U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Advancing Coal Research and Development for a Secure Energy Future

Thursday, October 13, 2011
2:00 p.m. to 4:00 p.m.
2318 Rayburn House Office Building

Purpose

On Thursday, October 13, 2011, at 2:00 p.m. in Room 2318 of the Rayburn House Office Building, the Subcommittee on Energy and the Environment will hold a hearing titled *"Advancing Coal Research and Development for a Secure Energy Future."* The purpose of this hearing is to examine current Department of Energy (DOE) coal research, development, and demonstration (RD&D) activities and identify future coal RD&D opportunities and priorities.

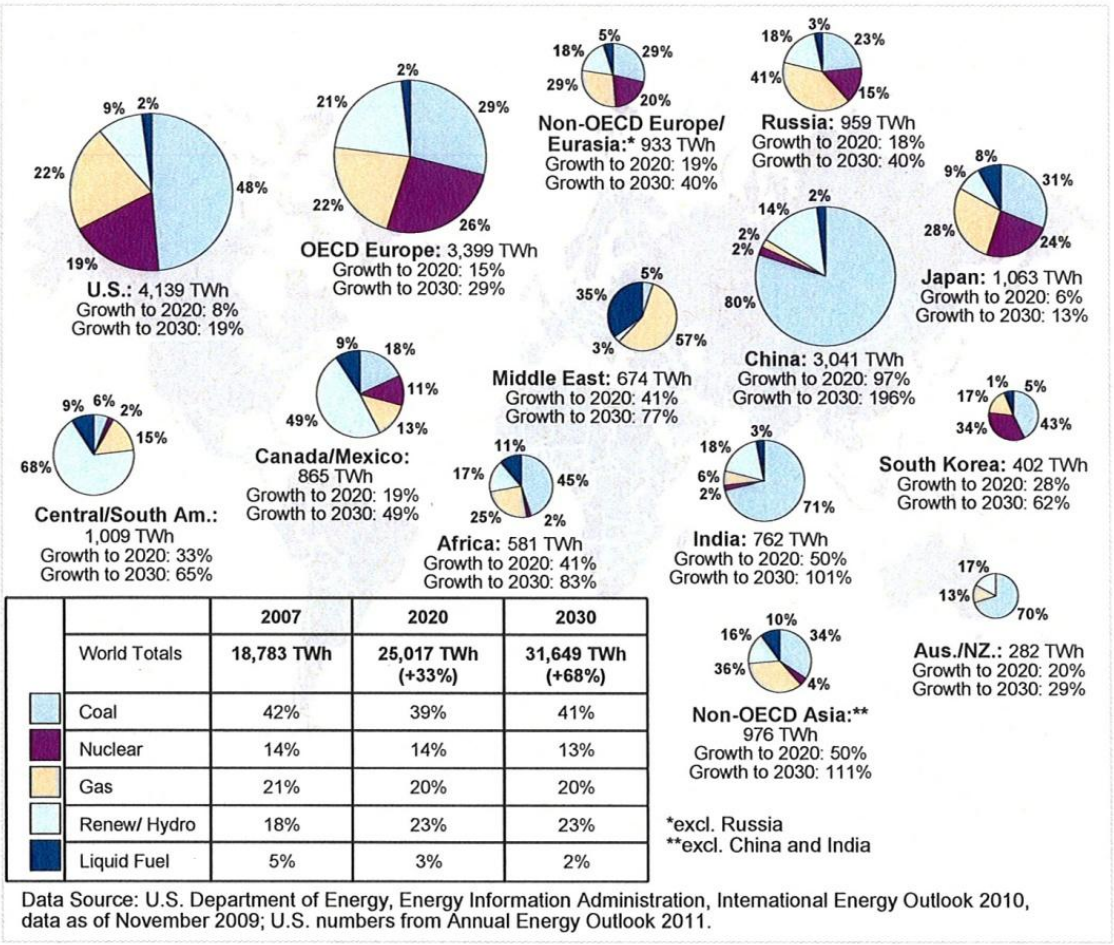
Witnesses

- **Mr. Scott Klara**, Deputy Director, National Energy Technology Laboratory
- **Ms. Janet Gellici**, Chief Executive Officer, American Coal Council
- **Mr. Nick Akins**, President, American Electric Power
- **Mr. David Foerter**, Executive Director, Institute of Clean Air Companies
- **Mr. Stu Dalton**, Senior Government Representative-Generation, Electric Power Research Institute

Overview

According to the Energy Information Administration (EIA), the United States currently generates approximately 45% of its electricity from coal-fired power plants.[1] EIA projects nationwide demand for electricity to increase 31% by 2035, with coal generation growing by 25% during this time. Globally, coal-fired generation currently produces over 40% of electricity,[2] and proven global coal reserves are estimated to be sufficient to last 118 years.[3] In 2010, 11 new coal-fired plants were commissioned in the United States, totaling 6,682 MW.[4]

[1] Energy Information Administration, "*Annual Energy Outlook 2011,"* April 2011. Accessible at: http://www.eia.gov/forecasts/aeo/
[2] International Energy Agency, *"2011 Key World Energy Statistics,"* 2011. Accessible at: http://www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf
[3] World Coal Institute, *"Coal Statistics,"* August 2011. Accessible at: http://www.worldcoal.org/resources/coal-statistics/
[4] National Energy Technology Laboratory, *"Tracking New Coal-Fired Power Plants,"* January 14, 2011. Accessible at: http://www.netl.doe.gov/coal/refshelf/ncp.pdf



	2007	2020	2030
World Totals	18,783 TWh	25,017 TWh (+33%)	31,649 TWh (+68%)
Coal	42%	39%	41%
Nuclear	14%	14%	13%
Gas	21%	20%	20%
Renew/ Hydro	18%	23%	23%
Liquid Fuel	5%	3%	2%

Data Source: U.S. Department of Energy, Energy Information Administration, International Energy Outlook 2010, data as of November 2009; U.S. numbers from Annual Energy Outlook 2011.

Figure 1-1
Electricity Generation by Fuel Type for Major Countries and Regions

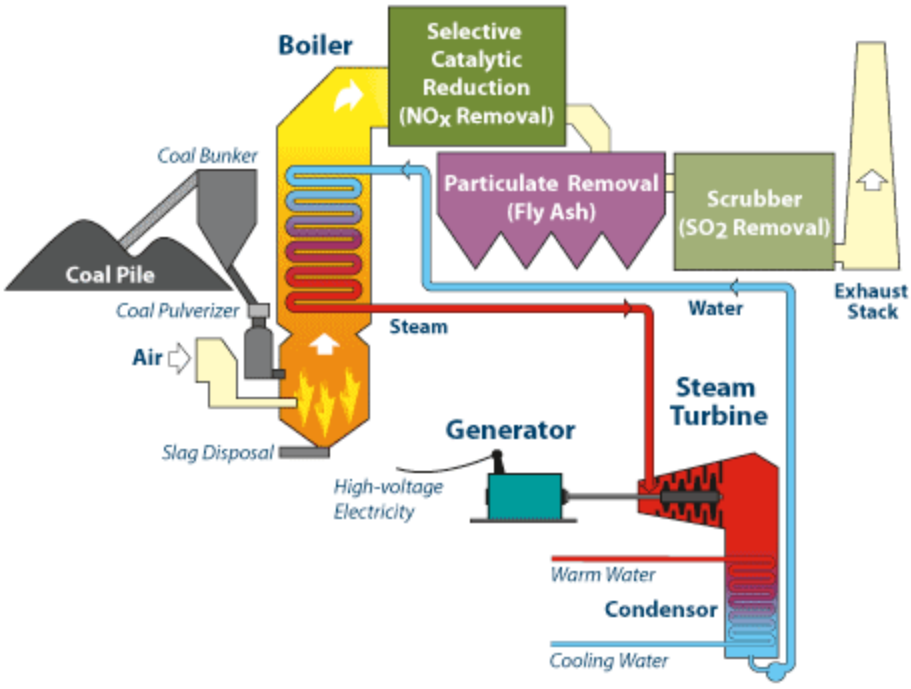
[5]

Key Components of Coal-fired Generation Plants

A number of variables contribute to the overall efficiency of a coal power plant. Key factors effecting overall plant performance and efficiency include the type of power cycle, combustion technology, and coal type employed. Typically as plants increase efficiency levels, fuel costs decrease, fewer traditional pollutants (such as SOx, NOx, particulate matter, and mercury) are emitted, less carbon dioxide is emitted, and water use per megawatt hour (MWh) decreases. For example, a gain of two percentage points in plant efficiency reduces the amount of fuel consumed by roughly 5% and provides similar reductions in CO_2 emissions.[6]

[5] Electric Power Research Institute, *"Advanced Coal Power Systems with CO2 Capture: EPRI's CoalFleet for Tomorrow Vision – 2011 Update,*" August 2011. P. 1-2
[6] EPRI CoalFleet for Tomorrow, p. 3-3.

Typical Coal-Fired Power Plant[7]



Steam Power Cycles

Steam power cycles reference the thermodynamic state of steam driving the turbines to produce electricity. As pressure and temperature increase, plants operate more efficiently. Cycles are classified[8] as:

- Subcritical—steam cycles with pressure levels of 2600 pounds per square inch absolute (psia) and steam temperatures of approximately 1000°F (538°C). Approximate efficiency, expressed as higher heating value (HHV): 34.3%[9];
- Supercritical—steam cycles, with steam conditions of 3500 psia and main steam temperatures of 1050°F (565°C). Approximate HHV efficiency: 38.5%;
- Ultra-Supercritical[10]—steam cycles with steam pressure greater than 3625 psia and steam temperatures greater than 1100°F (595°C). Approximate HHV efficiency: 43.3%. and
- Advanced" Ultra-Supercritical[11] with steam temperatures up to 1400°F (760°C). Approximate HHV efficiency: 47%.

Combustion Technologies

Many different approaches are used to combust coal to boil water, which generates steam. Combustion technologies include:

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[7] Partha Das Sharma, 2008.
[8] As defined by the EPRI CoalFleet for Tomorrow, p. 2-3.
[9] Massachusetts Institute of Technology, *"The Future of Coal,"* 2007. Accessible at: http://web.mit.edu/coal/The_Future_of_Coal.pdf
[10] A limited number of Ultra-Supercritcial plants are under construction globally.
[11] No current material exists resilient enough to withstand the high temperatures for sustained periods of time.

- Pulverized coal (PC) boilers, which are the most common combustion technology in existing plants and can be used with all steam power cycles currently in existence. PC boilers burn ground coal in a furnace for rapid combustion;
- Fluidized bed combustion (FBC), which burn coal in a bed of particles suspended in motion by combustion air;
- Circulating fluidized-bed combustion (CFBC), which build on FBC technology to accommodate higher heat and pressure steam cycles;
- Oxy-combustion boilers, which use separated oxygen to mix with recirculated flue gas to increase CO_2 concentrations. The CO_2-rich flue gas can be captured and easily compressed. No oxy-combustion commercial plants have yet been commissioned; however a number of oxy-combustion projects are under consideration.

Additionally, approximately ten integrated gasification combined-cycle (IGCC) plants are in operation globally. IGCC plants pair a gas turbine combined-cycle with a gasification unit to produce syngas from coal. Combined-cycle generation recovers heat from the hot exhaust of a gas turbine and produces steam to produce additional power.

Coal Types

Three types of coal are burned to produce electricity: bituminous, sub-bituminous, and lignitic. Each coal type has unique burn characteristics, which are matched with a specific coal-fired unit. Furnace size, boiler designs, and other power plant systems must align to optimally burn coal and produce power efficiently.

New Generation[12]

Technology Listings	**Operational (Since 2000)***	**Progressing (Permitted, Near, and Under Construction)***	**Announced***	**Total Proposed***
PC Subcritical	31	5	10	15
FBC	12	4	9	13
PC Supercritical	7	7	4	11
IGCC	1	5	13	18

*As of December 2010

Coal Research, Development & Demonstration Technology Issues

Areas of opportunity for RD&D exist throughout the entire generation system. Technological challenges and opportunities related to individual components typically impact an entire plant's operation and performance and thus must be pursued with the overall system in mind.

Carbon Capture and Sequestration

Current coal RD&D is primarily focused on efforts relating to carbon capture and storage (CCS). CO_2 can be captured using a variety of methods and either pre or post-combustion. Once CO_2 is

[12] NETL, *"Tracking New Coal-Fired Power Plants."*

captured, it must be condensed, transported, and stored in a geologic formation for an indefinite time period. According to DOE:

> "Existing CO_2 capture technologies are not cost-effective when considered in the context of large power plants. Economic studies indicate that carbon capture will add over 30 percent to the cost of electricity for new integrated gasification combined cycle (IGCC) units and over 80 percent to the cost of electricity if retrofitted to existing pulverized coal (PC) units. In addition, the net electricity produced from existing plants would be significantly reduced - often referred to as parasitic loss - since 20 to 30 percent of the power generated by the plant would have to be used to capture and compress the CO_2."[13]

DOE's current goal is to limit the additional cost of electric generation on a pulverized coal CCS plant to 30 percent, and 10 percent for an IGCC CCS plant.[14] Further, water use per MWh is expected to increase by 30-90% when a CO_2 system is installed.[15] Each portion of the CCS process needs additional RD&D to effectively demonstrate CCS technologies.

Enhanced Oil Recovery

CO_2 has been effectively used in a process known as enhanced oil recovery (EOR). EOR injects CO_2 into a previously depleted oil well, forcing additional pressure into the formation to extract oil unrecoverable using traditional extraction methods. A number of projects are underway in which a coal plant is sited near depleted oilfields for the sole purpose of providing CO_2 for EOR. EOR provides economic value for captured CO_2 and offers a potential revenue stream to offset some of the additional costs incurred in a coal-fired CCS system.

Efficiency

A significant hurdle to increasing plant efficiency is the lack of advanced materials resilient enough to withstand the high heat conditions for extended time periods. Various metal composites, such as nickel-based alloys and certain types of steel, have the necessary characteristics to allow higher firing temperatures, however such alloys are currently cost prohibitive. Further advances in materials research are needed to move beyond current plant efficiency limits.

Another opportunity to increase output of coal-fired plants rests with improving turbine efficiency. Larger blade sizes, new material, and gas turbine design optimization can result in increased output at greater efficiency rates. Incremental gains in turbine efficiency have significant impacts on the fleet of coal-fired plants, due to the size of each plant.

Water

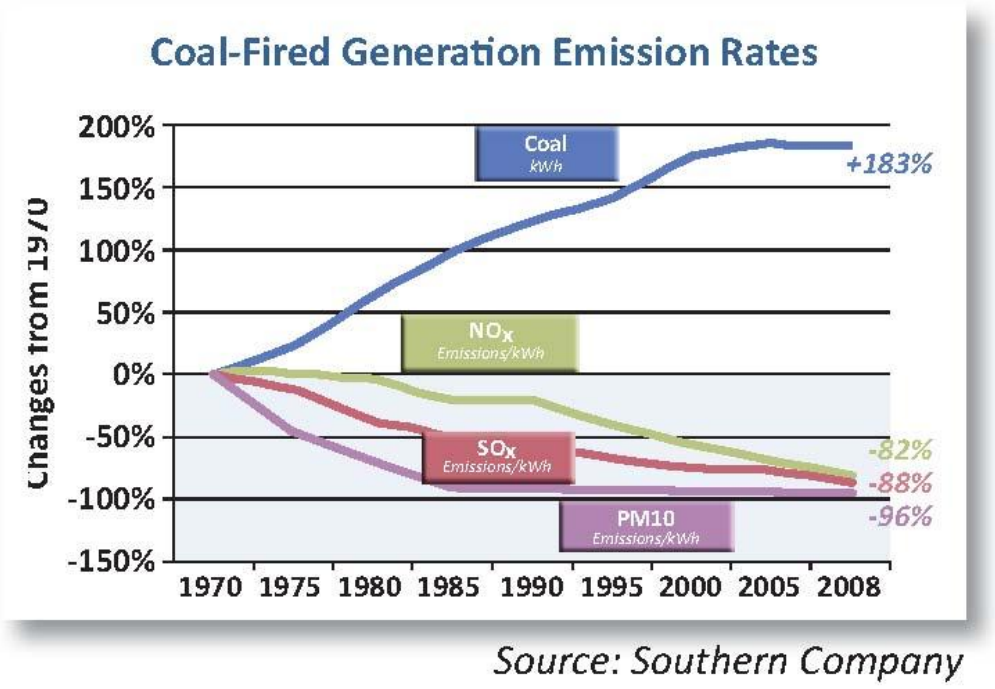
Water availability is of growing concern in certain regions of the United States and RD&D opportunities exist to reduce overall water impact. Supercritical PC plants use over nine gallons of water per minute for each MW of output (gpm/MW). That number rises to over 17 gpm/MW

[13] Department of Energy, "Retrofitting the Existing Coal Fleet with Carbon Capture Technology." Accessible at: http://fossil.energy.gov/programs/powersystems/pollutioncontrols/Retrofitting_Existing_Plants.html
[14] Department of Energy, "Carbon Capture and Storage R&D Overview." Accessible at: http://fossil.energy.gov/programs/sequestration/overview.html
[15] EPRI CoalFleet for Tomorrow, p. 7-1

if CCS is included.[16] IGCC units consume between six and ten gpm/MW which can increase to 16 gpm/MW with CCS. RD&D opportunities exist to reduce impact on water supply through various technology development. For example, optimizing steam cycles or using cooler condensers to lower steam backpressure would reduce water use.

Pollutant Control

While coal use has increased considerably in the last thirty years, traditional criteria pollutant emissions have significantly decreased due to increased effectiveness of pollutant control systems. The reduction in pollutants has been driven by the availability and installation of a number of pollutant control systems, such as flue gas desulfurization systems (commonly known as "scrubbers") to remove SO_2, post-combustion control technologies to remove NOx, or fabric filters (baghouses) to limit particulate matter. Technological advances in these areas could enable cost-effective compliance with continually tightening coal-related environmental regulations.



Source: Southern Company

More broadly, a wide range of related RD&D can advance the use of coal, lessen the associated environmental impact, and improve plant efficiency. Engineered coal fuels consist of pre-treated coal to increase the energy content of the fuel, reduce the total amount of flue gases to be remove pollutants, and improve power plant efficiency. Opportunities also exist to improve system modeling to enable development of computational tools aimed at improving integration of system components and optimizing plant performance.

[16] EPRI CoalFleet for Tomorrow p. 7-2

Department of Energy's Coal Research and Development Activities

The Department of Energy funds a variety of coal research, development, and demonstration activities. DOE's Office of Fossil Energy (FE) is the primary office supporting coal RD&D. DOE's coal program mission is to "ensure the availability of near-zero atmospheric emissions, abundant, affordable, domestic energy to fuel economic prosperity, strengthen energy security, and enhance environmental quality."[17]

DOE Coal RD&D Budget (in thousands)

DOE Coal Programs and Subprograms	**FY 10 Appropriated**	**FY 11 CR**	**FY 12 Request**	**FY 12 House Approps Subcommittee Mark**	**FY 12 Senate Approps Subcommittee Mark**
Fuels and Power Systems Program Total	**403,078**	**400,165**	**0**	**n/a**	**n/a**
Innovations for Existing Plants	*52*	*64.8*	*0*		
Advanced Integrated Gasification Combined Cycle	*63*	*52.9*	*0*		
Advanced Turbines	*32*	*30.9*	*0*		
Carbon Sequestration	*154*	*142.0*	*0*		
Fuels	*25*	*12.0*	*0*		
Fuel Cells	*50*	*49.8*	*0*		
Advanced Research	*27.078*	*47.6*	*0*		
CCS and Power Systems Program Total	**0**	**n/a**	**291,358**	**338,762**	**291,358**
Carbon Capture	*0*	*n/a*	*68,938*		
Carbon Storage	*0*	*n/a*	*115,477*		
Advanced Energy Systems	*0*	*n/a*	*64,193*	*105*[*]	
Cross Cutting Research	*0*	*n/a*	*42,750*	*49,347*	
TOTAL: Coal	**403,078**	**400,165**	**291,358**	**338,762**	**291,358**
TOTAL: Fossil Energy Research and Development	**672,383**	**444,528**	**452,975**	**476,993**	**445,471**

* Of this amount, the recommendation includes not less than $25 million to continue RD&D of solid oxide fuel cell systems, $5 million for High Performance Materials, and $10 million for the Coal and Coal-Biomass to Liquids Program. The recommendation also includes $8 million for continuing activities improving advanced air separation technologies, found within Gasification Systems, a subprogram of Advanced Energy Systems.

[17] Department of Energy, *"Department of Energy's Office of Fossil Energy: Budget in Brief FY12,"* February 2011. Accessible at: http://fossil.energy.gov/aboutus/budget/12/budget_in_brief_fy2012.pdf

In Fiscal Year (FY) 2011, FE received $444 million, of which $400 million was directed to coal RD&D. A recent study by Management Information Systems estimated FE's RD&D program would result in a benefit of $111 billion between 2000-2020, a 13 to 1 return for each dollar spent.[18]

The National Energy Technology Laboratory (NETL) is the primary energy research facility for FE. NETL conducts a broad spectrum of fossil energy research and administers FE's coal RD&D activities. NETL's coal RD&D programs fall into three categories: "technologies that enable existing coal power plants to cost-effectively meet environmental requirements, technologies for coal power plants of the future with dramatically improved performance, and clean coal demonstration projects."[19]

FE's coal RD&D consists of the Clean Coal Power Initiative (CCPI), which fund demonstration projects, and the Fuels and Power Systems program. The Fuels and Power Systems program currently consists of seven subprograms: Innovations for Existing Plants (IEP), advanced integrated gasification combined cycle, advanced turbines, carbon sequestration, fuels, fuels cells, and advanced research.

The Administration proposes to restructure the coal RD&D program in the FY 2012 budget request. FE explains:

> The proposed budget structure change reflects the increased focus of the program on Carbon Capture and Storage technologies. The new budget structure aligns the existing work of the Clean Coal program with four key sub-program research areas: Carbon Capture, Carbon Storage, Advanced Power Systems, and Cross-cutting Research.[20]

The program restructuring would shift the IEP subprogram to the carbon capture subprogram and the turbines, fuels, and fuels cells activities will be conducted by the advanced power systems subprogram. The cross-cutting research subprogram would consist primarily of the computational system dynamics ($11.8 million requested) and computational energy science ($13.4 million requested). The full explanation of the restructuring is included in Appendix A.

Additionally, the budget request proposes to eliminate or significantly reduce a number of coal RD&D activities. The proposal requests $973,000 for high performance materials research, down from $8.8 million in FY10. Hydrogen turbines funding request is $14.5 million, less than half the $31.2 million received in FY10. The budget request seeks to eliminate the coal and coal-biomass to liquids, solid oxide fuel cells, water management, and fine particulate control/air toxics programs.

FE currently is funding a portfolio of eight CCS demonstration projects. The American Recovery and Reinvestment Act (ARRA) provided $3.4 billion for CCS, of which the vast

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[18] Department of Energy, "*Fossil Energy Research Benefits,*" June 2011. Accessible at: http://www.fossil.energy.gov/aboutus/history/researchsuccesses/ReturnInvest_FC_HRes_draft2.pdf

[19] National Energy Technology Laboratory, Coal and power Systems. Accessible at: http://www.netl.doe.gov/technologies/coalpower/index.html

[20] Department of Energy 2012 Congressional Budget. Accessible at: http://fossil.energy.gov/aboutus/budget/12/FY2012_Coal_Budget_Structure.pdf

majority ($3.2 billion) was for nine large-scale demonstration projects. These demonstrations included carbon capture from coal-fired power plants (five), industrial sources (three), and FutureGen 2.0 (one). Typically, cost-sharing for these demonstration projects is 50-50 between DOE and industry. Currently, all of the projects are still in initial stages and are conducting engineering and technical activities. The full list of these projects is included in Appendix B.

Funding for CCS extends beyond FE. The Advanced Research Projects Agency – Energy (ARPA-E) issued a Funding Opportunity Announcement titled "Innovative Materials & Processes for Advanced Carbon Capture Technologies" (IMPACCT) in April 2010. IMPACCT seeks to reduce the costs associated with CCS through new materials research, improvements to existing processes, and demonstration of new capture processes. Fifteen awards totaling $30.6 million were disbursed (Appendix C).

The Administration has focused on CCS issues throughout multiple agencies. On February 3, 2010, President Obama established an Interagency Task Force on Carbon Capture and Storage, consisting of 14 Executive Departments and Federal Agencies. The Task Force issued their "Report of the Interagency Task Force on Carbon Capture and Storage" in August 2010. The Executive Summary noted:

> While there are no insurmountable technological, legal, institutional, regulatory or other barriers that prevent CCS from playing a role in reducing GHG emissions, early CCS projects face economic challenges related to climate policy uncertainty, first-of-a-kind technology risks, and the current high cost of CCS relative to other technologies. Administration analyses of proposed climate change legislation suggest that CCS technologies will not be widely deployed in the next two decades absent financial incentives that supplement projected carbon prices. In addition to the challenges associated with cost, these projects will need to meet regulatory requirements that are currently under development. Long-standing regulatory programs are being adapted to meet the circumstances of CCS, but limited experience and institutional capacity at the Federal and State1 level may hinder implementation of CCS-specific requirements. Key legal issues, such as long-term liability and property rights, also need resolution. [21]

The Environmental Protection Agency (EPA) also has taken action to facilitate the development of CCS. For example, EPA recently proposed a rule to exclude CO_2 streams from EPA's hazardous waste regulations under the Safe Drinking Water Act.[22]

[21] *"Executive Summary: Report of the InteragencyTask Force on Carbon Capture and Storage,"* August 2010. Accessible at: http://www.fe.doe.gov/programs/sequestration/ccstf/es_ccstf_2010.pdf

[22] Environmental Protection Agency, *"EPA Takes Action on Reducing Barriers to the use of Carbon Capture and Sequestration Technologies,"* August 4, 2011. Accessible at: http://yosemite.epa.gov/opa/admpress.nsf/0/FDE8D083AF16268E852578E10080F49B

Appendix A

New Budget Structure for Clean Coal Program The Office of Fossil Energy's Clean Coal program has a new budget structure for FY 2012. The changes better reflect the increased focus within the Clean Coal program on carbon capture and storage technologies. The new budget structure will align the existing work of the Clean Coal program to four key areas: Carbon Capture, Carbon Storage, Advanced Clean Energy Systems, and Cross-cutting Research. A comparison of the old and new budget structures is shown below.

Old Structure
CLEAN COAL POWER INITIATIVE
FUELS AND POWER SYSTEMS
INNOVATIONS FOR EXISTING PLANTS (IEP)
CO2 Carbon Capture and Storage
Fine Particulate Control/Air Toxics
By-Products and Water Management
CARBON SEQUESTRATION
Greenhouse Gas Control
Focus Area for Carbon Sequestration Science
IGCC
Gasification Systems Technology
Systems Analysis/Product Integration
ADVANCED TURBINES
Hydrogen Turbines
FUELS
Hydrogen from Coal
Coal and Coal-Biomass to Liquids
FUEL CELLS
Innovative Systems Concepts/SECA
ADVANCED RESEARCH
Coal Utilization Science (CUS)
Sensors and Controls - Novel Innovations
Computational System Dynamics
High Performance Materials
Coal Technology Export
Bioprocessing of Coal
Environmental Activities
Technical & Econ. Analyses
International Prog. Support
Focus Area for Computational Energy Science
University Coal Research
HBCUs, Education & Training

New Structure Beginning in FY 2012 New Program (*Old Program*)
CCS DEMONSTRATIONS *(CCPI, FutureGen 2.0, Industrial CCS)*
CCS AND POWER SYSTEMS *(Fuels and Power Systems)*
CARBON CAPTURE
Post-Combustion Capture *(Innovations for Existing Plants)*
Pre-Combustion Capture *(Sequestration)*
CARBON STORAGE
Regional Carbon Sequestration Partnerships/Storage Projects *(Sequestration)*
Geologic Storage Technologies *(Sequestration)*
Monitoring, Verification, Accounting, and Assessment *(Sequestration)*
Carbon Use and Reuse *(Sequestration)*
Focus Area for Carbon Sequestration Science *(Sequestration)*
ADVANCED ENERGY SYSTEMS
Advanced Combustion Systems *(IEP and Advanced Research)*
Gasification Systems *(IGCC)*
Hydrogen Turbines *(Advanced Turbines)*
CROSS CUTTING RESEARCH
Fine Particulate Control / Air Toxics *(IEP)*
By Products / Water Management *(IEP)*
Sensors and Controls *(Advanced Research)*
Systems Analysis/Product Integration *(Advanced Research)*
Coal Utilization Science
Computational System Dynamics *(Advanced Research)*
Computational Energy Science *(Advanced Research)*
Energy Analyses
Bioprocessing of Coal *(Advanced Research)*
Environmental Activities *(Advanced Research)*
Technical & Econ. Analyses *(Advanced Research)*
International Activities
International Prog. Support *(Advanced Research)*
Coal Technology Export *(Advanced Research)*
University Training and Research
University Coal Research *(Advanced Research)*
HBCUs, Education & Training *(Advanced Research)*

Appendix B

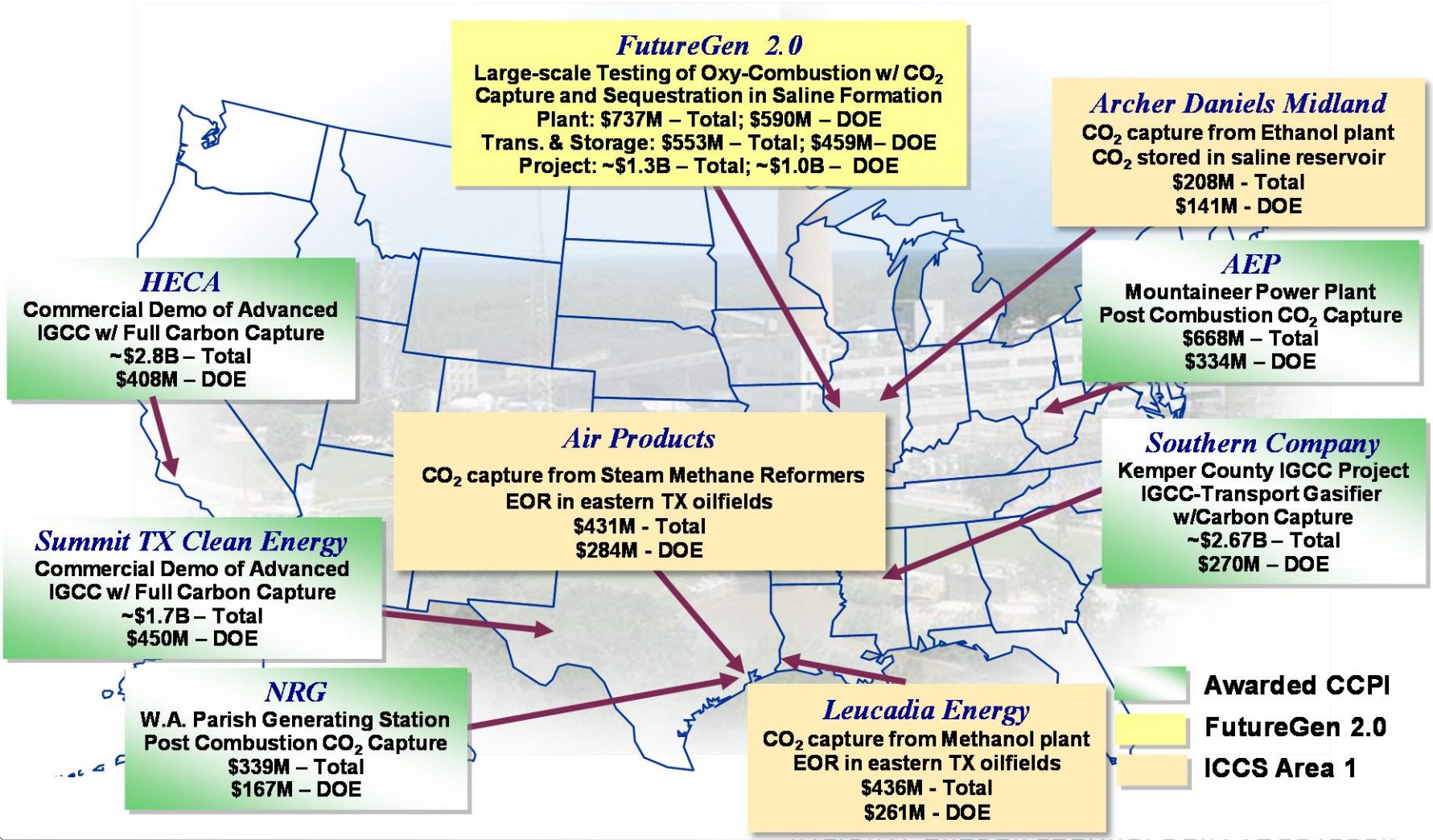
DOE CCS Projects and Costs (in Thousands)

Current as of June 2011

Program	Project	Recipient	CO2 Capture Technology	Sequestration	DOE Share	Non-DOE Share	Total Cost	Start Date
CCPI-2	Kemper	SCS	Selexol	EOR	$293,750	$1,331,332	$1,625,082	2014
CCPI-3	WA Parish	NRG	Fluor Econamine FG Plus	EOR	$166,804	$166,804	$333,608	2014
CCPI-3	TCEP	Summit	Rectisol	EOR	$450,000	$1,276,628	$1,726,628	2014
CCPI-3	Mountaineer	AEP	Chilled Ammonia Process	Saline	334,000	$334,000	668,000	2015
CCPI-3	HECA	HECA	TBD	EOR	308,000	$2,531,577	$2,839,577	TBD
ICCS	SMR H2 Production	APCI	VSA	EOR	284,012	146,636	$430,648	2012
ICCS	Fermentation CO2	ADM	Dehydration	Saline	$141,405	$66,536	207,942	2013
ICCS	Methanol from Petcoke Gasification	Leucadia Energy, LLC	Rectisol	EOR	$261,382	$174,204	$435,587	2014
FuturGen	Futuregen 2.0	Ameren, FGA	Oxycombustion with CO2 Purification	Saline	$1,000,000,000	$300,000	$1,300,000	2016

*CCPI = Clean Coal Power Initiative *ICCS = Industrial Carbon Capture & Storage

CCS Demonstration Projects
Locations & Cost Share



Appendix C
ARPA-E: Innovative Materials & Processes for Advanced Carbon Capture Technologies (IMPACCT)[23]

Coal-fired power plants generate approximately 45 percent of electricity for the United States. While coal is a cheap and abundant natural resource, continued use of coal as an energy source will lead to increasing levels of greenhouse gases as carbon dioxide is released into the atmosphere. Capturing the emitted carbon dioxide and storing it would enable the continued use of domestic coal resources while reducing greenhouse gas emissions into the atmosphere. The primary challenge is the current cost of capturing carbon dioxide from a coal power plant, which is unacceptably high.

The IMPACCT program seeks to reduce the cost of carbon capture significantly through a combination of new materials, improvements to existing processes, and demonstration of new capture processes. Fifteen high-risk, high-reward projects are underway among a group of universities, businesses, and national laboratories. IMPACCT is pushing the boundaries of carbon capture research through technologies such as new liquid chemistries that dissolve carbon dioxide and a capture system inspired by jet engines that transforms carbon dioxide from a gas into pellets of dry ice. If successful, the IMPACCT program will secure the continued use of America's coal infrastructure without further increases in harmful greenhouse gas emissions.

Awardee	**Amount**	**Technology**
Codexis Inc.	$4,657,045	Solvents / Catalysts
Texas A&M	$1,019,874	Sorbents
Massachusetts Institute of Technology	$1,000,000	Sorbents
University of Kentucky- Center for Applied Energy Research	$1,955,078	Membranes / Solvents
GE Global Research Center	$3,017,511	Phase Change
Lawrence Livermore National Laboratory	$3,665,000	Solvents / Catalysts
Lawrence Berkeley National Laboratory	$3,663,696	Sorbents
Georgia Institute of Technology	$1,000,000	Membranes
Notre Dame University	$2,559,563	Phase Change
ATK	$1,000,000	Phase Change
Columbia University	$1,014,707	Solvents / Catalysts
University of Colorado at Boulder	$3,144,646	Membranes
Oak Ridge National Laboratory	$987,547	Sorbents
Research Triangle Institute	$2,000,000	Solvents

[23] From Funding Opportunity Announcement II – April 29, 2010. Accessible at: http://arpa-e.energy.gov/ProgramsProjects/IMPACCT.aspx