment Programs		Moved under Education and Outreach activity within Crosscutting Research and Analysis.

- In FY 2017, the Coal/CCS and Advanced Power Systems budget line item will be renamed Carbon Capture and Storage (CCS) and Advanced Power Systems to reflect that the research and development performed under this program is focused on developing CCS technologies and innovative power systems that reduce the costs of CCS for both coal and natural gas power generation.
    - Within CCS and Advanced Power Systems, Advanced Combustion Systems will move from Advanced Energy Systems to Carbon Capture because development of technologies such as pressurized oxy-combustion and chemical looping processes facilitate carbon capture.
    - A new Natural Gas Carbon Capture activity will be created under Carbon Capture.
    - The Storage Infrastructure activity within Carbon Storage will be renamed Storage Field Management to clarify that this activity is focused on demonstrating safe and permanent geologic storage of CO_2 and providing best practices for doing so.
    - The Sub-Disciplinary Storage R&D activity will be renamed Risk and Integration Tools to reflect that this activity centers on risk assessment and system model integration and validation.
    - The Supercritical Transformational Electric Power (STEP) activity will be moved under Advanced Energy Systems (AES) appearing as STEP (Supercritical CO2). This previously was a separate program but is being moved under AES as it is part of this broader portfolio of new fossil-fuel energy conversion systems integrated with CCS that may be capable of producing competitively priced electricity.
    - The Cross-Cutting Research activity will be renamed Crosscutting Research and Analysis (CRA). Proposed changes will streamline the budget structure and align activities that support related efforts under the same subprogram.
    - There are 6 subprograms proposed under CRA – Computational Sciences, Education and Outreach, Energy Evaluation and Analysis, Extreme Environment Materials, Sensors and Controls, and Water Management R&D.
        - Computational Sciences combines the former Computational System Dynamics and Focus Area for Computational Energy Science.
        - Education and Outreach is comprised of the University Coal Research, Historically Black Colleges and Universities (HBCUs) and Other Minority Institutions, Special Recruitment Programs, and International Activities sub-activities. Special Recruitment Programs was previously not part of the CCS and Power Systems budget. All university educational initiatives are now consolidated under Education and Outreach.
            - The former HBCUs Education and Training area is renamed HBCUs and Other Minority Institutions to better reflect the breadth of institutions supported.
            - International Activities combines the former Coal Technology Export and International Program Support areas.

        - Energy Evaluation and Analysis combines the former Environmental Activities and Technical and Economic Analysis lines.
        - Extreme Environment Materials combines the former Crosscutting Materials R&D and Advanced Ultra-supercritical R&D lines.
        - Sensors and Controls, which was formerly Sensors, Controls and Other Novel Concepts, remains under Crosscutting Research and Analysis. The shortening of the name does not reflect a change in programmatic content.
        - Water Management R&D remains under Crosscutting Research and Analysis.
- In FY 2017, the NETL Research and Operations program is new for FY 2017. This restructuring of NETL operational lines is proposed to better describe NETL's funding requirements, increase consistency with other national laboratories, and increase transparency in how funds are utilized, promoting enhanced visibility into cost drivers and more efficient resource allocation decisions.
    - The new NETL Research and Operations program includes certain funds that were part of the former NETL Coal Research and Development program as well as certain funds that were formerly in the NETL portion of Program Direction. The Research and Development funding supports salaries/benefits and travel for NETL staff directly associated with conducting both intramural and extramural research activities, funding for Federal employees and contractors who perform site operations at the laboratories, and for Federal employees and contractors performing research-enabling functions such as legal, finance, procurement, information technology, and human resources that are necessary for the performance of NETL activities.
- In FY 2017, the NETL Infrastructure line item will be created. This restructuring of NETL operational lines is proposed to better describe NETL's funding requirements, increase consistency with other national laboratories, and increase transparency in how funds are utilized, promoting enhanced visibility into cost drivers and more efficient resource allocation decisions.
    - This budget line includes the former Supercomputer, and Plant & Capital Equipment programs as well as the vast majority of the former Environmental Restoration line. It also includes portions of the NETL Coal Research and Development and Program Direction budget lines.
- In FY 2017, the Natural Gas Technologies line item will be renamed Fuel Supply Impact Mitigation.
    - The former Emissions Mitigation from Midstream Infrastructure and Emissions Quantification from Natural Gas Infrastructure subprograms are combined into a single Emissions Mitigation and Quantification subprogram to enable more effective program management and execution.
    - Environmentally Prudent Development subprogram will continue research in water quality, water availability, air quality, induced seismicity, and mitigating the impacts of development (e.g. wellbore integrity) in collaboration with DOI and EPA.

- The Gas Hydrates subprogram, through public sector-led efforts, will continue to evaluate the occurrence, nature, and behavior of naturally occurring gas hydrates and the resulting resource, hazard, and environmental implications.

Appendix 2: Global active CCS projects, the operation start (or anticipated in italics) date, and amount of CO_2 injected (per Global Carbon Capture and Storage projects database and Regional Carbon Sequestration Partnerships).

Project Name	Location	Project Start	Operation Date	CO_2 injected	Units	DOE cost
Air Products and Chemicals Inc. CCS Project *	United States	11/16/2009	2013	2,740	Tonnes/day	$284,012,496
Century Plant Gas Processing	United States	10/8/2010	2010	23,016	Tonnes/day	
CO_2 Capture from Coffeyville Fertilizer Plant	United States	1/1/2013	2013	2,400	Tonnes/day	
Hydrogen Energy California Project	United States	12/1/2019	*2020*	7,124	Tonnes/day	$286,000,000
ADM Illinois Industrial CCS Project	United States	11/6/2009	2016	2,740	Tonnes/day	$141,405,945
Kemper County IGCC Project	United States	11/17/2008	2016	8,220	Tonnes/day	$270,231,360
Oakdale NG Processing	United States	1/1/2007		1,096	Tonnes/day	
Purdy, Sho-Vel-Tum EOR Project	United States	1/1/2003		675,000	Total tonnes	
Searles Valley Minerals	United States	1/1/1978		740	Tonnes/day	
Summit Energy - Texas Clean Energy Project (TCEP)	United States	1/1/2010	*2019*	6,302	Tonnes/day	$345,776,323
Val Verde NG Plants	United States		1972	3,562	Tonnes/day	
W.A. Parish Post-Combustion CO_2 Capture and Sequestration Project (Petra Nova)	United States	6/1/2010	*2016*	3,836	Tonnes/day	$166,804,425
Taichung CCS	Taiwan	1/1/2014		10,000	Total tonnes	
Caledonia Clean Energy Project	United Kingdom		2022			
Don Valley Power Project	United Kingdom		2020			
Teesside Collective Project	United Kingdom		2020's			
BP-Peterhead Hydrogen Power Plant/Miller Field Project	United Kingdom	1/1/2011		2,740	Tonnes/day	
Abu Dhabi Emirates Steel Industries (ESI) CCUS Project	United Arab Emirates		2016			
OXYCFB300 Compostilla Project	Spain	1/1/2009		100,000	Total tonnes	
Korea CCS1	South Korea	1/1/2018		2,740	Tonnes/day	
South Korea CCS2	South Korea	10/16/2009		3,288	Tonnes/day	

Uthmaniyah CO2 EOR Demo Project	Saudi Arabia	1/1/2015	2015	2,192	Tonnes/day	
Kedzierzyn	Poland	2/1/2009		6,850	Tonnes/day	
Mongstad Cogeneration Plant with CO2 Storage	Norway	1/1/2010		274	Tonnes/day	
Snøhvit Field LNG and CO2 Storage Project	Norway	4/22/2008		1,918	Tonnes/day	
CATO1 - Rotterdam ROAD project	Netherlands	1/1/2015		3,014	Tonnes/day	
Enecogen Cryogenic CO2 Capture	Netherlands	1/1/2013		25	Tonnes/day	
K12-B CO2 Injection Project	Netherlands	5/1/2004		55	Tonnes/day	
Nuon Magnum IGCC Plant with Capture Option	Netherlands	1/1/2012				
PEMEX CCS Project	Mexico	1/1/2004		8,459,550	Total tonnes	
Enel Brindisi CCS Project	Italy	1/1/2010		22	Tonnes/day	
Eni and Enel CCS Project	Italy	9/1/2010		22	Tonnes/day	
Veolia Environment CCS Project	France	1/1/2013		548	Tonnes/day	
Greengen Project in China	China	12/1/2009				
Japan-China EOR Project	China	1/1/2009		2,740	Tonnes/day	
Ordos Basin Project	China	12/30/2008		9,590	Tonnes/day	
China Resources Power (Haifeng) Integrated CCS Demonstration Project	China		*2019*			
Huaneng GreenGen IGCC Project	China		*2020*			
PetroChina Jilin Oil Field EOR Project	China		*2017*			
Shanxi International Energy Group CCUS Project	China		*2020*			
Shenhua Ningxia CTL Project	China		*2020*			
Shenhua Ordos CTL Project	China		*2020*			
Sinopec Qilu Petrochemical CCS Project	China		*2017*			
Sinopec Shengli Power Plant CCS Project	China		*2018*			
Yanchang Integrated CCS Demonstration Project	China		*2017*			
Alberta Carbon Trunk Line	Canada	1/1/2012	*2016-2017*	40,004	Tonnes/day	
Aquistore Project	Canada	1/1/2009		1,000	Tonnes/day	
Boundary Dam Integrated CCS Project	Canada	1/1/2014	2014	2,740	Tonnes/day	
Bow City Power Project	Canada	1/1/2011		2,740	Tonnes/day	
Northwest Upgrader Refinery	Canada	1/1/2011		3,288	Tonnes/day	
Quest	Canada		2015	3,013	Tonnes/day	

Great Plains Synfuel Plant and Weyburn-Midale Project	Canada		2000			
Petrobras Lula Oil Field Offshore CCS Project	Brazil	3/1/2011	2013	1,918	Tonnes/day	
Petrobras Miranga CO2 injection	Brazil	1/1/2009		400	Tonnes/day	
Collie South West Hub Project	Australia	6/1/2009		6,850	Tonnes/day	
CS Energy Callide Oxyfuels Project	Australia	3/1/2006		82	Tonnes/day	
Gorgon Project	Australia	1/1/2009	*2017*	9,042	Tonnes/day	
Hazelwood Post-Combustion 2030 Project	Australia	12/1/2008		50	Tonnes/day	
Otway Basin Project - CO2CRC	Australia	4/2/2008		65,000	Total tonnes	
Tarong Plant Algae Oil Project	Australia	1/1/2013		2	Tonnes/day	
In Salah CO2 Storage	Algeria		2004-2011	3,013	Tonnes/day	
CO2EuroPipe	Europe	4/1/2009				
Regional Carbon Sequestration Partnerships						
MGSC Development Phase - Illinois Basin Decatur Project	United States	1/1/2010	2011-2014	999,215	Total tonnes	$108,233,845
Farnsworth Unit Project (SWP) *	United States	10/1/2007	2013	1,000,000	Total tonnes	$65,618,315
MRCSP Development Phase - Michigan Basin Project	United States	10/1/2005		1,000,000	Total tonnes	$89,267,913
SECARB Development Phase - Cranfield Project	United States	2007-10	2008-11	4,743,898	Total tonnes	
SECARB Development Phase - Citronelle Project	United States	9/22/2007	2014-09	114,104	Total tonnes	$129,910,744
SECARB Development Phase - Citronelle Project	United States	9/22/2007		114,104	Total tonnes	$95,059,185
PCOR Development Phase - Bell Creek Project	United States	10/1/2007		2,740	Tonnes/day	$95,453,751