Fossil Forward: Revitalizing CCS
Bringing Scale and Speed to CCS Deployment

January 2015

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The National Coal Council is a Federal Advisory Committee to the U.S. Secretary of Energy.
The NCC advises, informs and makes recommendations to the Secretary on matters requested by the Secretary relating to coal or the coal industry.
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The National Coal Council (NCC) was chartered in 1984 based on the conviction that an industry advisory council on coal could make a vital contribution to America's energy security. NCC's founders believed that providing expert information could help shape policies relevant to the use of coal in an environmentally sound manner. It was expected that this could, in turn, lead to decreased dependence on other less abundant, more costly, less secure sources of energy.

These principles continue to guide and inform the activities of the Council. Coal has a vital role to play in the future of our nation's electric power and energy needs. Our nation's primary energy challenge is to find a way to balance our social, economic and environmental needs.

Throughout its 30-year history, the NCC has maintained its focus on providing guidance to the Secretary of Energy on various aspects of the coal industry. NCC has retained its original charge to represent a diversity of perspectives through its varied membership and continues to welcome members with extensive experience and expertise related to coal.

The NCC serves as an advisory group to the Secretary of Energy, chartered under the Federal Advisory Committee Act (FACA), providing advice and recommendations to the Secretary of Energy on general policy matters relating to coal and the coal industry. As a FACA organization, the NCC does not engage in lobbying activities.

The principal activity of the NCC is to prepare reports for the Secretary of Energy at his/her request. During its 30-year history, the NCC has prepared more than 30 studies for the Secretary, at no cost to the Department of Energy. All NCC studies are publicly available on the NCC website.

Members of the NCC are appointed by the Secretary of Energy and represent all segments of coal interests and geographic distribution. The NCC is headed by a Chair and Vice Chair who are elected by its members. The Council is supported entirely by voluntary contributions from NCC members and receives no funds from the federal government. Studies are conducted solely at the expensive of the NCC and at no cost to the government.

The National Coal Council values the opportunity to represent the power, the pride and the promise of our nation's coal industry.

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The Secretary of Energy
Washington, DC 0585

May 15, 2014

Mr. John Eaves
Chairman
The National Coal Council
1730 M Street NW, Suite 907
Washington, DC 20036 Dear

Chairman Eaves:

I am writing to request the National Coal Council (NCC) conduct a study that assesses the value of the Department of Energy's Carbon Sequestration Program. The capture of carbon dioxide (C02) emissions from the combustion of fossil fuels used in electrical power generation is critical to the future of fossil fuels, particularly coal, used in this country.

The assessment would address the following question: what is the industry's assessment of the progress made by the DOE and others regarding cost, safety, and technical operation of CCS/CCUS? In other words, how does industry see and accept major technical findings from the CCS/CCUS community, and how do those relate to DOE programs and investments.

In order to meet U.S. economic, energy and environmental goals, power generators are being called upon to enhance the environmental performance of fossil fueled plants. For coal, that enhanced environmental performance requires the application of CCS/CCUS technology. Therefore, an assessment based on technical soundness and results to date would provide a welcome perspective from leading companies with experience in CCS/CCUS technology.

Upon receiving this request and establishing your internal study working groups, please advise me of your schedule for completion of this study.

Sincerely,

Ernest J. Moniz

June 9, 2014

The Honorable Dr. Ernest Moniz
U.S. Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Mr. Secretary:

On behalf of the members of the National Coal Council (NCC), I am pleased to accept your request that the NCC conduct the study you requested in your letter dated May 15th, 2014. Activity has begun on preparing this study which will provide an industry assessment of the progress made by the DOE and others regarding cost, safety and technical operation of CCS/CCUS.

NCC member, Amy Ericson, US Country President of ALSTOM Inc. will serve as the Council Chair for this study. We will provide you with a projected completion date as soon as our Technical Work Group for this study has had a chance to meet and outline the scope of work involved.

Thank you for your support of the National Coal Council. We look forward to completing the requested study in a timely manner for use in the continuing dialogue on issues related to our nation's energy future.

Sincerely,

Jeff Wallace

Jeff Wallace
NCC Chairman & President

Fossil Forward - Revitalizing CCS

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Abbreviations

ARRA – American Reinvestment and Recovery Act
A-USC – Advanced Ultra Super Critical
BACT – Best Available Control Technology
BECCS – Biomass Energy Carbon Capture & Storage
BSER – Best System of Emission Reduction
BTU – British thermal units
CAFE – Corporate Average Fuel Economy
CAP – Chilled Ammonia Process
CCR – coal combustion residuals
CCPI – Clean Coal Power Initiative
CCS – Carbon Capture & Storage
CCUS – Carbon Capture Utilization & Storage
CCWG – Climate Change Working Group
CERC – China Energy Research Center
CFD – computational fluid dynamics
CLC – Chemical Looping Combustion
CO_2 – carbon dioxide
COE – Cost of Electricity
COP – Conference of Parties
CSAPR – Cross State Air Pollution Rule
CSLF – Carbon Sequestration Leadership Forum
CURC – Coal Utilization Research Council
DOE – U.S. Department of Energy
EIA – Energy Information Administration
EGS – Enhanced Geothermal System
EOR – Enhanced Oil Recovery
EPA – Environmental Protection Agency
EPAct – Energy Policy Act
EPRI – Electric Power Research Institute
FEED – Front End Engineering and Design
FERC – Federal Energy Regulatory Commission
FOAK – First of a Kind
GCCSI – Global Carbon Capture and Storage Institute
GDP – Gross Domestic Product
GHG – greenhouse gas
GW – gigawatt

HECA – Hydrogen Energy California
ICCS – Industrial Carbon Capture & Storage
IEA – International Energy Agency
IGCC – Integrated Gasification Combined Cycle
IPCC – Intergovernmental Panel on Climate Change
KWh – kilowatt hour
LCOE – Levelized Cost of Electricity
MEA – Monoethanolamine
MHI – Mitsubishi Heavy Industries
MW – megawatt
MWh – megawatt hour
NCC – National Coal Council
NCCC – National Carbon Capture Center
NETL – National Energy Technology Laboratory
NGCC – Natural Gas Combined Cycle
NOAK – N^{th} of a Kind
NO_x – nitrogen oxides
NREL – National Renewable Energy Laboratory
NSPS – New Source Performance Standards
NSR – New Source Review
OECD – Organization of Economically Developed
OEM – Original Equipment Manufacturer
PSD – Prevention of Significant Deterioration
QER – Quadrennial Energy Review
RCRA – Resource Conservation and Recovery Act
RECS – Research Experience in Carbon Sequestration
RCSP – Regional Carbon Sequestration Partnership
RFP – Request for Proposal
R&D – research and development
RD&D – research, development and demonstration
RPS – Renewable Portfolio Standards
SECARB – Southeast Regional Carbon Sequestration Partnership
SNCR – Selective Non Catalytic Reduction
SO_2 – sulfur dioxide
SO_3 – sulfur trioxide
SO_x – sulfur oxides
TCEP – Texas Clean Energy Project
TRL – Technology Readiness Level
U.K. – United Kingdom
U.S. – United States
UIC – Underground Injection Control
USDW – U.S. Drinking Water
USGS – United States Geological Survey
WGC – Warm Gas Cleanup

Fossil Forward: Revitalizing CCS
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Executive Summary

Charge to the Council

This report was prepared in direct response to a request from the U.S. Secretary of Energy regarding the CCS program of the Department of Energy. The heart of that letter request was as follows:

> "I am writing to request the National Coal Council (NCC) conduct a study that assesses the value of the Department of Energy's Carbon Sequestration Program. The capture of carbon dioxide (CO_2) emissions from the combustion of fossil fuels used in electrical power generation is critical to the future of fossil fuels, particularly coal, used in this country.
>
> The assessment would address the following question: what is the industry's assessment of the progress made by the DOE and others regarding cost, safety, and technical operation of CCS/CCUS? In other words, how does industry see and accept major technical findings from the CCS/CCUS community, and how do those relate to DOE programs and investments?
>
> In order to meet U.S. economic, energy and environmental goals, power generators are being called upon to enhance the environmental performance of fossil fueled plants. For coal, that enhanced environmental performance requires the application of CCS/CCUS technology. Therefore, an assessment based on technical soundness and results to date would provide a welcome perspective from leading companies with experience in CCS/CCUS technology."

The May 2014 NCC report on the value of the existing coal fleet explained the importance of retaining coal as a fuel resource option for electric power generation. "The existing fleet of coal fired power plants underpins economic prosperity in the U.S. Coal based generation has dominated U.S. electricity supply for nearly a century. In 2013, coal again led U.S. generation, at 39%. Low cost coal keeps U.S. electricity prices below those of other free market nations. For example, in 2013 the average price of residential and industrial electricity in the U.S. was one half to one third the price of electricity in Germany, Denmark, Italy, Spain, the U.K. and France. These price differentials translate into more disposable income for U.S. consumers, and a competitive edge for U.S. industry in global markets. If the existing coal fleet were replaced with the next cheapest alternative generating source, natural gas combined cycle power plants, a conservative estimate of the impact on the U.S. economy would be a 1.5% drop in Gross Domestic Product (GDP) and a loss of 2 million jobs per year." [1]

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[1] The National Coal Council, "The Value of Our Existing Fleet: An Assessment of Measures to Improve Reliability and Efficiency While Reduction Emissions", May, 2014

That report also pointed out the need for CCS/CCUS technology in order to meet proposed CO_2 emission reduction goals in the future.

Overview of Approach

This report assesses the status of the current DOE program through a series of 5 chapters as follows:

- Chapter A: The CCS/CCUS Imperative
- Chapter B: Global Status of CCS/CCUS
- Chapter C: Overview of the Current DOE CCS/CCUS Programs
- Chapter D: CCS/CCUS Deployment Challenges
- Chapter E: Gap Analysis

The basic theme of this report is that while the DOE is indisputably a world leader in the development of CCS technology, the DOE CCS/CCUS program has not yet achieved critical mass. While there have been some successes, there is a need for a substantial increase in the number of large scale demonstration projects for both capture and storage technologies before either system even approaches commercialization. The current number of demonstration projects that are in operation or under construction globally is 22. The projected need by 2050 is 3400. The current global CO_2 storage rate is 40 million tons/year. The projected need is 10 billion tons/year. There are not enough demonstration projects to meet the need. Without adequate demonstration, there can be no commercialization. This fact applies to all aspects of CCS, including capture, transportation, utilization, and storage. There is no point in capturing CO_2 if there is no place to use it or store it. The key considerations supporting this analysis are as follows:

- In order to achieve CCS deployment at commercial scale, policy parity for CCS with other low carbon technologies and options is required.

- Technology and funding incentives must be significantly better coordinated to be effective.

- DOE program goals need far greater clarity and alignment with commercial technology and funding approaches used by industry.

- Funding for CCS RD&D is limited and must be enhanced and focused.

- Public acceptance continues to be a major hurdle.

- Control of CO_2 emissions is an international issue in need of international Initiatives.

Key Recommendations

In order to achieve CCS deployment at commercial scale, policy parity for CCS with other low carbon technologies and options is required.

- Policy parity for CCS in funding, extending tax credits and other subsidies provided to renewable energy sources, will facilitate creation of a robust CCS industry in the U.S., benefiting the American people and leading to the development of the lowest cost, near zero emission energy technology. Such technology would be available for electric generation as well as all fossil fuel dependent industrial applications. The NCC recommends that DOE take a stronger position on the need for policy parity with respect to funding allocations.

Technology and funding incentives must be significantly better coordinated to be effective.

- The NCC recommends that DOE develop a plan to have a total of 5–10 GW of CCS/CCUS demonstration projects in operation in the U.S. by 2025.
- The NCC recommends that all federal incentives provided by the DOE and other federal agencies for CCS demonstration projects undergo a coordinated review for their combined adequacy and effectiveness in supporting CCS deployment. If necessary, combinations of incentives or new incentives could be utilized to achieve the desired level of demonstration projects. Examples of such incentives include feed in tariffs, tax credits, production credits, loan guarantees, and "contracts for differences". This coordinated review needs to be completed in time to achieve the installation of 5–10 GW of CCS demonstration projects by 2025.
- The NCC recommends that DOE expand its Regional Carbon Sequestration Partnership (RCSP) program to identify and certify at least one reservoir in each region that is capable of storing a minimum of 100 million tons of CO_2 at a cost of less than $10/ton by 2025.

DOE program goals need far greater clarity and alignment with commercial technology and financing approaches used by industry.

- The NCC recommends that DOE and industry convene a task force to clearly define the role and objectives of individual projects in achieving broad program goals. The aim is to better understand industry technology goals and needs and to understand industry criteria for investment in CCS technologies throughout the entire development pipeline. Prioritization of projects is critical to achieving overall goals with limited budgets, consistent with the need to bring CCS technologies up to Technology Readiness Level 9 (TRL-9).

Funding for CCS RD&D is limited and must be enhanced and focused.

- The NCC recommends that DOE continue its strategy of fostering a portfolio of technologies for implementing CCS. It is important to maintain DOE's approach of "priming the pump" with early stage funding for promising concepts, but in recognition of budgetary constraints and the need to move more quickly in getting larger scale CCS projects operating, the NCC recommends that after technologies reach TRL 4, DOE cull its support to only those technologies which show a clear promise of meeting or exceeding DOE's CCS performance goals.
- The NCC recommends that DOE develop a plan for demonstrating second generation and transformational CCS technologies at a scale of 25–50 MW by 2020 and make subsequent budget requests to Congress to carry out the plan. However, these demonstrations should only move forward for technologies which have a clear advantage in cost and performance compared to first generation CCS technologies.

Public acceptance continues to be a major hurdle.

- The NCC recommends that DOE accelerate its current efforts in CCS/CCUS public engagement, education, and training activities. Outreach efforts should target counties and states with demonstration projects and regions that have potential infrastructure developments (e.g., CO_2 pipelines and storage sites). Training activity should build workforce capacity across the CCS/CCUS chain and build U.S. leadership and knowhow to meet potential national and international demand.

Control of GHG emissions is an international issue in need of international initiatives.

- The NCC recommends that DOE maintain its existing CCS/CCUS international collaboration efforts including the Carbon Sequestration Leadership Forum (CSLF) and the U.S.-China Clean Energy Research Center (CERC).
- International partnerships in commerce should also be pursued. The NCC recommends that the DOE explore ways to foster CCS/CCUS demonstrations in developing nations which are rapidly increasing their CO_2 emissions, such as China and India. In particular, conducting CO_2 utilization and storage projects using CO_2 from new and existing coal gasification projects in these countries, could be a low cost means to increase global knowledge and acceptance of commercial scale CO_2 storage.

Chapter A: The CCS/CCUS Imperative

Chapter Lead: **Holly Krutka**
Chapter Authors: Carl Bozzuto
Desmond Chan
Dawn Santoianni
Steve Winberg

1. Key Findings

- CCS is the only large scale technology that can mitigate CO_2 emissions from fossil fuel use for electricity generation and key industrial sectors including cement production, iron and steel making, oil refining, and chemicals manufacturing.
- Not including CCS as a key mitigation technology is projected to increase the overall costs of meeting CO_2 emissions goals by 70% to 138%.
- U.S. CO_2 emissions represent less than 16% of world emissions. Thus, global and wide scale implementation of CCS is necessary to meet CO_2 emissions goals.
- DOE has taken on a leadership role in advancing CCS technology by supporting first mover CCS projects and fostering international collaborative efforts to deploy CCS, but this role must be strengthened if CCS is to be commercialized.

"With coal and other fossil fuels remaining dominant in the fuel mix, there is no climate friendly scenario in the long run without CCS."[2]

Maria van der Hoeven
Executive Director
International Energy Agency

2. The Need for CCS

Globally, the vast majority of energy is supplied through fossil fuels. In fact, fossil fuel use continues to expand rapidly, which in turn fosters economic growth. In 2013, 87% of global primary energy consumption was supplied by fossil fuels.[3] The three most widely consumed energy sources were fossil fuels (in descending order): petroleum, coal, and natural gas.[4] Coal produces about 40% of electricity around the world and is the fastest growing fossil fuel today, which can be largely attributed to growth in developing countries, where coal is enabling affordable, reliable electricity that is needed to lift men, women, and children out of poverty. For the 1.2 billion people that live without any access to electricity and the 2.8 billion that do not have access to clean cooking facilities, electricity offers a chance to live a healthier, more productive life.[5] Fossil fuels will remain the world's dominant energy source for decades to come. If the world is to address climate change by reducing CO_2 emissions, the key approach will not be replacing fossil fuels, but addressing the CO_2 emissions from them.

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[2] IEA, 2013, Technology Roadmap: Carbon Capture and Storage, OECD/IEA, France. www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf

[3] BP, 2014, BP Statistical Review, www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html?cigx=d.kac,stid.57543,sid.37075,lid.11,mid.49400

[4] Ibid

[5] World Bank, 2013, Global Tracking Framework, www.worldbank.org/en/topic/energy/publication/Global-Tracking-Framework-Report

In 2013, coal provided nearly 1,600 TWh (nearly 40%) of the U.S.'s electric power.[6] Further, by both International Energy Agency (IEA) and U.S. Energy Information Agency (EIA) projections, coal will continue to be the mainstay of the electric power sector for decades to come. The energy security, reliability, and affordability offered by coal are the fundamental reasons it will continue to play an important role in the U.S. and abroad into the foreseeable future.

While increased fossil fuel consumption is pivotal for global poverty alleviation as well as for competitive energy pricing in the U.S., it also results in the release of greenhouse gas (GHG) emissions, which are increasing in magnitude. Making emissions reduction even more challenging is the fact that carbon dioxide (CO_2) emissions are spread across virtually every sector critical to modern life, as is shown in Figure A.1.[7]

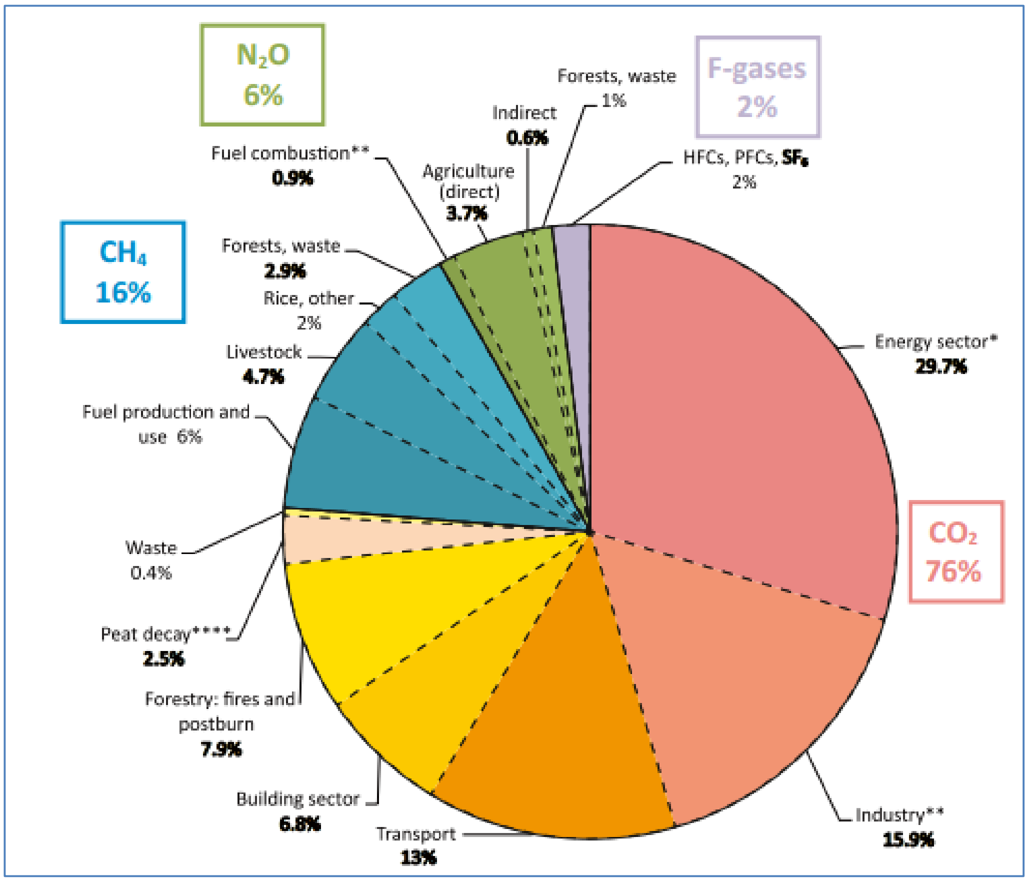

Figure A.1. Global GHG Emissions By Sector (2010)

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[6] EIA, 2014, www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf

[7] United Nations Environmental Program, 2012, The Emissions Gap Report 2012, www.unep.org/pdf/2012gapreport.pdf

In the energy sector, coal remains the world's largest resource for power production and is the fuel of choice for developing countries, generating 40% of electricity. For example, coal supplied 69% of China's energy needs in 2011 compared to 7% from renewables, including hydropower.[8] Coal also plays an important role in construction as an essential energy source for the manufacture of cement and steel. Today, 70% of the world's steel is produced using coal. Global coal consumption grew 60% from 2000 through 2012, and IEA projects that coal will surpass oil as the top energy source worldwide by 2017.[9] Figure A.2 shows historic and projected coal consumption (not taking into account any GHG control strategies).[10]

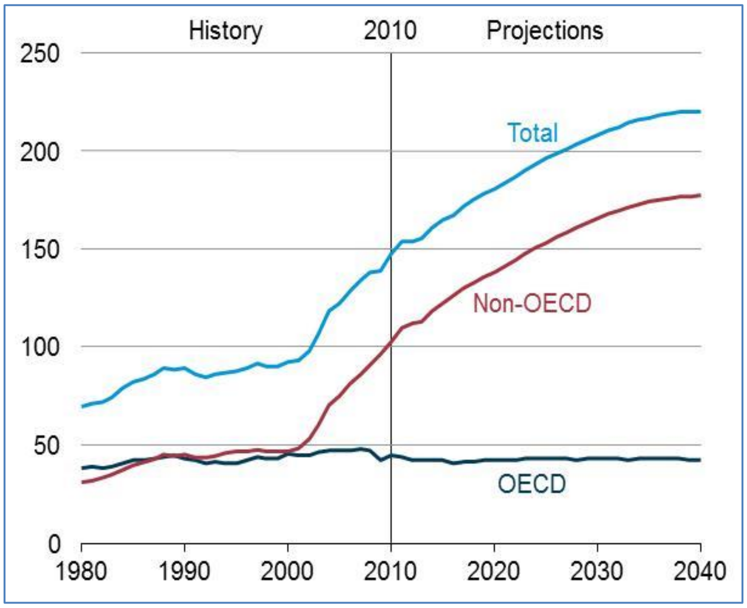

Figure A.2. Projected Coal Consumption Through 2040 in Quadrillion BTU/year (EIA Reference Case)

The bottom line is that due to an increasing global population and expanded energy access, total world energy consumption is projected to grow by 56% through 2040, with fossil fuels providing nearly 80% of that demand.[11] The effect of these trends on future CO_2 emissions could be substantial. Mitigating potential impacts, while enabling emerging economies to benefit from a reliable energy supply, will require commercially available and cost competitive carbon capture and storage (CCS) technology.

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[8] EIA, Energy Information Administration, International Energy Outlook 2013, www.eia.gov/forecasts/archive/ieo13/

[9] IEA, 2014a, http://www.iea.org/topics/ccs/

[10] Energy Information Administration, International Energy Outlook 2013, www.eia.gov/forecasts/archive/ieo13/

[11] Energy Information Administration, International Energy Outlook 2013, www.eia.gov/forecasts/archive/ieo13/

The international community has not yet formed a consensus on how to balance development efforts and climate change objectives. Yet many countries are advancing their own solutions. CCS (which includes utilization for the purposes of this chapter) is the only technology mitigation option that will allow for deep cuts in CO_2 emissions from fossil fuels. Given the ongoing global growth in fossil fuel consumption, CCS deployment is critical and necessary to achieve meaningful reductions in global CO_2 concentrations. The concept of CCS is typically associated with coal fueled electricity generation, but has an equally important application for oil and natural gas combustion in both the electricity and industrial sectors. Therefore, CCS is a substantial mitigation option for both industrial and utility applications, be they coal or natural gas fueled.

Economical, commercial scale application of CCS is the most important component of a portfolio of technologies that will be necessary to successfully reduce GHG emissions.[12,13,14,15] Without CCS, it is highly improbable that CO_2 emission reduction goals will be met. More importantly, without CCS the projected costs of achieving these goals will be much higher, with some estimates forecasting a greater than 70% increase in cost due to the higher estimated cost of alternatives, including renewables.[16]

The U.S. Department of Energy (DOE), in partnership with U.S. industry, is the leader in the advancement of CCS. However, the U.S. accounts for only 16% of annual global CO_2 emissions and is projected to account for virtually zero incremental CO_2 emissions through 2040.[17] From this viewpoint, it will make little difference if the U.S. is the sole implementer of commercial CCS. DOE and industry must continue its efforts to commercialize CCS, but more importantly develop strong international support for global CCS commercialization. DOE's international leadership is crucial for CCS to fulfill its required role in reducing global CO_2 emissions.

3. Understanding International Climate Objectives

The Copenhagen Accord, drafted by the Conference of Parties (COP) under the United Nations Framework Convention on Climate Change in December 2009, states that climate mitigation strategies must bear "[I]n mind that social and economic development and poverty eradication are the first and overriding priorities of developing countries…"[18] Thus, climate solutions that hamper economic growth, especially in developing countries, are not acceptable.

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[12] National Coal Council, 2007, Technologies to Reduce or Capture and Store Carbon Dioxide Emissions, www.nationalcoalcouncil.org/Documents/NCCRB_June2007.pdf

[13] National Coal Council, 2009, Low-Carbon Coal: Meeting U.S. Energy, Employment, and CO_2 Emissions Goals with 21st Century Technologies, www.nationalcoalcouncil.org/reports/Executive_Summary.pdf

[14] National Coal Council, 2009, Low-Carbon Coal: Meeting U.S. Energy, Employment, and CO_2 Emissions Goals with 21st Century Technologies, www.nationalcoalcouncil.org/reports/Executive_Summary.pdf

[15] National Coal Council, Expedited CCS Development: Challenges & Opportunities, 2011

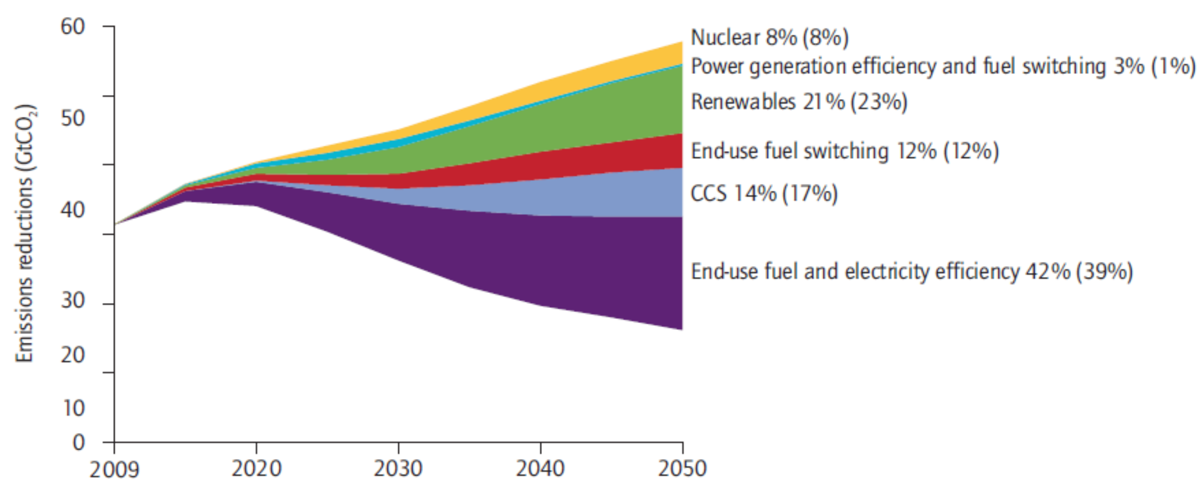
[16] IEA, 2009, Technology Roadmap: Carbon Capture and Storage, International Energy Agency, OECD/IEA, Paris

[17] US DOE Carbon Dioxide Information Analysis Center, Fossil Fuel CO_2 Emissions 2010 Data

[18] UNFCCC (United Nations Framework Convention on Climate Change), COP, 2009, Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009. Addendum. Part Two: Action

To date, more than 100 countries have endorsed the Copenhagen Accord goals supporting deep cuts in global GHG emissions. The purpose of these goals was to limit the increase in average global temperature to less than 2°C.[19] The IEA has developed scenarios under which global GHG emissions could be reduced. The 450 parts per million (ppm) scenario, which is associated with a 2°C change in average global temperature (also known as the two degree scenario or 2DS), is intended to show changes that would be needed "to set the energy system on track to have a 50%" chance of limiting global CO_2 concentrations to 450 ppm.

To meet this goal the IEA found that a diverse set of technologies would be required.[20] IEA estimated that CCS would provide about 14% of the cumulative needed emissions reductions by 2050 or 17% of the yearly reductions in 2050, as shown in Figure A.3.[21] Therefore, not only is CCS critical, but its relative importance is projected to grow over time. It is also important to recognize that IEA's goal assumes very significant efficiency improvements and renewables growth. If either of these does not occur at the rate shown below, it is most certain that fossil fuels will fill the remaining gap, thus further increasing the need for wide spread global deployment of CCS. CCS is the scalable hedge against failure to achieve renewable or efficiency goals.



Note: numbers in brackets are shares in 2050. For example, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6DS.

Figure A.3. IEA Technology Road Map

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taken by the Conference of the Parties at its fifteenth session, FCCC/CP/2009/11/Add.1, United Nations Office at Geneva, Switzerland.

[19] Ibid

[20] IEA, 2008, Energy Technology Perspectives 2008: Scenarios and Strategies to 2050, International Energy Agency, OECD/IEA, Paris.

[21] IEA, 2013, Technology Roadmap: Carbon Capture and Storage, OECD/IEA, France. www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf

4. Sectors Where CCS Must Play a Role

CCS is a critical part of any plan to reduce CO_2 emissions in the global electric power sector because it is the only large scale technology available that can achieve deep cuts in CO_2 emissions. Indeed, the 2050 Energy Road Map calls for 190 GW of CCS by 2050.[22] The second area in which CCS is critical is in the industrial sectors, including cement, chemicals, refining, and iron and steel. There is no suitable, widely available mitigation alternative for coal use in these industries in a carbon constrained world.[23]

Figure A.4 shows IEA's breakdown of sources for CO_2 capture.[24] Note that the largest contribution is from coal fueled power plants, but CO_2 capture for gas processing and gas fueled power plants is also necessary and must contribute a significant amount of emissions reductions. In fact, to meet climate goals CCS must be applied to all fossil fuels used for energy production to the greatest extent possible. Nuclear and renewables have an important role to play as well, but this role is in addition to, not instead of, CCS.

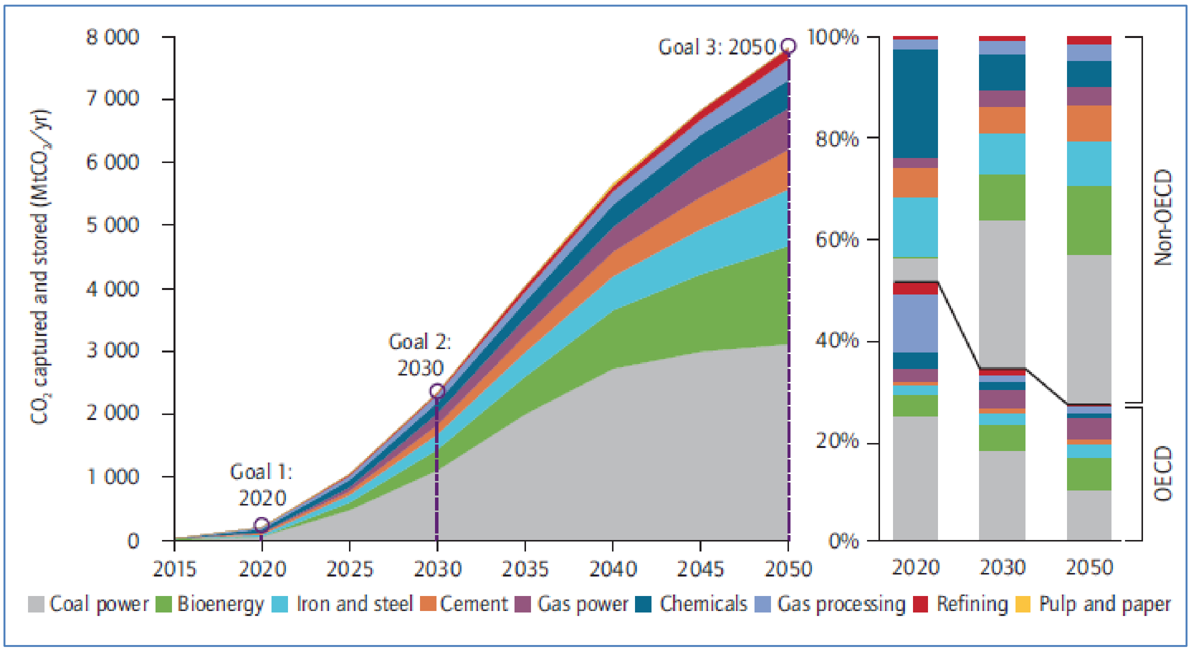

Figure A.4. IEA Targets for CCS Deployment Through 2050

[22] "Communication to the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions on the Future of CCS in Europe", European Commission, Brussels, March, 2013

[23] IEA, 2013, Technology Roadmap: Carbon Capture and Storage, OECD/IEA, France. www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf

[24] Ibid

To meet international goals, IEA estimated that CO_2 would need to be captured at a rate of approximately 10 billion tons per year globally through the implementation of 3400 CCS projects by 2050. Cumulative worldwide CO_2 storage through 2050 would be 145 billion tons of CO_2.[25] Based on these end goals the IEA published a roadmap for CCS outlining what would be necessary.[26]

Notably, the IEA showed that in order to meet this target:

- 65% of the cumulative captured CO_2 needs to be achieved in non OECD (Organization for Economic Cooperation and Development) countries. More recently this figure was revised to 70%.[27]
- In order for global CCS deployment to be "on track" 100+ commercial scale integrated CCS projects should be "up and running" by 2020.

In a 2013 update of its roadmap, IEA reduced the number of projects needed by 2020 from 100 to 30.[28] The reduced number of CCS projects underscores the reality that the global CCS industry will not be ready for deployment unless project development is drastically accelerated and scaled. Achieving the level of CCS needed in the future is still possible, but it will not be achieved without the leadership of DOE, as well as considerable financial support.

5. The Cost Reduction Benefits of CCS

Meeting CO_2 emission reduction goals may be technically feasible without CCS, but this would increase the net cost. Although today's CCS technologies may increase energy production costs (e.g., estimates are that today's technologies will increase the cost of electricity by 70–80%), it is substantially less expensive to include CCS as part of the mitigation portfolio.[29] For example, the IEA has estimated that the exclusion of CCS as a technology option for the power sector alone would increase mitigation costs by around $2 trillion USD by 2050.[30]
The strategic importance of CCS was well demonstrated when the International Panel on Climate Change (IPCC) considered the impact of the absence of CCS as a carbon mitigation option. Figure A.5 presents a sensitivity analysis from the IPCC 5th Assessment Report.[31]

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[25] IEA, 2008, Energy Technology Perspectives 2008: Scenarios and Strategies to 2050, International Energy Agency, OECD/IEA, Paris.
[26] IEA, 2009, Technology Roadmap: Carbon Capture and Storage, International Energy Agency, OECD/IEA, Paris
[27] IEA, 2013, Technology Roadmap: Carbon Capture and Storage, OECD/IEA, France. www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf
[28] Ibid
[29] Testimony of Dr. S. Julio Friedmann, Deputy Assistant Secretary for Clean Coal Before the House Energy and Commerce Subcommittee on Oversight and Investigations, energy.gov/congressional/downloads/house-energy-and-commerce-subcommittee-oversight-and-investigations-0
[30] IEA, 2012, Energy Technology Perspectives 2012: Pathways to a Clean Energy System, International Energy Agency, Paris
[31] IPCC, Working Group III, Climate Change 2014: Mitigation of Climate Change, http://mitigation2014.org/report/publication/

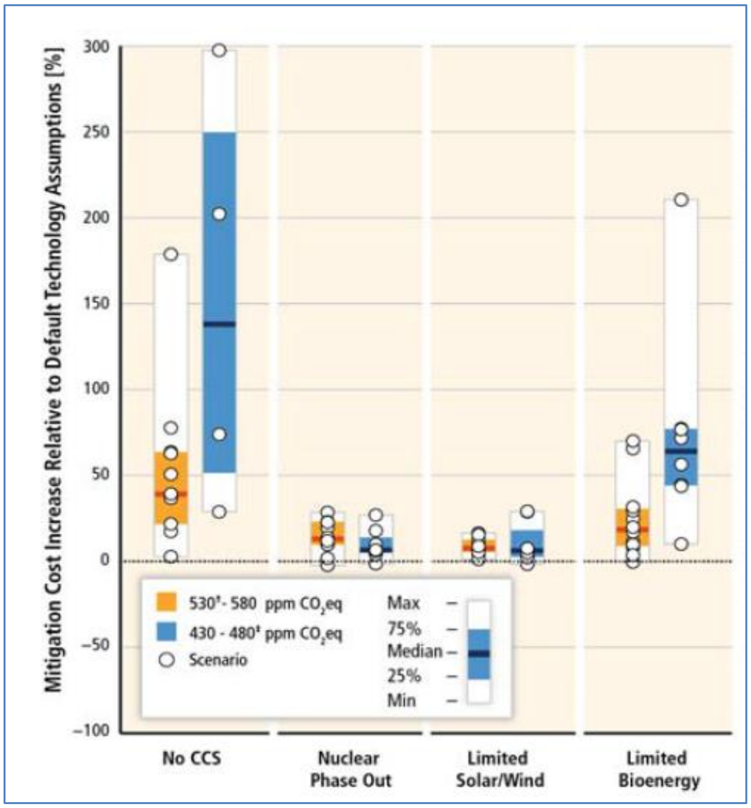

Figure A.5. Climate Change Mitigation Costs Without CCS and Other Technologies

Figure A.5 shows that the mitigation cost without CCS would increase relative to a global energy scenario with default technology assumptions. The increase in cost estimated by the IPCC was about 138% (median estimate), significantly greater than the IEA's assessment of a 70% increase. By comparison, a nuclear phase out would increase the median cost by only ~7%. Similarly, if wind and solar expansion was limited, the increase in global mitigation costs would also increase by only ~6%. While these figures are only estimates, the relative magnitudes are significant.[32]

The IPCC analysis reveals that the inclusion of CCS in the portfolio of mitigation options substantially *decreases* overall mitigation costs. This was well explained by the IPCC. "Many models cannot reach concentrations of about 450 ppm CO_{2eq} by 2100 in the absence of CCS. The importance of CCS relates not only to its use for fossil fuels but also via biomass energy with carbon capture and storage (BECCS). According to the IPCC, "Many models could not limit likely warming to below 2°C if bioenergy, CCS, and their combination (BECCS) are limited (high confidence).

[32] IPCC, Working Group III, Climate Change 2014: Mitigation of Climate Change, http://mitigation2014.org/report/publication/

Although cost estimates vary, there is no question that meeting climate goals will be significantly more expensive without CCS. This point raises additional uncertainty about the viability of solely relying on other methods of CO_2 emission reductions to achieve these goals.[33] Looking specifically at GHG mitigation in the U.S., DOE estimates the cost of CO_2 capture in coal fueled power plants using current technology (oxy-combustion or amine scrubbing) stands at \$58/ton of CO_2 captured or \$72/ton of CO_2 avoided.[34] These are cost projections for an N^{th} of a kind (NOAK) plant. This cost is high compared to the current market prices of CO_2 in various trading systems in the U.S. and EU (ranging from \$3 – 30/ton).[35]

However, the projected CCS costs are lower than the estimated costs of some current policy approaches such as Corporate Average Fuel Economy (CAFE) standards and Renewable Portfolio Standards (RPS). For instance, the cost of using a hybrid vehicle to meet CAFE standards has been estimated to be \$100–140/ton CO_2.[36] Other studies have reported that such standards impose a cost of 6–14 times the cost of a gasoline tax for the same level of emissions reductions.[37] Preliminary results from more recent studies at MIT on CAFE and RPS standards indicate that the cost per ton of CO_2 avoided would be much higher.[38,39] Should technology development ultimately reach the goal of cost parity with conventional technology, CCS could become the "technology of choice" with near zero emissions and relatively low cost.

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[33] Williams, R.H., Li, Z., September 2014, Toward Getting the Global CCS Enterprise Back on Track, Submitted with the report: Tackling the Challenge of Climate Change: A Near-Term Mitigation Agenda, Commissioned by the Republic of Nauru, Chair of the Alliance of Small Island States (AOSIS), Presented at the 2014 Climate Summit, New York, NY, U.S., A Contribution to Tackling the Challenge of Climate Change: A Near Term Actionable Mitigation Agenda. Commissioned by the Republic of Nauru, FORMER chair of the Alliance of Small Island States (AOSIS). BOTH PAPERS AVAILABLE AT: www.aosis.org

[34] U.S. DOE, National Energy Technology Laboratory, 2014 DOE/NETL-2007/1281, Cost and Performance Baseline for Fossil Energy Plants, Volume 1, Bituminous Coal and Natural Gas to Electricity, Revision 4

[35] Murray, J., April 2, 2014, EU carbon price rides the "rollercoaster" as emissions fall, Green Business, www.businessgreen.com/bg/analysis/2337543/eu-carbon-price-rides-the-rollercoaster-as-emissions-fall and www.businessgreen.com/bg/analysis (accessed April 4, 2014).

[36] Holzman, D., Environmental Health Perspectives, Volume 117, Issue 7, July 2009, Climate Change Abatement Strategies Which Way is the Wind Blowing?, National Institute of Environmental Health Sciences, Lexington, MA

[37] Karplus, V., et al, "Should a Vehicle Fuel Economy Standard Be Combined With an Economy-Wide Greenhouse Gas Emissions Constraint? Implications for Energy and Climate Policy in the United States", Energy Economics, 36: pp 322 -333, 2013, Elsevier

[38] Paltsev, S. et al., 2014, Regulatory Control of Vehicle and Power Plant Emissions: How Effective and at What Cost?", 21 pp, www.tandfonline.com/doi/full/10.1080/14693062.2014.937386#.U_TiFRDLJ3v

[39] Private Communication, MIT CEEPR with C. Bozzuto

National Energy Technology Laboratory (NETL) researchers found that CCS deployment can limit increases in electricity prices, allow for the same levels of electricity generation, and provide more CO_2 reductions than a clean energy standard at levels similar in scale to a tax or cap and trade.[40] In a separate study, the Energy Modeling Forum ran nine different models in a 50% reduction scenario and found that most models could not converge on a solution when CCS deployment was limited.[41]

Finally, a previous National Coal Council (NCC) study looked in depth at the economic benefits to the U.S. economy of the deployment of enhanced oil recovery (EOR) using anthropogenic CO_2 (CO_2 EOR).[42] Today most CO_2 EOR operations utilize natural CO_2, representing a missed opportunity to capture emissions from CCUS (carbon capture, utilization, and storage) projects. The revenue stream from such utilization can partially offset the increased costs of the capture system.

While there are several promising CCUS projects on the horizon, today CCUS with EOR represents a major underutilized opportunity that could benefit the U.S. economy, create jobs, increase U.S. oil production, reduce oil imports, and help expedite the advancement of CCUS demonstration projects. However, these projects are not yet able to produce CO_2 as cheaply as natural (non-anthropogenic) sources. As there is a strong need to reduce the costs associated with CCS through "learning by doing", the CO_2 EOR opportunities in North America (and elsewhere in the world) represent a major opportunity to provide additional revenue for CCS demonstrations. Other potential uses include enhanced coal bed methane recovery and the substitution of CO_2 for water in fracking operations where water is scarce. These examples indicate that coal can continue to play a major role in U.S. energy if CCS is kept in the mix of clean energy technologies used to mitigate U.S. CO_2 emissions.[43]

6. The Role of Other Nations

The developed world alone cannot reduce emissions enough to meet international CO_2 emission reduction goals. Growth in energy utilization, especially in non OECD countries, is fundamental to improve living conditions globally. Limiting access to energy is not a realistic, nor a humanitarian approach to climate change mitigation. For the world's poor, inadequate electricity supplies exacerbate unhealthy living conditions because clean drinking water, sanitation, non-polluting cooking facilities, and modern healthcare rely on dependable energy. Even in OECD countries, policies that hamper economic growth will ultimately fail.

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[40] Nichols, C., 2011, The Role of CCS Under a Clean Energy Standard, 30th USAEE/IAEE Conference, www.usaee.org/usaee2011/submissions/Presentations/Nichols.pptx

[41] Clarke, L., et al., 2014, Technology and U.S. Emissions Reductions Goals: Results of the EMF 24 Modeling Exercise. The Energy Journal, Volume 35, Special Issue 1

[42] National Coal Council, 2012, Harnessing Coal's Carbon Content to Advance the Economy, Environment, and Energy Security, www.nationalcoalcouncil.org/reports/NCC-Full-Report-June-2012.pdf

[43] Williams, R., 2014, Capture Technology Cost Buydown in CO_2 EOR Market Applications under an Alternative Energy Portfolio Standard, Presented at Greenhouse Gas Technologies Conference, Austin, TX.

Developing countries are building new fossil fueled power plants and placing them into service to meet their energy needs. IEA projects that 90% of energy demand growth through 2035 will be from developing countries led by China and India.[44] China is bringing online an average of 500 MW of new coal capacity per week through 2030. Without CCS, these power plants will continue to operate over their projected lifetimes of 40–60 years.

Another important global phenomenon that should be considered is the widespread acceleration of urbanization, largely occurring in non OECD nations. Urbanization is a means to improve quality of life by significantly reducing the physical and environmental impacts of energy poverty in rural areas, especially for the women and children who walk for hours each day collecting biomass for heating and cooking. By 2050, about 70% of humanity, which could be equivalent to nearly the entire current global population, will live in cities.[45] Vast amounts of electricity, steel, and associated materials will be needed to support these urban concentrations. Although rapid urbanization can strain infrastructure, it provides the opportunity to provide electricity to more homes, which are more difficult to service in rural areas. Centralized electricity generation, needed by urban centers, lends itself to the application of CCS in the future, although most developing countries will need international support to advance CCS projects. A first step in advancing CCS is to provide financial incentives for investment in state of the art, high efficiency, low emission, coal fueled, electricity generating stations instead of older, less efficient technologies. These state of the art units are reliable and well suited to meet growing urban electricity requirements. In addition, when the time comes, these units could be potential options for CCS retrofit.

As a final consideration regarding the international situation, the United Nations' (U.N.) projections on population growth continue to show increases beyond 2050 up to 2100. Figure A.6 shows the reference case data from the U.N. analysis.[46] Figure A.7 shows the high case projections, indicating that world population could conceivably double in the next two generations. These additional people will still need power, food, drinking water, and other basic requirements that will only make CO_2 reductions that much more difficult.

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[44] Energy Information Administration, International Energy Outlook 2013, www.eia.gov/forecasts/archive/ieo13/
[45] Vidal, J. (2010, 22 March). UN Report: World's Biggest Cities Merging into "Mega-Regions". The Guardian, www.theguardian.com/world/2010/mar/22/un-cities-mega-regions
[46] " World Population Prospects", United Nations, New York, 2013-- pages 96 and 97, graphs by Frank Clemente

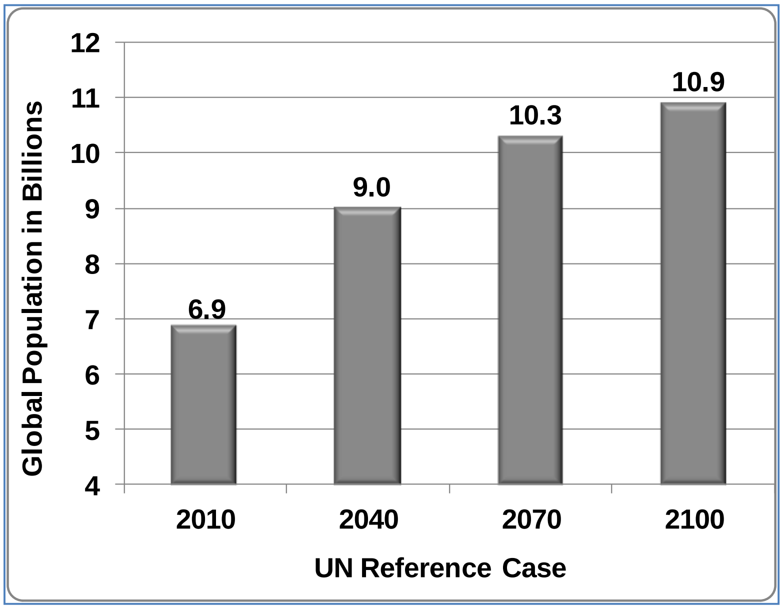

Figure A.6. United Nations Population Projections: Reference Case

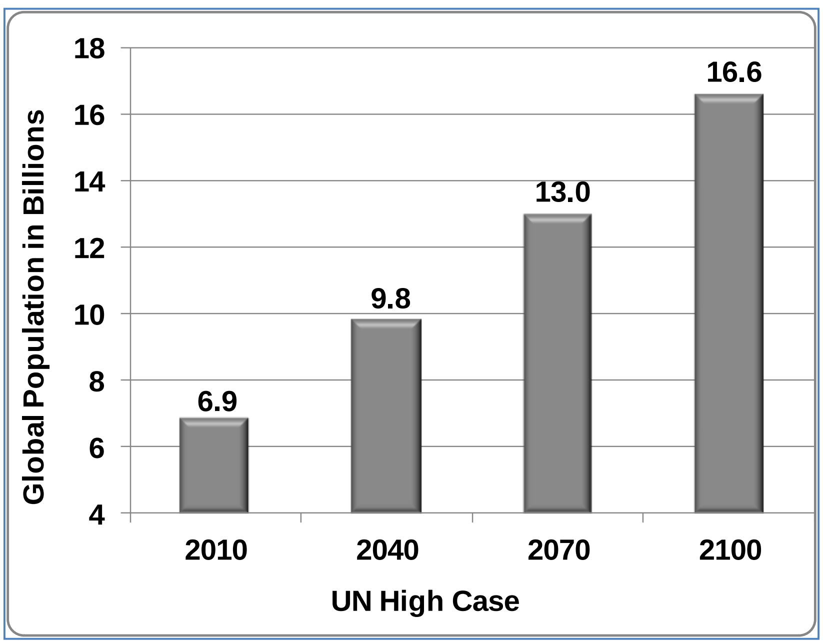

Figure A.7. United Nations Global Population Projections: High Case

It would seem prudent to develop technologies that could continue to provide such power at reasonable costs well into the future. These developing economies will want and need to use the natural resources that are available to them. The successful development and deployment of CCS technology can only help bring about the needed improvements in living conditions that these countries are striving for.

7. Building on U.S. Goals

The Obama Administration has recognized the need to reduce domestic CO_2 emissions. In November of 2009, President Obama offered a U.S. target for reducing emissions by 17% below 2005 levels by 2020. In addition, the President set a goal of reducing CO_2 emissions by 83% below 2005 levels by 2050. In late 2014, during a trip to China, the President agreed to a 26-28% reduction below 2005 levels by 2025.

In 2013, U.S. CO_2 emissions were 10% lower than 2005 levels and appeared to be decreasing.[47] This trend is, in part, due to improved energy efficiency in the residential and commercial sectors, better fuel economy in the transportation sector, lower natural gas prices (resulting in natural gas displacing some coal in the electricity generation sector), and reduced energy consumption in the manufacturing sector, largely due to the recession.

The overall progress in reducing per capita energy consumption has been supported by DOE's technology developments. However, when viewed from the perspective of reduced CO_2 emissions, the reduction is only 2% of 2012 U.S. CO_2 emissions, using the 2005 baseline year. When compared to global CO_2 emissions, these efficiency improvements represent less than 0.5% of global emissions.

Another example that helps illustrate the limited impact of domestic policy on global emissions is that retiring the U.S. coal fueled generation fleet and replacing this fleet with natural gas based power generation, an unrealistic scenario, would only reduce global carbon emissions by 2% and this assumes zero growth in electricity consumption. If electricity growth is factored into this scenario, there is no net decrease in emissions. When viewed globally, the challenge becomes even greater. According to IEA, if every country around the world fully enacted all of the GHG reduction measures currently being considered (which do not include significant CCS deployment), global CO_2 emissions would still rise 20% by 2035.[48]

8. Leading the Charge

Fossil fuels will continue to play a significant role in the world's energy mix and coal consumption, specifically, is projected to grow. CCS deployment is critical to achieving reductions in CO_2 emissions from fossil fuel use. To date, the DOE has been a principal world leader in advancing CCS technologies. Figure A.8 summarizes the status of the large scale, ongoing CCS projects globally, and reveals that a majority of these plants are located in the U.S.[49]

[47] EIA, 2014, www.eia.gov/environment/emissions/carbon/
[48] IEA, 2008, Energy Technology Perspectives 2008: Scenarios and Strategies to 2050, International Energy Agency, OECD/IEA, Paris.
[49] Global CCS Institute, *The Global Status of CCS 2014*, November 2014.

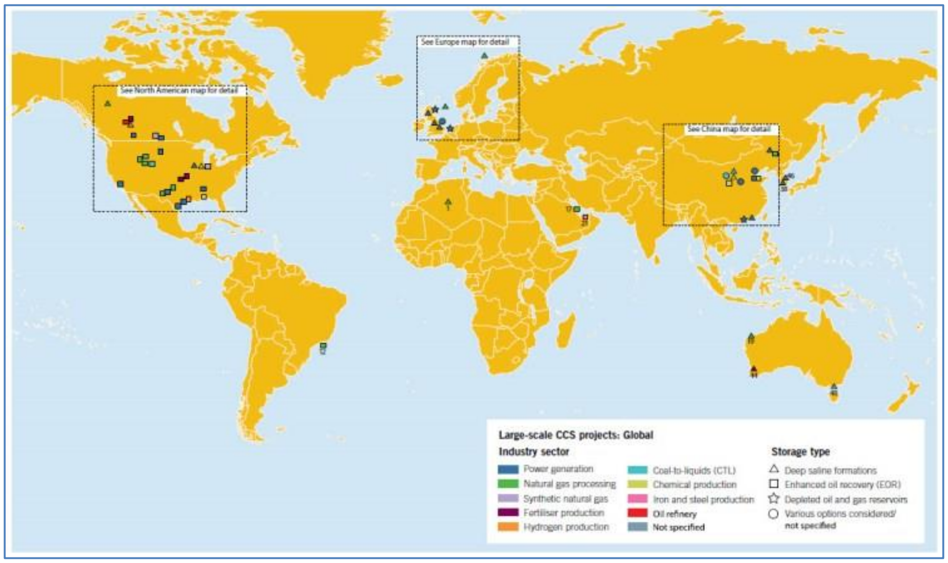

Figure A.8. Large Scale CO_2 Capture Projects in Operation or Under Construction

DOE has been instrumental in moving several of these projects forward. Although the DOE annual budget is insufficient to fund all the first mover projects that are needed, there is no question that the dollars spent to date have advanced, and will continue to advance, CCS.

While the DOE has supported efforts to advance CCS technology, full commercialization and deployment is unquestionably a global challenge, especially as non OECD countries' CO_2 emissions eclipse those of the OECD countries. An international effort led by the U.S. is needed, but it must be supported financially and technically by the rest of the world. As was stated in the 1972 Stockholm Declaration:[50]

"Both aspects of man's environment, the natural and the manmade, are essential to his wellbeing and to the enjoyment of basic human rights, the right to life itself."

CCS can be an enabling technology to protect the natural world while also placing the necessary value on human welfare; but CCS is at a crossroads and needs strong international leadership with extensive financial commitment to fulfill this potential role.

[50] United Nations, 1972, Stockholm Declaration

Chapter B: Global Status of CCS/CCUS
Chapter Lead: **Pam Tomski**

1. **Key Findings**

- Capital and operating costs for projects with CCS are more expensive than conventional technologies and carry greater technology and commercial risk. The bulk of the capital expenditure is associated with the addition of the capture plant and compression units, as well as the modifications to the power or industrial plant in the case of retrofits. Project risks include financing, permitting, public acceptance, cost overruns, schedule delays, performance, environmental compliance, operational flexibility, storage, and long term liability.

- Funding remains a major challenge. All large scale projects have a combination of public and private funding to help minimize risk exposure. Significant investments in time and resources are required even before reaching a final investment decision (e.g., storage site characterization for saline which can take 5-10 years, detailed plant and capture integration design, off take agreement negotiations, etc.). Projects generally include a basket of federal and state or provincial incentives (e.g., grants, tax credits, loan guarantees, etc.).

- Projects with CCS are more complex than conventional projects (from a project management, operations, and technical perspective), which can significantly impact overall project timelines and, thereby, increase costs. The regulatory approval process (especially associated with air and storage site permitting) is a key issue for many projects, which must typically factor in an additional 12-36 months into overall project timelines. Power plants or polygeneration facilities operating in competitive electricity markets must account for the additional time and complexity of negotiating power purchase agreements and other offtake contracts (e.g., CO_2, urea, etc.). Finally, many of these pioneer projects typically include a more rigorous investment due diligence process that is conducted during the front end engineering and design (FEED) study and final investment decision stages, which can significantly add time and complexity to project schedules.

- The portfolio of large scale CCS projects is the result of public and private investments that were initiated 5-10 years ago. They were intended to advance technologies to the point of achieving commercial readiness. The CO_2 capture capacity of all projects in the operate, construction, and advanced planning stages (totalling nearly 65 million ton/year) is something less than the current CO_2 emissions from West Virginia's coal fired power sector (77.6 million ton/year), which is multiples below the CCS levels called for by the IEA and other organizations. A substantial increase in new projects nearing the construction phase is needed.

The path of CCS/CCUS technologies toward commercialization and deployment is shown graphically in Figure B.1. The current, large scale CCS project activity is largely a function of policies and funding programs established toward the end of the last decade. Additional policy action is required now to improve the investment climate for CCS and ensure that CCS is not disadvantaged relative to other low carbon technology solutions.

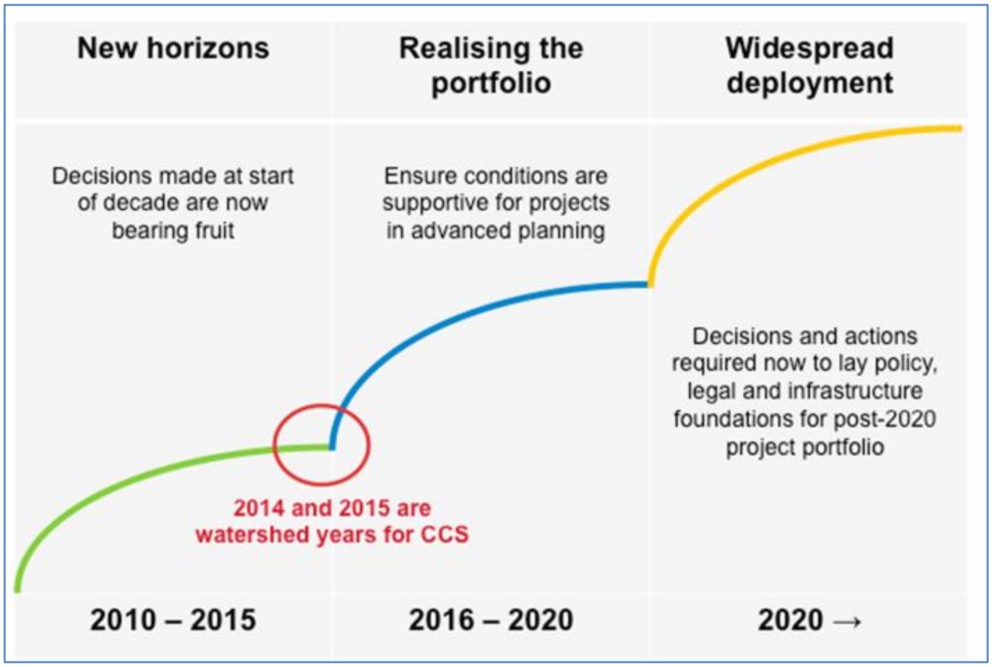

Figure B.1. Pathway to CCS Deployment[51]

2. Global CCS Status: Large Scale Project Overview

The development of carbon capture and storage (CCS) technologies for power sector applications began in earnest only two decades ago, but there is more than 60 years of operational experience from projects in the oil and natural gas industries that are similar to CCS. Examples include underground CO_2 injection for enhanced oil recovery (CO_2 EOR) and CO_2 separation from natural gas production. In the case of CO_2 EOR, once the field is produced, substantially all of the CO_2 that is left in the formation is stored underground. The success of these operations provides considerable confidence in the potential to safely store large volumes of CO_2 underground.

[51] Global CCS Institute, The Global Status of CCS 2014, November, 2014

According the Global Carbon Capture and Storage Institute (GCCSI), every region of the world has CCS project activity from research and development (R&D) to pilot and large scale demonstration. While CCS can be cost competitive with other low carbon options (e.g. solar, wind, nuclear) on an unsubsidized basis, costs and risks for CCS projects remain high compared to conventional technologies without CCS.[52] In order for CCS to become commercially available beyond EOR and other niche markets, continued investments in second and third generation capture systems that reduce costs, maintain operational flexibility, and build confidence are critical. These investments need to be accompanied by sustained policy action that provides certainty and incentives, enabling CCS to be recognized within the low carbon technology portfolio. Furthermore, there must be commitments to knowledge sharing through international collaboration.

As of November, 2014, there are 13 large scale CCS projects in operation around the world, with another 9 under construction.[53] There are also 19 projects in the early planning stage and 14 in advanced planning. North America and the U.S. dominate in terms of project numbers and investment levels, followed by China as shown in Table B.1.[54]

	Early Planning	Advanced Planning	Construction	Operation	Total
North America	5	6	6	9	26
China	8	4	-	-	12
Europe	2	4	-	2	8
Gulf Cooperation Council	-	-	2	-	2
Rest of World	4	-	1	2	7
Total	19	14	9	13	55

Table B.1. Large Scale CCS Projects by Region or Country

All of the 22 projects in operation or under construction utilize first generation capture technologies and are pioneer projects in demonstrating CCS integration at modest scale. Most of the projects separate CO_2 as part of normal operations (e.g., natural gas processing or production of synthetic fuels, hydrogen, and fertilizer) with the power sector accounting for only 3 projects. CO_2 EOR is the dominant storage option (11 out of 13 in operation and 6 out of 9 under construction). The Weyburn-Midale Project in Canada is the only CO_2 EOR operation that included a dedicated monitoring program to demonstrate storage permanence. Saline reservoir storage accounts for 4 of the 22 projects (two in operation and two under construction). More information on these projects is included in Appendix A.

By 2017, all of the projects currently under construction are expected to be in operation, bringing the total CO_2 capture and storage capacity of operational projects to around 40 million ton/year as seen in Figure B.2.[55] As a point of comparison, coal fired power plants in the U.S. emit about 2.2 billion tons/year. While these projects represent a good start, many more projects will be needed.

[52] Alstom CCS Cost Analysis, 2011, Power Gen Europe
[53] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[54] Ibid
[55] Ibid

There are an additional 14 projects in the most advanced stage of development, which includes projects that vary by region, storage option, and capture technology. These projects are expected to reach final investment decisions by 2015-2016. Should all of these projects proceed to construction and operation, there would be an additional 25 million ton/year of CO_2 captured to bring the potential total by the 2020 time frame to approximately 65 million ton/year. While not insignificant, this level of deployment remains well below what the International Energy Agency (IEA) projects as needed for CCS to contribute to global CO_2 emissions reductions, as pointed out in Chapter A. By 2050, 10 billion tons/year will need to be captured and stored. Further, 3,400 CCS plants will be needed. It should also be noted that in the last year, 10 projects have been cancelled, largely because of high costs and project complexities (e.g. technical, regulatory, and permitting issues).[56] It would be instructive to review the main reasons why so many plants were cancelled or withdrawn in this one year time period.

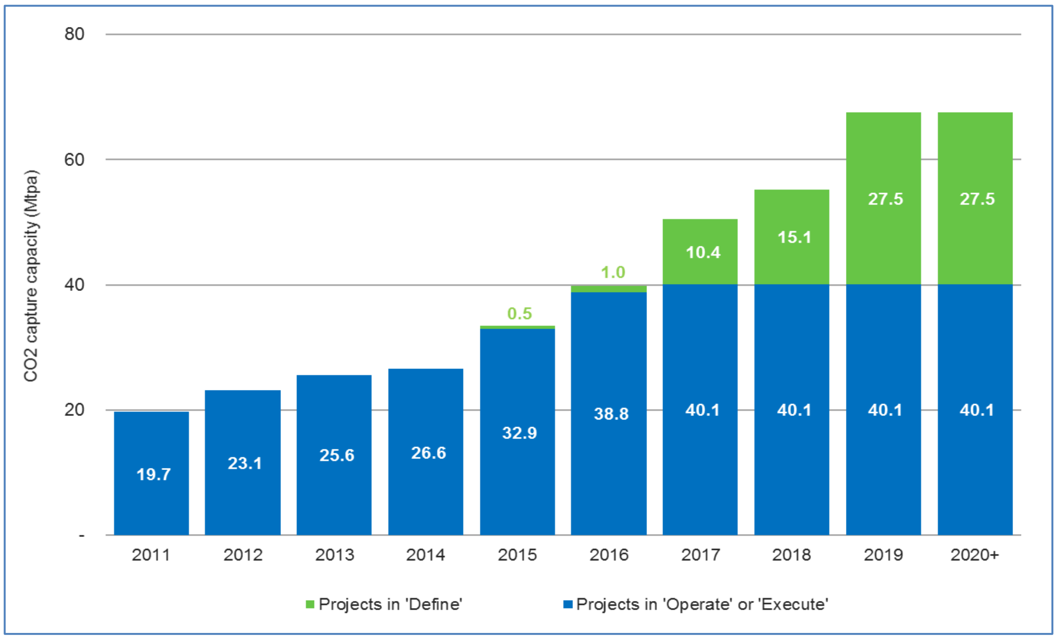

Figure B.2. CO_2 Capture Capacity by Project Lifecycle

In addition, the total number of projects in the pipeline has been decreasing over the last 3 years, as shown in Figure B.3. This trend needs to be reversed. Many more demonstration projects are needed, but the number of projects being planned is being reduced, especially in the power sector.

[56] Global CCS Institute, "The Global Status of CCS 2013", November 2013.

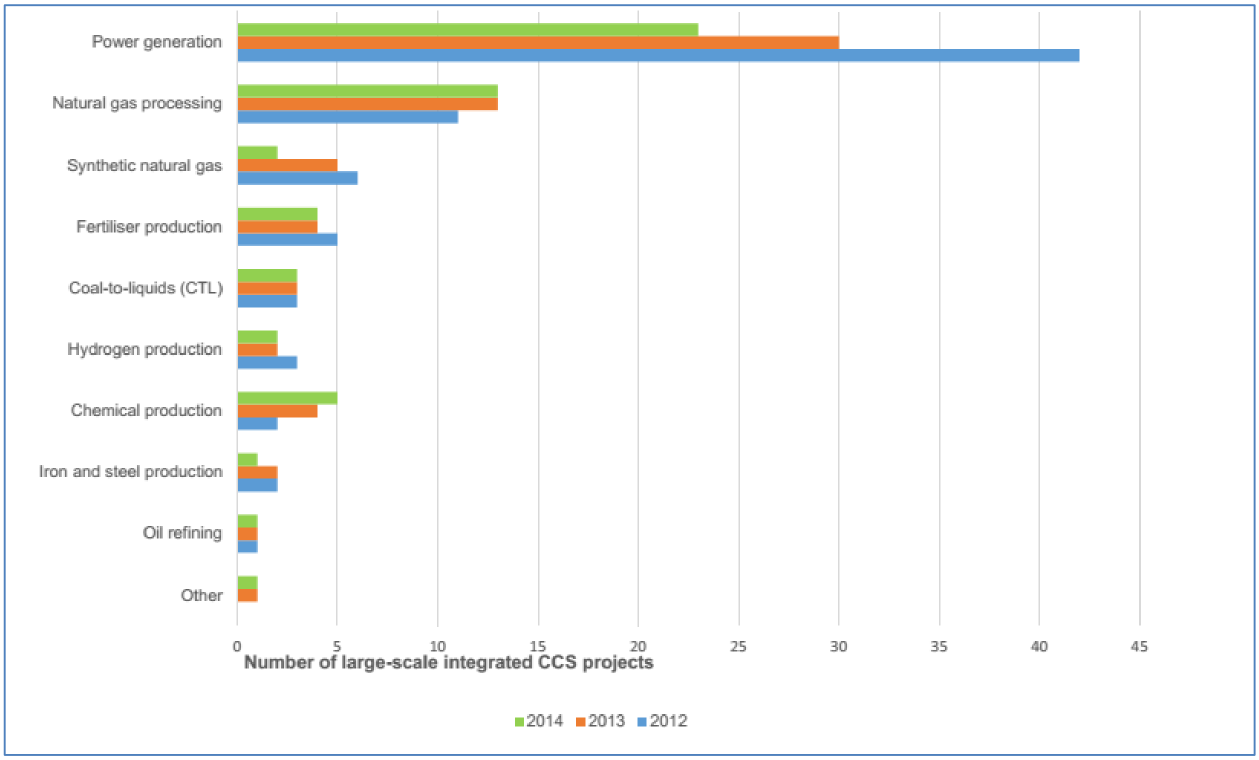

Figure B.3. Large Scale CCS Projects for 2012 – 2014.[57]

3. Power Sector CCS Project Successes

CCS in the power sector has experienced some significant developments recently. One large scale project has begun operation (Boundary Dam, 110 MW) and two others will start up in 2016 (Kemper County, 580 MW and Petra Nova, 240 MW). However, implementation in the power sector has progressed more slowly over the past two decades compared to projects in the industrial sector that include CO_2 separation as a normal part of operations (e.g., natural gas processing, fertilizer production, etc.). The main challenges for power generation with CCS include high cost (capital and operating which influences project financing), large scale integration, access to suitable storage sites, and high energy requirements ("energy penalty") to run the capture unit, including CO_2 compression. The addition of CCS to a power plant will inevitably increase the complexity of the plant. The need is to manage the increased complexity in order to minimize or avoid the extra cost. While there is often a perception that CCS is a technology for coal fired power plants, a large natural gas combined cycle (NGCC) plant produces nearly two million ton/year of CO_2 and will also require CCS under international CO_2 reduction goals. NGCC CCS demonstration projects currently in the advanced planning stage (Sargas in Texas, U.S. and Peterhead in the U.K.) are critical to advancing CCS for NGCC applications. The size, status, and accomplishments of key electricity generating projects with CCS are highlighted in the following sub sections.

[57] GCCSI: Global Status of CCS, 2014, global-status-ccs-2014-supplementary-information-presentation-package.pdf

Plant Barry CCS Project (Status: Operation)[58]

In June 2011, the Plant Barry CCS Project (the world's first coal fired power plant with CO_2 capture, pipeline transport, and saline storage) began capturing CO_2 from a 25 MW slipstream at Alabama Power's Plant Barry using Mitsubishi Heavy Industries' (MHI's) KM-CDR Process® (amine absorption) at a rate of approximately 550 tons per day. (Prior to the Barry Plant CCS Project, AES Shady Point (300 MW) and AES Warrior Run (240 MW) captured CO_2 from a slip stream for the production of dry ice and food grade CO_2, respectively, using the Lummus-Kerr McGee MEA process at the level of about 30 MW each.) The demo plant is capable of capturing up to 0.15 million tons/year of CO_2. Over the life of the project, approximately 0.5 million tons of CO_2 will be transported via a 12 mile pipeline to Denbury Resources' Citronelle Oil Field for injection about 9,400 feet into the Paluxy Formation (saline) as in conjunction with the Southeast Regional Carbon Sequestration Partnership (SECARB) Anthropogenic Test. An extensive CO_2 monitoring, verification, and accounting program was implemented that includes a three year, post injection phase. The Plant Barry demonstration has enabled improvements in system integration and process optimization and reductions in the capture unit's energy penalty. Initially in 2009, DOE awarded $295 million to Alabama Power for an 11 year contract under the Clean Coal Power Initiative for a larger, 160 MW demonstration.[59] This project was withdrawn, citing cost commitments for the overall program. No cost estimates were given for the current 25 MW demonstration project.

Boundary Dam Integrated CCS Demonstration Project (Status: Operation)[60]

In October 2014, SaskPower began operation of the CAN $1.35 billion Boundary Dam Project, the world's first large scale CCS project with integrated post combustion capture technology (amines) on a rebuilt coal fired power generation unit. The cost breakdown was $600 million for the capture plant and $750 million for plant modernization.[61] The plant generates 110 MW of electricity and approximately 90% of the CO_2 emissions (1 million ton/year) are captured for pipeline transport to Saskatchewan oil fields for CO_2 EOR. Any CO_2 from the project that is not used for CO_2 EOR will be injected into a nearby saline formation through the Aquistore project. The Canadian Government contributed CAN $240 million to the project and the Saskatchewan government provided funds through the SaskPower Crown Corporation.

[58] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[59] MIT CCS Database, http://sequestration.mit.edu/tools/projects/plant_barry.html
[60] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[61] www.zeroco2.no/projects/saskpowers-boundary-dam-power-station-pilot-plant

Kemper County Energy Facility (Status: Construction)[62]

Mississippi Power's Kemper County Energy Facility is the world's first greenfield (new build) CCS project on a coal based power plant. This "first of its kind" facility will use Transport Integrated Gasification (TRIG™) technology (a coal gasification method designed for lower rank coals) developed by Mississippi Power's parent Southern Company and KBR in conjunction with the U.S. DOE. The 582 MW mine mouth facility will capture 65% of total CO_2 emissions (approximately 3 million ton/year making it nominally equivalent in CO_2 emissions to a large NGCC plant) using Selexol™ (physical solvent). The CO_2 will be transported via a 61 mile pipeline to EOR fields. While electricity is the plant's primary output, the facility plans to sell other byproducts, including ammonia and sulphuric acid, when possible to help offset costs. Startup is expected in 2016. The $6.1 billion project is the recipient of several federal, state, and local incentives including a $270 million grant from the U.S. DOE Clean Coal Power Initiative (CCPI) and $133 million in investment tax credits approved by the U. S. IRS.[63] With the delays to the project, some of the tax credits will be lost. Over the life of the project, the company calculates the cost savings associated with various incentives to be over $1 billion. The combined cycle portion of the plant has commenced operation on natural gas.

Petra Nova Carbon Capture Project – W.A. Parish (Status: Construction)[64]

The Petra Nova CCS Project is an example of a CCS project with a novel business model. The joint venture (Petra Nova Parish Holdings, LLC) between NRG Energy and JX Nippon Oil & Gas Exploration will capture approximately 1.4 million ton/year of CO_2 (amine absorption) from the W.A. Parish Generating Station, a 3,565 MW coal fired power station near Houston, Texas. A second joint venture (Texas Coastal Ventures) between Petra Nova Parish Holdings and Hilcorp Energy Company will manage the CO_2 transport via an 80 mile pipeline for CO_2 EOR. In cooperation with the Texas Bureau of Economic Geology, Texas Coastal Ventures will develop a CO_2 monitoring plan designed to satisfy requirements of the Railroad Commission of Texas certification program for tax exemptions related to use of anthropogenic CO_2 for CO_2 EOR. A 250 MW slipstream for the 610 MW unit 8 will be sent to the capture plant for 90% CO2 capture.[65] The capture unit will be run with power from a cogeneration plant, which is expected to reduce overall capture costs and increase system flexibility and efficiency. Anticipated startup is the end of 2016. NRG received $167 million from the DOE Clean Coal Project Initiative (CCPI) March 10 2010. Japan Bank for International Cooperation and Mizuho Bank (backed by Nippon Export and Investment Insurance) are providing loans totaling $250 million.[66]

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[62] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[63] MIT CCS Database, http://sequestration.mit.edu/tools/projects/kemper.html
[64] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[65] MIT CCS Database, http://sequestration.mit.edu/tools/projects/wa_parish.html
[66] http://www.bizjournals.com/houston/morning_call/2014/09/nrg-jx-nippon-hilcorp-break-ground-on-worlds.html

Sargas Texas Point Comfort Project (Status: Advanced Planning)[67]

The most advanced CCS project on natural gas fired power, the Sargas Texas Point Comfort Project, is in late stage development. The project plans to capture around 0.8 million ton/year of CO_2 (hot potassium carbonate absorption) from a greenfield, 500 MW NGCC power plant. The site is at the location of the retired ES Joslin power plant. The interconnect and infrastructure needed to support the project, including cooling water diversion and discharge, is currently available and permitted. The CO_2 would be transported via pipeline approximately 50 miles for injection into EOR fields in South Texas. Construction is expected to commence in early 2015. Discussions are underway with DOE for a loan guarantee.

FutureGen 2.0 (Status: Construction)[68]

FutureGen 2.0 involves the oxy-combustion repowering of a unit at the Meredosia Energy Center in Illinois. The repowered unit is designed to have 168 MWe gross output. In steady state operations, it will have near zero SOx, NOx, mercury, and particulate emissions, as well as capturing approximately 1.1 million tons of CO_2/year. Oxy-combustion and CO_2 capture technology is being provided by the Babcock & Wilcox Company and Air Liquide. Captured CO_2 will be transported from the power plant via pipeline to a deep geologic storage site. The project was issued the nation's first Class VI CO_2 injection permits in late summer 2014. Initial construction activities began in August 2014. However, a citizen's suit over the final air permit, PPA litigation, as well as a landowner challenge to the Class VI CO_2 injection permits remain as challenges for the nation's first oxy-combustion power plant. DOE is contributing $1 billion of the total $1.8 billion project cost. The project owner is the FutureGen Alliance, a consortium of global coal mining and equipment companies. Operations are slated to begin in 2018.[69] However, a lawsuit by the Sierra Club over the lack of a Prevention of Significant Deterioration (PSD) permit has jeopardized the project.[70]

The Peterhead CCS Project (Status: Advanced Planning)[71]

Shell U.K. Ltd, with strategic support from SSE Generation Ltd, is developing a CCS project at the Peterhead Power Station, a 385 MW natural gas fired power plant in Aberdeenshire in the U.K. The project plans to capture about 1 million ton/year of CO_2 for transport offshore via a 62 mile pipeline (most of it existing) to the depleted Goldeneye gas reservoir located about 2.5 km beneath the North Sea. In March 2013, the project was chosen as one of two CCS demonstration projects under the U.K. Government's CCS competition. The next phase in the competition is Front End Engineering Design (FEED) after which time Shell and the U.K. Government should make a final investment decision.

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[67] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[68] MIT CCS Database, http://sequestration.mit.edu/tools/projects/futuregen.html
[69] Joseph Divoky, B&W, email communication.
[70] Tomich, J., Midwest Energy News, "FutureGen Officials Say Sierra Club Suit Jeopardizes Project", 8/8/2014, E&E Publishing, LLC
[71] Global CCS Institute, "The Global Status of CCS 2014", November 2014.

White Rose (Status: Advanced Planning)[72]

The White Rose CCS Project in the U.K. is planned as the first large scale oxy-combustion project in the world that is planning to be equipped to co-fire biomass with coal, which, with CCS, could lead to zero or negative emissions. The White Rose project also includes the development of the Yorkshire Humber CCS Trunk line, which will have CO_2 pipeline capacity to enable transport of additional CO_2 from other potential CCS projects in the area, which hosts approximately one fifth of the U.K.'s current CO_2 emissions. The project is receiving funding support from the U.K. government and design studies are underway. The next decision point is expected to occur in 2015. The 448 MW project was awarded a multimillion pound FEED study in July, 2014. Alstom is designing the boiler for the project. Construction is planned to start in 2016 with operation commencing in 2020. The project has been awarded up to €300 million from the European Commission's NER300 program. A consortium consisting of Drax, Alstom, and British Oxygen Corp. will carry out the project.

GreenGen (Status: Advanced Planning)[73]

China based GreenGen, managed by China Huaneng Group, is a joint venture between seven Chinese enterprises and one U.S. company (Peabody Energy). In December 2005, GreenGen Co. was officially established with the mandate from the Government of the People's Republic of China (PRC) to lead the research, development, and demonstration of clean coal technologies leading to a near zero emission coal based power plant by 2015. GreenGen's near term objective is to design, build, and operate the country's first IGCC power plant in Tianjin. The 250 MW IGCC plant went into operation at the end of 2012. As part of an R&D program, some CO_2 is expected to be sent for CO_2 EOR. The next phase will be a 400 MW IGCC with capture and storage. GreenGen is expected to produce a total of 650 MW and 3,500 tons of syngas per day and complete the R&D of key technologies, including large scale hydrogen production from coal, power generation from fuel cells, the hydrogen and gas combined cycle power generation, and CCS. CO_2 storage is planned to begin around 2020.

[72] Ibid

[73] Global CCS Institute, "The Global Status of CCS 2014", November 2014.

4. Polygeneration Project Highlights

With regulatory challenges in the power sector, a number of project developers are looking to polygeneration configurations that have a lower emissions profile than conventional coal plants and, in addition to power, produce a range of products. A polygeneration plant schematic is shown in Figure B.4.[74]

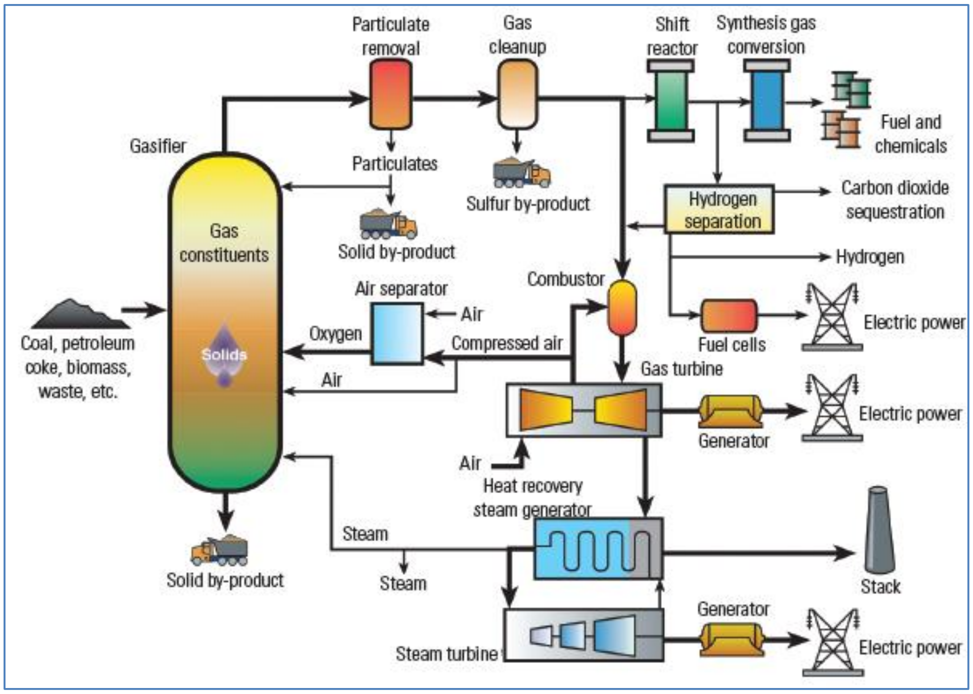


Figure B.4. Polygeneration Plant Schematic

Various feedstocks (e.g., coal, petcoke, biomass, etc.) can be gasified to produce syngas (a mix of carbon monoxide and hydrogen) that can in turn be used to produce fertilizer, methanol, various liquid fuels, specialty chemicals, etc.

The perceived advantages of polygeneration are its product flexibility and its ability to meet tight emissions standards. However, there are also a number of challenges. Coal gasification and CO_2 capture technology have very high capital and operating costs. Polygeneration facilities are even more complex than conventional plants (essentially blending a power and chemical plant). Although Integrated Gasification Combined Cycle (IGCC) technology has been under development for several decades, there are only three full size plants operating in the U.S. (the 260 MW Polk Power Station, the 260 MW Wabash River Plant, and the 618 MW Edwardsport Plant). None of these plants include CCS. Costs have been high for all of these plants.

[74] Ibid

The Texas Clean Energy Project (TCEP) (Status: Advanced Planning)[75]

TCEP, developed by Summit Power Group, is a planned 195 MW_{net} IGCC and urea production polygeneration plant that will be located on a 600 acre greenfield site in Penwell, Texas, about 15 miles southwest of Odessa. (This site had previously been selected as a finalist for DOE's FutureGen project.) The plant will sit atop the oil and natural gas producing Permian Basin and be fully integrated with CCUS technology. Summit's multi revenue stream approach primarily includes the sale of electricity, urea for fertilizer, and CO_2 for CO_2 EOR. All CO_2 EOR operations will include a monitoring, verification, and accounting (MVA) program specially designed by the University of Texas Bureau of Economic Geology to meet the Texas storage requirement for CO_2 storage.[76] This FOAK plant will have fewer emissions than even the cleanest natural gas power plants and be one of the first power producing gasification facilities to demonstrate CCUS at commercial scale. TCEP has received a $450 million DOE grant in support of the project and is expected to reach a final investment decision by the first quarter of 2015.

Hydrogen Energy California (HECA) (Status: Advanced Planning)[77]

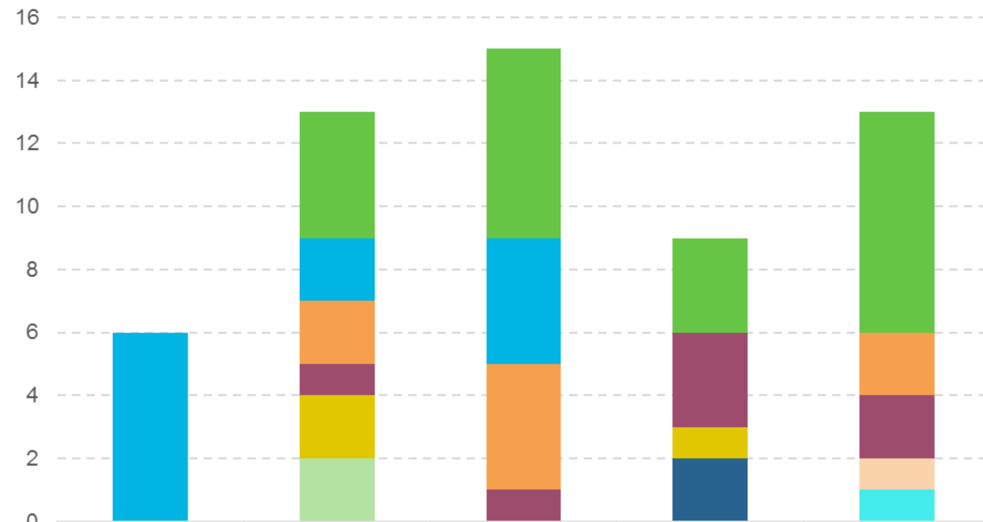
HECA, originally developed by BP and Rio Tinto, is now under the direction of SCS Energy. The polygeneration plant, located in the Central Valley of California, will use a mixture of coal and petcoke from Southern California refineries to generate around 280 MW of electricity for the grid, with the balance being used on site. The facility is projected to capture about 3 million ton/year of CO_2 for CO_2 EOR in the Elk Hills basin and produce about one million tons/year of fertilizer year. HECA is about two thirds of the way through the permitting process and is still negotiating purchase agreements for its electricity, fertilizer, CO_2, and other products.

5. International Trends and Project Highlights

There is considerable CCS large scale project activity worldwide with the U.S. in the lead in terms of project numbers and public and private sector investments. Figure B.5 shows the distribution of projects in the various phases.[78] However, of some concern is the limited number of projects in the very early stages of development ("identify"). As many more demonstration projects will be necessary for the commercialization of CCS (on the order of 5 – 10 GW), projects need to be identified now in order to be planned, designed, permitted, constructed, started up, and operated in a reasonable time frame. Of the 22 projects identified by the GCCSI that are either in operation or under construction, the U.S. is home to 10 with another 6 of 9 in the advanced planning stage. Canada has 5 projects in operation or construction, followed by two in operation in Europe. Brazil and Algeria each have one project in operation. However, the In Salah project in Algeria has ceased injection and is currently in the post closure monitoring phase. China has a total of 12 projects, but only 4 are in an advanced stage of development planning with a final investment decision expected in 2015.

[75] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[76] Texas House Bill 469, passed and signed into law in June 2009, sets the standard of 99 percent retention of CO2 in the subsurface for a minimum of 1,000 years.
[77] Global CCS Institute, "The Global Status of CCS 2014", November 2014.
[78] Global CCS Institute, "The Global Status of CCS 2014", November 2014.

Also, in the advanced planning stage in Europe, 5 are in the U.K. and one is in the Netherlands (ROAD Project). It is important to emphasize that, due to the long lead times needed to successfully complete these projects, commercial scale demonstration projects need to be identified now in order to be in operation by 2025.



	Identify	Evaluate	Define	Execute	Operate
United States	0	4	6	3	7
China	6	2	4	0	0
Europe	0	2	4	0	2
Canada	0	1	1	3	2
Australia	0	2	0	1	0
Middle East	0	0	0	2	0
Other Asia	0	2	0	0	0
South America	0	0	0	0	1
Africa	0	0	0	0	1

Figure B.5. Large Scale CCS Projects by Lifecycle and Region/Country[79]

For convenience, Figure A.8 has been copied below showing a map with the worldwide distribution of projects.

[79] GCCSI uses "execute" for "construction" and "define" for "advanced planning" stages.

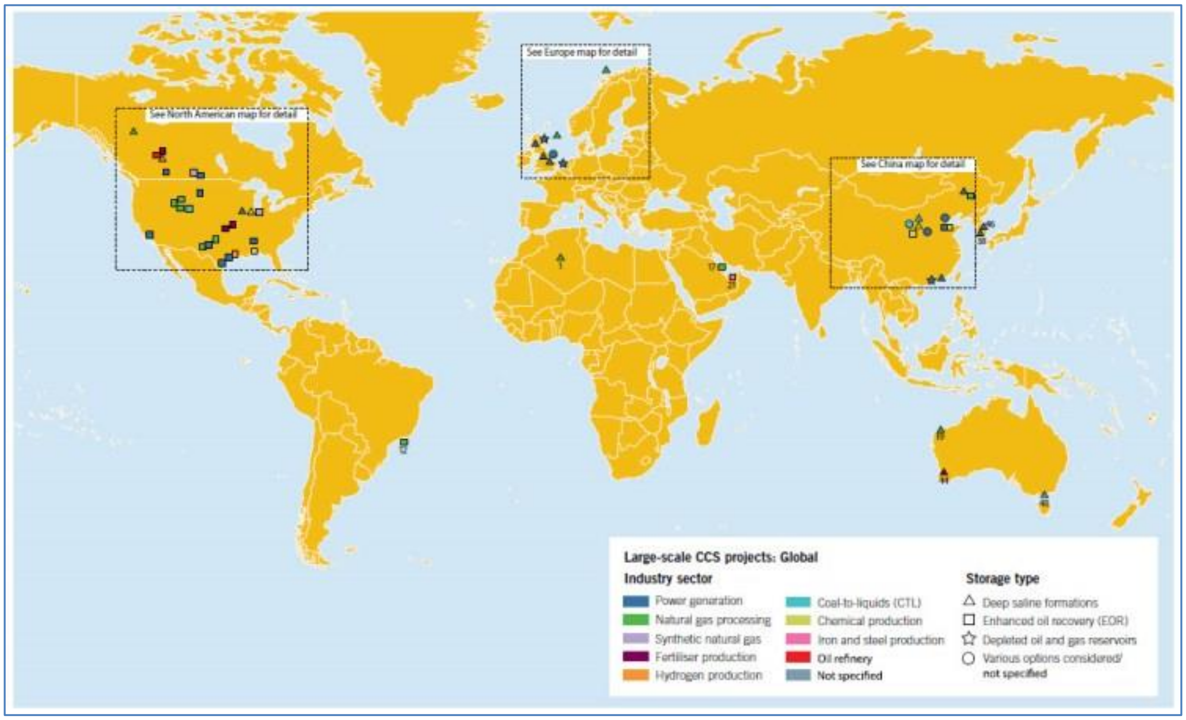


Figure A.8. Large Scale CO_2 Capture Projects in Operation or Under Construction

Project Highlights in the Americas

North America has most of the world's large scale CCS project activity, driven largely by opportunities for CO_2 EOR in the U.S., Canada, and Mexico. Both the U.S. and Canadian governments have also provided CCS investment funds that have been more than matched by industry. Most of the U.S. commercial demonstrations capture and transport CO_2 for CO_2 EOR and only two have dedicated saline storage. In 2016, the world's first greenfield CCS project in the coal based power sector (the Kemper County Energy Facility) is expected to come on line, further demonstrating U.S. and DOE leadership.

Canada's federal and provincial governments have also committed significant public investments in CCS (approximately CAN$3 billion combined with CAN $2 billion from the province of Alberta) with the western provinces of Alberta and Saskatchewan seeing most of the country's project activity. In October 2014, SaskPower started up the Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project, the world's first large scale operational power facility equipped with CCS.

Other notable Canadian projects in construction include Shell's Quest Project and the Alberta Carbon Trunk Line Project, which will connect to two industrial sources of CO_2, Agrium Fertilizer Plant CO_2 Stream and North West Sturgeon Refinery CO_2 Stream. Operations for the Quest Project and the Agrium CO_2 Stream are expected to start in 2015. The Quest Project will be the first commercial scale CCS project at an oil sands facility (the Scotford Upgrader). The CO_2 will be injected into a deep saline geological formation and include a dedicated monitoring program. The Weyburn-Midale oilfield in Saskatchewan, which sources its CO_2 from Dakota Gasification in Beulah, North Dakota, is home to the world's largest CO_2 monitoring project.

Mexico has also begun efforts to lay the foundation for CCS project developments that focus on storage via CO_2 EOR. Finally, Petrobras in Brazil is operating the Lula CCS Project, an offshore gas processing facility with CCS.

Project Highlights in Europe

CCS project activity and ambition in Europe has been significantly curtailed since the start of this decade with a number of project cancellations largely due to limited public funding and the economic downturn. There have also been projects in Germany that have been cancelled due public opposition to on shore CO_2 storage. Norway continues to lead Europe in terms of large scale project investments and activity followed by the UK and the Netherlands.

Technology Focus: The CCS Test Centre Network

The CCS Test Centre Network was launched in late 2012 and currently has four members: CO_2 Technology Centre Mongstad (Norway), National Carbon Capture Center (Alabama, US), SaskPower (Canada), and Statoil. The network's primary goals include:

- Provide enhanced technical learning and confidence that can be beneficial for projects in applying more efficient CCS solutions
- Increase insight and awareness of different technologies for relevant stakeholders that may reduce risks and increase investments in CCS technology
- Provide a broader base of factual evidence which can increase general transparency of CCS, and thereby enhance public awareness and acceptance of the technology
- Increase the value of public and private CCS research and technology investments through increased sharing of lessons learned and results from parallel activities networks.

The Sleipner and Snøhvit projects offshore Norway (both operated by Statoil) have been operational since 1996 and 2008 respectively for a combined storage total of over 17 million tons of CO_2. Norway is also home to Europe's only CO_2 capture test facility, the Technology Center Mongstad (see text box).[80] However, the commercial scale integrated CCS project that was planned at Mongstad has been cancelled largely because of high costs. In the U.K., the CCS Commercialisation Programme has made £1 billion in funding available for first mover CCS projects through a competition process. The White Rose CCS Project and the Peterhead CCS Project both have agreements with the U.K. Government and are currently in the define stage. Final investment decisions are expected in late 2015. The ROAD Project in the Netherlands is the only project in the advanced planning stage in Europe and is expected to make a final investment decision in the coming year.

[80] https://sequestration.mit.edu/tools/projects/statoil_mongstad.html

Project Highlights in the Middle East[81]

CCS is still in early stage development in the Middle East (largely because most oil fields are not yet in the CO_2 EOR stage and there is no regulatory requirement for CCS). A number of projects are advancing in the Gulf region including the world's first CCS/CCUS iron and steel sector project in the United Arab Emirates. In Saudi Arabia, the King Abdullah Petroleum Studies and Research Center has developed "CCS Implementation Strategies for the Kingdom of Saudi Arabia" that will guide project activity. The Uthmaniyah CO_2 EOR Demonstration Project captures 0.8 million ton/year of CO_2 from the Hawiyah Natural Gas Liquids Recovery Plant, which is transported 70 km to the injection site in the Ghawar field for CO_2 EOR. The project includes a comprehensive CO_2 monitoring plan.

Qatar has established the Qatar Carbonates and Carbon Storage Research Centre, a $70 million, 10 year research partnership between Shell, Qatar Petroleum, Qatar Science and Technology Park, and Imperial College London to build Qatar's CCS capacity. The Qatar Fuel Additives Company is building a CO_2 capture unit with a capacity of around 500 tons/day at its methanol production plant near Doha. The captured CO_2 will be used as feedstock to boost methanol production.

Project Highlights in Asia Pacific[82]

China follows the U.S. in terms of the number of projects and has been advancing pilot and demonstration projects, several in cooperation with the U.S. Currently 5 of China's 12 large scale projects are in late stage development, all of which include CO_2 EOR. The Yanchang Petroleum Group intends to capture more than 0.4 million ton/year of CO_2 from coal to chemicals conversion facilities located in Shaanxi Province. The captured CO_2 would be used for CO_2 EOR in the Ordos Basin.

In Eastern China, the Bohai Gulf Basin hosts another major Chinese oil field, the Sinopec Shengli Oil Field. Sinopec is planning two large scale projects, which would utilize CO_2 for CO_2 EOR. These include 1 million ton/year of CO_2 from a coal fired power station (the Sinopec Shengli Power Plant CCS Project) and 0.5 million ton/year of CO_2 "captured" from a Sinopec fertilizer facility in Zibo city, Shandong Province (the Sinopec Qilu Petrochemical CCS Project).

In Northeastern China, the Songliao Basin accommodates two large oil fields, Daqing and Jilin. The China National Petroleum Company plans to capture 0.8 million ton/year of CO_2 from a new natural gas processing facility in Songyuan for CO_2 EOR in the Jilin oil field (the PetroChina Jilin Oil Field CO_2 EOR Project, Phase 2). The GreenGen project plans to initiate CO_2 storage in 2020.

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[81] Global CCS Institute, "The Global Status of CCS 2014", November 2014

[82] Global CCS Institute, "The Global Status of CCS 2014", November 2014

Expanding on work under the Climate Change Working Group (CCWG) and the U.S./China Clean Energy Research Center (CERC) in partnership with the private sector, the U.S. and China will undertake a major CCS project in China that supports a long term, detailed assessment of full scale sequestration. The U.S. and China will make equal funding commitments to the project and will seek additional funding commitments from other countries. In addition, both sides will demonstrate a new frontier for CCUS by implementing a project that captures and stores CO_2 while producing fresh water, thus demonstrating power generation as a net producer of water instead of a water consumer. The project will eventually inject about 1 million tons/year of CO_2 and create approximately 1.4 million m^3/year of freshwater.[83]

Australia's most significant CCS project is based at the Gorgon Liquid Natural Gas plant on Barrow Island where the Gorgon Carbon Dioxide Injection Project will capture over 100 million tons of CO_2 over the life of the project from the LNG facility. Injection of CO_2 is expected to commence in 2016.

6. Global Carbon Capture and Storage Institute Perceptions Survey

The GCCSI conducts an annual survey of CCS project principals covering various aspects of project activities and requirements. Of particular interest are the results concerning the most important enablers for CCS projects. The results are shown in Table B.2[84]

	MOST IMPORTANT ENABLERS FOR YOUR PROJECT				
	RANK	PREFERENCES (%)			NUMBER OF RESPONSES
		1ST	2ND	3RD	
Access to direct subsidies	1	55%	36%	9%	11
Access to a viable CO_2 storage solution	2	31%	31%	38%	13
Off-take arrangements offering guaranteed prices	2	67%	22%	11%	9
Streamlined and efficient regulatory approvals processes	4	21%	21%	57%	14
Regulated returns on CCS investment/s	4	56%	22%	22%	9
An appropriate carbon price	6	20%	40%	40%	10
Access to indirect subsidies	7	25%	38%	38%	8
Compliance with performance standards obligations	8	40%	60%	0%	5
Being paid a premium price for the off-take through a feed-in tariff	9	20%	40%	40%	5
Selling output into a guaranteed market with tradable certificates	10	25%	50%	25%	4
Access to common user infrastructure	11	0%	25%	75%	4

Table B.2 Most Important Policy Enablers

[83] http://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c

[84] Global CCS Institute, "The Global Status of CCS 2014", November 2014

Of particular significance is that the top 3 enablers are access to direct subsidies, access to viable CO_2 storage, and off take arrangements offering guaranteed prices. These are followed by streamlined regulatory approval processes and regulated returns on CCS investments. Lack of these enablers represents the major stumbling block to the successful deployment of large scale CCS projects.

Chapter C: Overview of Current DOE CCS/CCUS Programs: Status & Achievements

Chapter Lead: **Shannon Angielski**
Chapter Authors: Dick Bajura
Frank Burke
William Morris
Andy Paterson
Massood Ramezan
Pam Tomski

1. Key Findings

- Significantly more CCS/CCUS pilot and demonstration projects are needed in order to commercially deploy the technology.

  Due to the high cost and high risk associated with power plant construction, demonstration projects are an absolute necessity. Without adequate demonstration, there can be no commercialization of CCS/CCUS. One or two demonstration units are not sufficient for "adequate demonstration". Plant owners are looking for serial number 6, not serial number 2. That translates into a number of demonstration projects for several technologies. The penalties associated with the potential failure to meet cost and schedule estimates are too great for an individual plant owner to secure PUC rate base acceptance, permits, adequate funding, and insurance for a CCS/CCUS power plant project.

- It is impossible to objectively assess progress against the DOE program goals.

  DOE has a world leading CCS RD&D portfolio. It has enabled the advancement of CCS technology to a point at which some newer CCS technologies are ready for pilot scale testing. Other technologies in the R&D pipeline hold promise for achieving significantly improved cost and environmental performance over the state of the art in the long term. However, the goals are presented in terms of the performance and cost of NOAK commercial systems, but the programs themselves consist of numerous relatively small projects in the early stages of development.

- Funding for DOE programs is inconsistent with DOE goals.

  The DOE programs have consistently been inadequately funded and, as a result, DOE incentive programs for deploying CCS are not as effective as they can and should be. In the absence of any near term market for CCS, significant federal financial support will be necessary for successful development, demonstration, and deployment of CCS. However, the level of federal funding provided to the CCS program is not sufficient to achieve the aggressive goals of the program. The current basket of incentives has not proven to be effective in getting a substantial number of demonstration projects to come to fruition. Without adequate demonstration, there can be no commercialization of CCS.

- CCS technology is not commercially available at large power plant scale.

  The state of CCS development within DOE (no operating demos, two small demos/large pilots, and numerous R&D projects) establishes that CCS is not commercially available for large scale deployment at this time.

- Opportunities to exploit CO_2 for CO_2 EOR applications to expedite CCS/CCUS technology are hampered.

  Projects that couple CO_2 EOR with CO_2 storage tend to have better economics and typically a higher chance for success than CCS projects with just storage. While the Weyburn-Midale CO_2 Monitoring and Storage Project has successfully demonstrated the possibility of safe storage and monitoring, verification, and accounting to support a CO_2 EOR storage system, there are still unresolved regulatory issues in the U.S. associated with EOR storage that could impact project development.[85]

2. Historical Prospective

In the early 1990s, the U.S. DOE encouraged programmatic activities to support entity wide GHG emissions reductions as authorized under Section 1605 of the Energy Policy Act of 1992. Several other DOE initiatives regarding GHG emissions reductions led to the DOE launching the CCS program in 1997 with $1 million in funding. Initially, the program supported both carbon capture and carbon storage activities, with very limited budgets to initiate new efforts. Support for CCS R&D continued during the following few years, with an emphasis on the need to better understand geologic storage of CO_2. As a result, DOE formed the Regional Carbon Sequestration Partnership (RCSP) Program in seven regions across the country in 2003 to help develop the technology, infrastructure, and regulations to implement large scale CO_2 storage. In 2007, DOE initiated 19 small scale and, subsequently, 8 larger scale CO_2 injections in field tests.[86]

During this time, DOE also supported significant efforts to develop and advance carbon capture technologies for both pre and post combustion capture, and added a dedicated post combustion capture program budget to support development of CCS retrofits to existing plants in 2008. Recognizing that CCS could only be successful with integrated CCS technology demonstrations, DOE consolidated demonstration funding to solicit CCS projects under a 3rd Round Clean Coal Power Initiative (CCPI) RFP and also conceived of the FutureGen project as a mechanism to support the demonstration and integration of newly developed technologies.

[85] http://water.epa.gov/type/groundwater/uic/class6/upload/epa816p13004.pdf
[86] http://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure/rcspii

By its 10 year anniversary, the DOE CCS R&D program had advanced to a $100 million annual program, and included major domestic and international initiatives to support the advancement of CCS. Today, the DOE CCS R&D program has grown to a $200+ million annual program with a portfolio of nearly 200 projects across the CCS chain in different stages of development. As a point of contrast, the DOE Office of Energy Efficiency and Renewable Energy has a 2014 budget of $1.9 billion, of which $775 million is in direct support of renewable energy projects.[87] The power industry perceives a policy mismatch in this respect and would like to see CCS technology given the same level of project funding and incentives as that which renewable technologies receive.

3. Background on CCS/CCUS Technology Readiness and the DOE Program

The DOE CCS R&D program has traditionally maintained two areas of focus: Carbon Capture and Carbon Sequestration (including CO_2 EOR). In each of these focus areas, the DOE programs support R&D, pilot scale testing (of various scales), and commercial scale demonstration. Component technologies as well as integrated systems of several different technologies with new power generation platforms can be demonstrated, as well as the transport and storage of CO_2 (or for use in CO_2 EOR). DOE uses a 9 level scale to quantify the technology readiness that the CCS program supports. Table C.1 lists the 9 Technological Readiness Levels (TRLs) with their appropriate criteria.

Table 1 Proposed TRL scale for carbon capture

Technology Readiness Level (TRL)		
9	Commercial operation in relevant environment	
8	Commercial demonstration, full scale deployment in final form	650 MW
7	System prototype in an operational environment	> 100 MW
6	Fully integrated pilot (prototype) tested in a relevant environment	10 - 50 MW
5	Component validation in relevant environment (coal plant)	1 MW
4	Component validation tests in laboratory environment	1 kW
3	Analytical and experimental critical function proof-of-concept	
2	Formulation of application	
1	Basic principles	

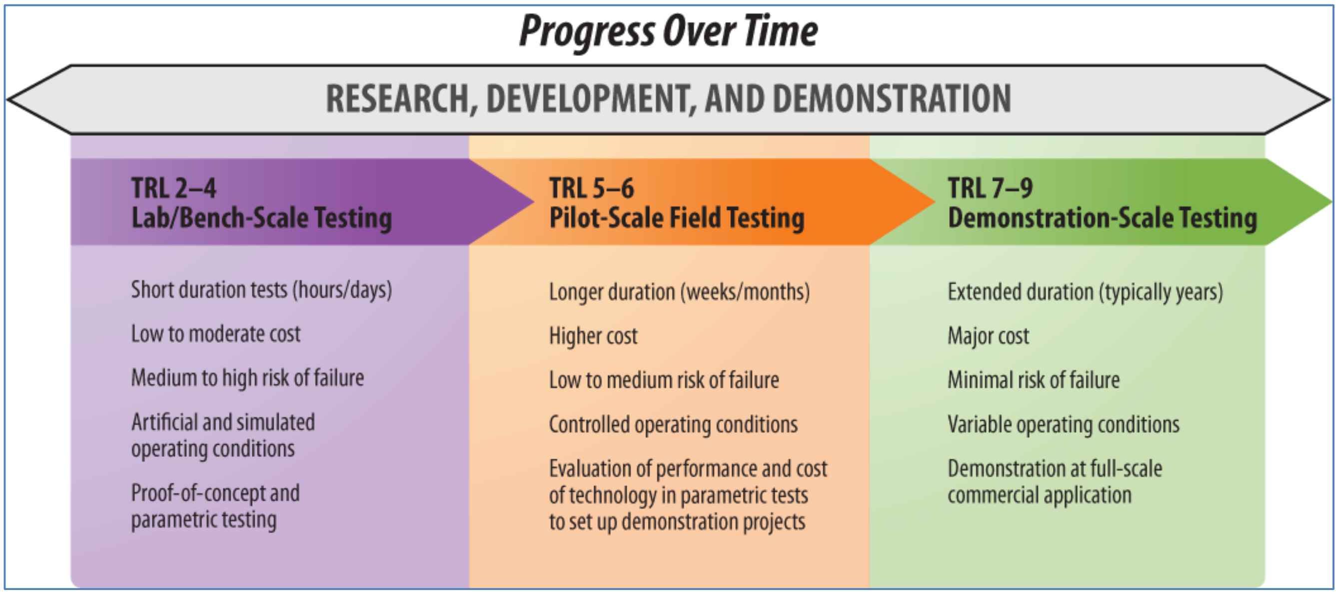
EPRI 2011 (Freeman and Bhown) & GAO 2010

Table C.1. TRL Scale for Carbon Capture

Appendix B includes a chart of the DOE Coal R&D program and provides a brief of description of the different CCS technologies in the DOE program and their TRL levels (as of 2012). Figure C.1 shows the relevant time frame for the DOE program.[88]

[87] Renewable Energy World.Com, "The US DOE's 2014 Renewable Budget Request", Dec. 27, 2014.

[88] http://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/handbook/CO2-Capture-Tech-Update-2013.pdf



2005--------------------------2010------------------------------2020---------------------------2030

Figure C.1. Stages of CO_2 Capture Technology R&D

At the present time, none of the DOE CCS programs have evolved above TRL level 6, the pilot scale field testing in the 10 – 50 MW range. The pilot scale CCS technologies in these programs include monoethanolamine (MEA) scrubbing, chilled ammonia (CAP) scrubbing, and oxy-combustion. Various integrated gasification combined cycle (IGCC) generation projects are advancing to the demonstration stage but are not CCS technologies, in and of themselves. Additional equipment must be provided to adjust the product gas for more substantial CO_2 capture and then the captured CO_2 must be transported to be utilized or stored. The Kemper County IGCC plant will be the first IGCC plant with CCS and, if successful, would be at TRL 8. The PetraNova plant would be at TRL 7. The Boundary Dam demonstration project would be at TRL 7, after some longer period of successful operation. It should be pointed out that commercialization occurs after the successful completion of TRL 9. None of the technologies, thus far, have completed TRL 9, which includes extended operation (typically years) at full scale.

Looking at CO_2 storage, the RCSPs were originally defined according to three different phases: Phase I included site characterization (2003-2005). Phase II included validation (2005 – 2009). Phase III included demonstration and deployment (2008-2017), with injections up to one million tons/year in Phase III. The RCSPs are currently in Phase III and are described in subsequent sections.

4. Current Development Status of DOE Supported CCS/CCUS Technologies

Carbon Capture R&D Program[89]

DOE's Carbon Capture R&D Program consists of two core research technology areas: post combustion capture and pre combustion capture. The current program is focused on developing second generation and transformational CO_2 capture technologies that could provide significant reductions in both cost and energy penalty compared to present day, first generation technologies, resulting in a lower cost of electricity for power generation with carbon capture.

- First Generation Technologies (state of the art technologies): Technologies that are ready for demonstration today. These include MEA scrubbing, chilled ammonia scrubbing, and oxy-combustion (at atmospheric pressure).
- Second Generation Technologies: Technologies currently in R&D, scheduled to become available for large scale testing around 2020, and available for deployment in the 2025 timeframe. These include technologies such as chemical looping, pressurized oxy-combustion, etc.
- Transformational Technologies: Emerging technologies in early stages of development that offer the potential for significant improvements in cost and performance, forecast to be available for large scale testing in 2030 and available for deployment in the 2035 timeframe. These include advanced thermodynamic cycles, novel sorbents, membranes, etc.

Current R&D efforts include development of advanced solvent, sorbent, and membrane technologies. For a complete description of these technology areas, refer to previous NCC reports (2011 and 2012).[90,91] The DOE's existing portfolio includes 70 projects ranging from small scale laboratory and bench level testing, through small scale sub pilot work, to large scale pilot plants as shown in Figure C.2[92]

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[89] DOE Carbon Capture Plan, http://ww.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/Program-Plan-Carbon-Capture-2013.pdf

[90] NCC 2011 Report, http://www.nationalcoalcouncil.org/reports/03_29_11_Final_NCC_Report.pdf

[91] NCC 2012 report, http://www.nationalcoalcouncil.org/reports/NCC-Full-Report-June-2012.pdf

[92] U.S. Department of Energy Office of Fossil Energy and the National Energy Technology Laboratory 2014 Transformational Carbon Capture Technology Workshop, Arlington, Virginia, September 23, 2014, "Interpreting Transformational", presentation by Michael Matuszewski, NETL Program Manager, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/workshop-2014/1-1.pdf

Program Area	Key Technology	Number of R&D Projects					Total
		TRL 1	TRL 2	TRL 3-4	TRL 5-6	TRL 7	
Post-Combustion Capture	*Solvents*		3	9	5	-	**17**
	Sorbents		3	9	2	-	**14**
	Membranes		4	5	1	-	**10**
	Hybrid/Novel		5	3	1	1	**10**
Pre-Combustion Capture	*Solvents*		2	1	→	-	**3**
	Sorbents		2	1	1	-	**4**
	Membranes		2	5	-	-	**7**
	Hybrid/Novel		3	-	-	-	**3**
Compression	*Compression*		-	-	2	-	**2**
TRL Totals			**24**	**33**	**12**	**1**	**70**

Need for fresh, transformational ideas
"Wave" of bench scale projects approaching graduation (1/2 of portfolio)
Up to 12 candidate ≤1MW pilots progressing toward large pilot scale

Figure C.2. TRL Levels of Carbon Capture R&D Portfolio, DOE/NETL

There are currently a dozen second generation projects testing different carbon capture technologies at ~1 MW size that could be ready for large scale pilot testing (~ 25-50 MW) by 2020.

In 2009, DOE established the National Carbon Capture Center (NCCC), operated and managed by Southern Company in Wilsonville, AL. This facility provides an opportunity for developers to test their technologies for extended periods under commercially representative conditions with coal derived flue gas and syngas. The NCCC provides a platform to test and evaluate CO_2 control technologies, including CO_2 capture solvents, mass transfer devices, low cost water gas shift reactors, scaled up membrane technologies, and improved means of CO_2 compression. With the ability to operate under a wide range of flow rates and process conditions, research at the NCCC enables the evaluation of technologies at different levels of maturity.

The NCCC has two different platforms to focus on both pre combustion CO_2 capture and post combustion CO_2 capture. The Post Combustion Carbon Capture Center was installed at the Alabama Power Gaston power plant Unit 5, an 880 MW supercritical pulverized coal unit, to support development of multiple post combustion CO_2 capture technologies at several scales.

The NCCC Pre Combustion CO_2 test facility includes slipstreams with a range of gas flow rates and process conditions using coal derived syngas for verification and scale up of fundamental research and development CO_2 capture projects. The NCCC has the capability to test these systems using a wide range of fuels, including biomass and bituminous, subbituminous, and lignite coals. Since 2008, the NCCC has facilitated the testing and evaluation of over 30 different technologies, and continues to work with developers to test new technologies under development both within and outside of the DOE CCS R&D Program. For a listing of recent and ongoing CCS projects worldwide and at different stages of development, see Chapter B.

In FY 2013 DOE shifted emphasis in its combustion efforts with a new program area called the "Advanced Combustion Systems Program."[93] This program now includes development of oxy-combustion and chemical looping combustion (CLC).

Carbon Storage R&D Program[94]

The DOE's Carbon Storage Program advances the development and validation of technologies that enable safe, cost effective, permanent geologic storage of CO_2 both onshore and offshore in different depositional systems. The Carbon Storage Program is developing enabling technologies, in support of the deployment of advanced power generation with CCS to ensure effective and efficient storage of CO_2. The Program describes the different phases of advancement as "first mover projects" and "broad deployment projects". These phases correspond to the timeframes of second generation technologies and transformational technologies of the carbon capture program, respectively.

- First Mover Projects— First mover projects include early commercial scale CO_2 storage projects, deployed by 2025, with economic incentives that could offset capture costs in depleted oil reservoirs and saline formations.
- Broad Deployment Projects—Broad deployment projects include the next generation of commercial scale advanced and cost effective technologies, deployed by 2035, for challenging storage projects in all storage types.

[93] "Advanced Combustion Systems Technology Program Plan", DOE Clean Coal Program, January, 2013
[94] DOE Carbon Storage Program Plan, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/Program-Plan-Carbon-Storage.pdf

The DOE's Carbon Storage Program includes three principal components: i) Core Research and Development, ii) Infrastructure, and iii) Program Support.

i) Core Research and Development (R&D) focuses on specific aspects of CO_2 storage, including trapping mechanisms, plume tracking and stabilization, pressure management, and identification and mitigation of potential release pathways. The Core R&D efforts range from laboratory to pilot scale activities for the technologies necessary for deployment by 2025 to support first mover projects and by 2035 to support broad deployment projects. The Core R&D includes projects within Geologic Storage Technologies and Simulation and Risk Assessment (GSRA); Monitoring, Verification, Accounting and Assessment (MVA); and Carbon Use and Reuse. The on-going research provides improved understanding of CO_2 trapping and stabilization and the geomechanical and geochemical impacts of injection. In addition, new modeling tools are being developed to reduce uncertainties in prediction of the behavior of CO_2 in the subsurface as well as methods for assessing and mitigating risks.

ii) Infrastructure includes the seven RCSPs, site characterization projects, and other small and large scale field projects. The majority of the effort is conducted by the RCSP network to help develop the technology and infrastructure to implement large scale CO_2 storage regionally and to provide the foundation for commercial scale storage. The RCSP Initiative began in 2003 with initial characterization to assess CO_2 storage potential in various geologic formations throughout the seven partnerships. Currently, the RCSPs are conducting large scale field projects involving the injection of up to one million metric tons of CO_2 per project. RCSP field projects involve site specific characterization, application of simulation and risk assessment, and MVA and assessment technologies in different types of storage reservoirs.

iii) Program Support activities contribute to an integrated approach to ensure that storage technologies are cost effective and commercially available. NETL's Office of Research and Development and the National Laboratory network are working to complement the Storage Program approach to reducing carbon emissions.

Table C.2 shows the RCSP storage types and CO_2 injection volumes.[95]

RCSP	Project Location	CO_2 Source	Storage Type	Storage Goal, Tons of CO_2	Injection to Date, Tons of CO_2
Big Sky	Kevin Dome, Toole County, MT	Natural	Saline	1 million	0
MGSC	Decatur, IL	Ethanol Plant	Saline	1 million	>1.000,000
MRCSP	Ostego County, MI	Natural Gas Processing	EOR	1 million	>250,000
PCOR	Ft. Nelson, British Columbia, Canada	Natural Gas Processing	Saline	2 million	0
PCOR	Bell Creek, MT	Natural Gas Processing	EOR	1 million	>1,100,000
SECARB	Cranfield, MS	Natural	EOR	>3 million	>5,000,000
SECARB	Citronelle, AL	Coal Power	Saline	100-200,000	>120,000
SWP	Farnsworth, Ochiltree County, TX	Ethanol & Fertilizer Production	EOR	1 million	0

Big Sky Regional Carbon Sequestration Partnership (Big Sky)
Midwest Geological Sequestration Consortium (MGSC)
Midwest Regional Carbon Sequestration Partnership (MRCSP)
Plains CO_2 Reduction Partnership (PCOR)
Southeast Regional Carbon Sequestration Partnership (SECARB)
Southwest Regional Carbon Sequestration Partnership (SWP)
West Coast Regional Carbon Sequestration Partnership (WESTCARB)

Table C.2. RCSP Storage Type and Injection Totals (as of Fall 2014)

[95] DOE Carbon Storage Program Plan, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/Program-Plan-Carbon-Storage.pdf

Figure C.3 shows a map of the seven RCSP locations with the names of the storage projects being carried out in those regions.[96]

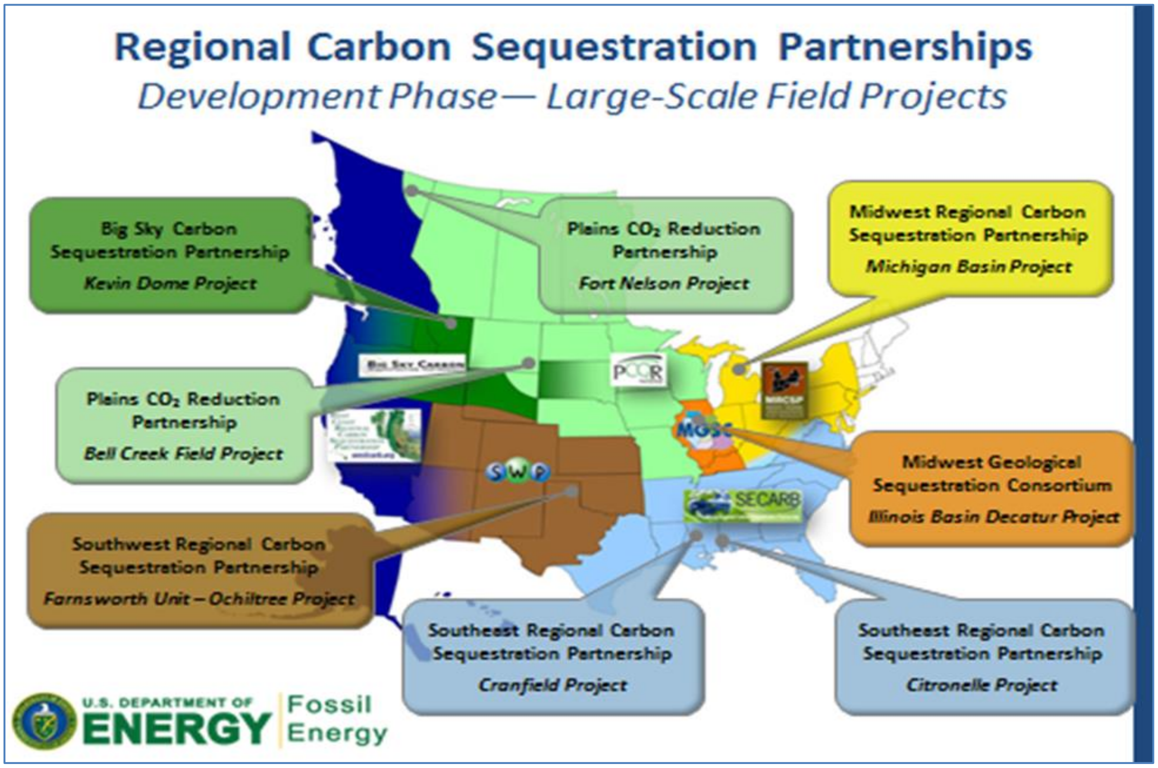

Figure C.3. Location Map for RCSP Storage Sites

[96] Ibid

Figure C.4 shows a map of all of the carbon storage project locations in the U.S.[97]

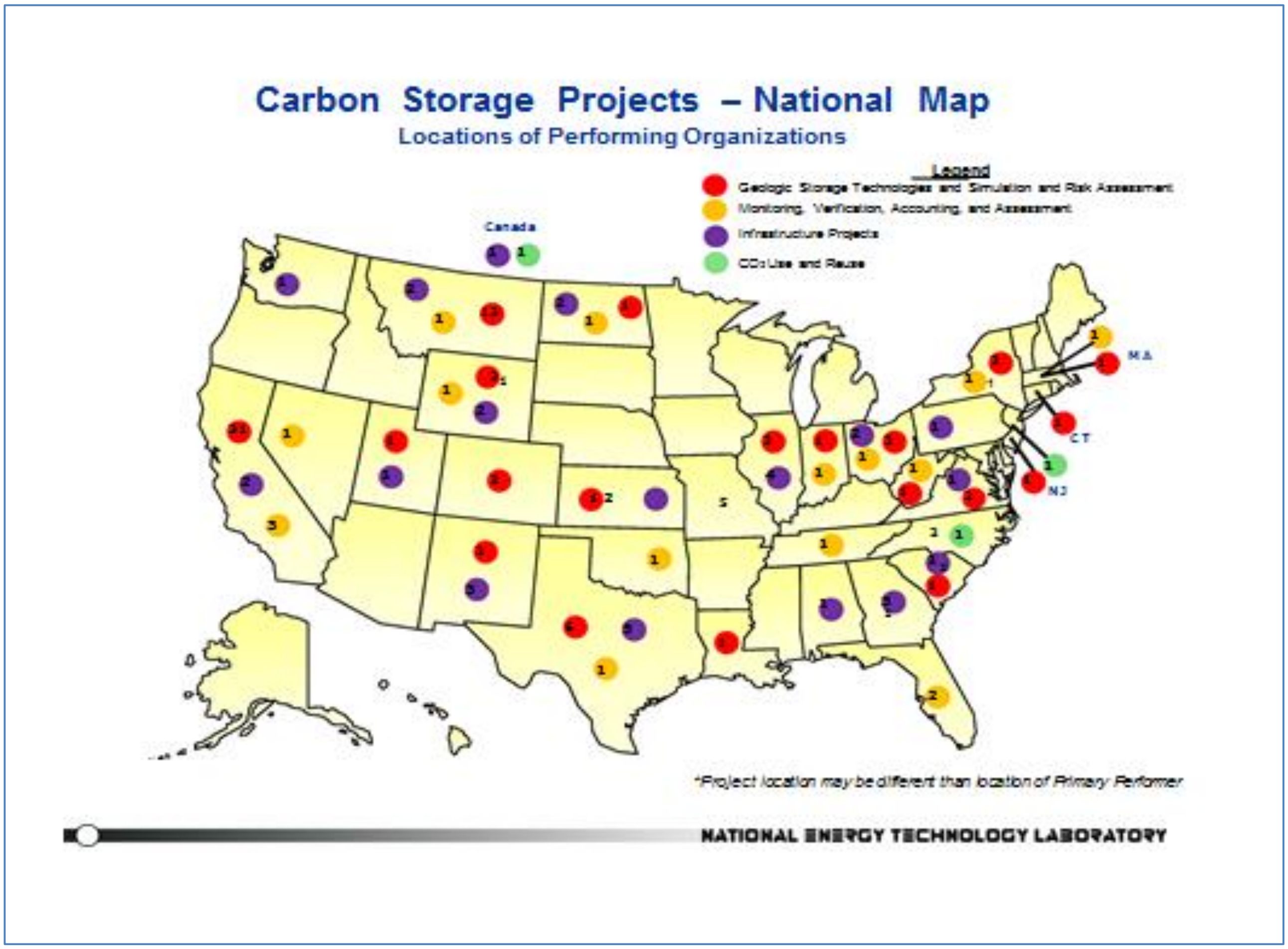

Figure C.4. National Map of DOE Carbon Storage Projects DOE/NETL

<u>CCS/CCUS Demonstration Programs</u>

DOE is addressing the key challenges that confront the industrial deployment of CCS/CCUS technologies by sponsoring large scale demonstrations of key technologies, including the capture, utilization, and storage of CO_2 integrated with power generation and industrial facilities. The programs that support these demonstration scale activities at DOE include the Industrial CCS Program (ICCS), FutureGen, and the Clean Coal Power Initiative (CCPI).

DOE's ICCS Program was initiated in 2009 with $1.52 billion, appropriated through ARRA, to demonstrate large scale CCS technology at industrial facilities such as cement plants, chemical plants, refineries, paper mills, and manufacturing facilities. The program has proceeded in two phases. In the first phase in 2009, 12 projects were awarded DOE research and development funding on a cost share basis. The second phase consisted of two rounds of competitive solicitations. In the second phase in 2010, 3 projects were awarded cost share funds for design, construction, and operation.

[97] Ibid

Two of the projects have been constructed and are currently operating:

- Air Products & Chemicals, Inc. (Allentown, PA): Air Products is partnering with Denbury Onshore LLC to capture and sequester one million tons/year of CO_2 from existing steam methane reformers in Port Arthur, Texas. Air Products is transporting the captured gas to oil fields in eastern Texas by pipeline for use in EOR operations. The project team includes Air Products & Chemicals, Denbury Onshore LLC, the University of Texas Bureau of Economic Geology, and Valero Energy Corporation. The project, which began operation in 2013, cost $431 million in total, $284 million of which came from the DOE ICCS program.[98] The DOE contract will conclude in September, 2015.

- Archer Daniels Midland Company's Decatur, IL project: This project, which began storage operations in 2011, involves the capture and sequestration of approximately one million tons over a three year period from an existing ethanol plant in Illinois. The CO_2 is being sequestered in the Mt. Simon Sandstone, a well characterized saline reservoir located about one mile from the plant. The project team includes Archer Daniels Midland, Schlumberger Carbon Services, and the Illinois State Geological Survey. DOE contributed $141.5 million of the $208 million project cost.[99]

The third project, the Leucadia Energy, LLC project in Lake Charles, LA, has been cancelled due to the anticipated high costs to construct the plant.[100]

The FutureGen program was originally conceived in early 2003 under the Administration of George W. Bush and Secretary of Energy Spencer Abraham. Originally, this multinational U.S. led program was a $1.0 billion, 10 year, public/private effort to construct the world's first pollution free, fossil fuel power plant, with an original IGCC design. The prototype power production facility was intended to serve as a research platform to demonstrate new technologies for electricity and hydrogen production, and to test the integration of full scale energy systems with carbon capture and sequestration in a saline storage reservoir. The original project was to be located in Mattoon, Illinois. In 2010, the project was converted to an oxy-combustion retrofit called FutureGen 2.0. This project will provide a new boiler, air separation unit, CO_2 purification unit, and CO_2 compression system to an existing steam turbine at unit 4 of the Meredosia, IL power plant.

DOE's CCPI Program was initiated in 2002 to address an array of domestic and global energy issues through a series of ongoing demonstrations. The mission of the CCPI is to accelerate the deployment of advanced technologies to produce affordable, reliable, and cleaner electricity. CCPI operates as a cost shared partnership between the government and industry to develop and demonstrate primarily advanced coal based power generation technologies at commercial scale. By law, CCPI demonstrations must meet specific technical requirements (see Energy Policy Act of 2005).

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[98] MIT Carbon Capture and Sequestration Technologies, http://sequestration.mit.edu/index.html
[99] Ibid
[100] http://www.businesswire.com/news/home/20140924006203/en/Leucadia-Ceasing-Development-Lake-Charles-Clean-Energy

Further, technologies selected under CCPI must be "leading edge" technologies not currently deployed in the utility industry. Applications for projects in each round are requested through solicitations. Since 2002, there have been 3 rounds of solicitations, each focused on specific advanced technologies related to coal based power generation. Appendix C summarizes all 3 Rounds of the CCPI Program. Figure C.5 shows the active demonstration projects under the DOE's demonstration scale programs, with the exception of the Leucadia project which has been cancelled.[101]

DOE CCS Demonstration Projects

Portfolio of Capture and Storage Approaches

	Plant Type		Sequestration			Feedstock
	Power	Industrial	Saline	EOR	Rate*	
Pre-combustion						
HECA (IGCC-Polygen)	X	X		X	2.55	NM Sub-bituminous Coal/Petcoke Blend
Southern-Kemper Co. (IGCC)	X			X	3.0	MS Lignite
Summit Texas (IGCC-Polygen)	X	X		X	2.2	WY Sub-bituminous Coal
Leucadia, Lake Charles (Methanol & Hydrogen)		X		X	4.5	Petroleum Coke
Air Products and Chemicals, Inc. (SMR)		X		X	0.925	Natural Gas
ADM (Ethanol Production)		X	X		0.900	Corn Fermentation
Post-combustion						
NRG Energy	X			X	1.4	WY Sub-bituminous Coal
Oxy-combustion						
FutureGen 2.0	X		X		1.0	IL Bituminous /PRB Coal Blend

CCPI | ICCS Area 1 | FutureGen 2.0 | *Rate in million metric tons per year

Figure C.5. Active CCS/CCUS Demonstration Projects, DOE/NETL

<u>CCS/CCUS Computational Modeling Tools</u>

Computational modeling of the dynamics of combustion and carbon capture equipment is one of the tools used to predict the performance of devices (e.g., turbines, gasifiers, absorbers, emissions control units, separation devices, etc.). Modeling of device operations must then be assembled into a process model to study, in an integrated system approach, the operation, performance, and cost of an overall power generation system.

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[101] DOE/FE-0565, Major Demonstration Programs: Program Update 2013, http://www.netl.doe.gov/technologies/coalpower/cctc/index.html

The DOE Office of Fossil Energy has developed a computational toolbox for analyzing the performance of power generation systems over the range of sizes from small, laboratory scale reactors to larger scale systems in the size range of bench scale and small pilot scale units. The DOE activity is organized around eight technical areas designed to produce validated results of process or system performance and to assess risk with a quantifiable uncertainty. Performance estimates are dependent on including the relevant physical processes in constructing the models, using computers with sufficient computational power to simulate the dynamics of the systems studied, and estimating the effects of changing the system size from small scale laboratory systems designed for proof of concept to large scale demonstration units.

The DOE modeling program includes conducting experiments on real systems for the purposes of model calibration and validation. Most model validation is obtained at small scales. The DOE modeling group works with an Industrial Advisory Board to obtain advice and data from industrial programs operating at larger scales than available at the federal laboratories for use in calibration of modeling assumptions. Conducting validation experiments at scales larger than units 1 MW or greater becomes expensive. The ability to predict the performance of new technologies at demonstration or commercial scales could result in substantial cost savings by reducing the amount of large scale testing that would need to be done on expensive demonstration units. Demonstration units are still needed, but the number and extent of testing might be reduced by accurate analysis from calibrated models. However, accurate calibration and validation usually entails substantial test work to generate the needed data on large scale testing platforms. Much of the modeling work has been conducted under the Carbon Capture Simulation Initiative, a collaboration of five national laboratories (Lawrence Berkeley, Lawrence Livermore, Los Alamos, Pacific Northwest, and the National Energy Technology Laboratory).

The National Risk Assessment Partnership (NRAP) is a collaboration involving the five national laboratories noted above. This program focuses on developing risk assessment tools for the safe and permanent storage of CO2 in geologic formations. Similar approaches are taken as with computational modeling of devices and power generation systems. Computational toolsets are being built and calibrated for underground storage along with gathering validation data to quantify the potential impacts related to the release of CO2 or brine from CO2 storage reservoirs and the potential ground motion impacts due to injection of CO2.

The DOE computational modeling effort would be enhanced by:

- Expanding the range of platforms studied to second generation and transformational technologies, for power system modeling and expanding the number of demonstration sites for geologic storage to provide validation information for computational predictions of storage reservoir performance,
- Continued interaction with industrial advisors with special emphasis on the analysis of device specific geometries for which high fidelity data is available for model validation, and
- Continued development of scale up rules to result in the reduction of risk and uncertainty as experimental systems approach demonstration or commercial scale in size.

5. DOE CCS/CCUS Program Goals

This section analyzes and assesses the DOE program goals for Carbon Capture and Carbon Sequestration RD&D activities.

Carbon Capture Program Goals

The original Carbon Capture program goals were documented in DOE presentations and published program plans beginning in 2005 and continuing through May 2014.[102] The original goal was to have 90% CO_2 capture with 99% permanent storage for no more than a 10% increase in the cost of services by 2012.[103] There may have been earlier goals reported, but these dates are sufficient to show how the aspirations of the DOE CCUS program have evolved over time. In 2005 and again in 2006, National Energy Technology Laboratory (NETL) presentations and budget requests contained the following information, shown here in Table C.3, identifying the goals of the carbon capture portion of the program.[104]

CURC-NETL 2005-2006 Goals

Year	COE Penalty IGCC Plants (% Increase)	COE Penalty PC Plants (% Increase)
2002	30	80
2007	20	45
2012	10	20
2015	<10	10
2018	0	0

DOE 2008-2012 Goals

2020 Demo	IGCC Plants	PC and Oxy-Combustion	
COE Penalty (% Increase)	<10%	<35%	
CO_2 Cost ($/tonne)	$25	2008 Goal	2012 Goal
		$45	$25

[102] "Carbon Sequestration", Scott M. Clara, U.S. DOE-NETL Coal Utilization Research Council Review. Pittsburgh, Pennsylvania, March 8-9, 2005

[103] National Research Council, "Report of the Panel on DOE's Carbon Sequestration Program", 2007

[104] "Carbon Sequestration", Scott M. Clara, U.S. DOE-NETL Coal Utilization Research Council Review. Pittsburgh, Pennsylvania, March 8-9, 2005

DOE 2013 Goals

2nd Generation 2020-2025 $/tonne		Transformational 2030-2035 $/tonne	
Retrofit	2nd Generation	Retrofit	Transformational
$45	<$40	<$35	<$10

DOE 2014 Goals

2nd Generation 2020-2025 $/tonne	Transformational 2030-2035 $/tonne
~ $40	< $40

Table C.3. DOE Program Goals Over Time

Early DOE program goals were overly optimistic in terms of both level of performance and cost. These have become progressively less optimistic over time, but still appear to be unrealistic, particularly with regard to the projected time to accomplish commercial demonstrations. With its current funding limitations, the DOE program can take technologies at most to the point of pilot testing. Thus, the DOE goals are unlike those of commercial entities, which must show a path through to commercial application to garner corporate financial support. These goals do not include transportation and storage costs and represent the presumed success of a number of technologies that would be applied in concert to each technology category.

There are certain external factors also impacting the ability to achieve DOE program goals that are outside the control of DOE, including U.S. market constraints, competition with low cost natural gas (the shale gas revolution), permitting, financing, legal challenges, delays for FOAK demonstrations, lack of support for the projects both at the federal and local levels (such as PUC support), and lack of sufficient funding to put the full weight needed behind both the R&D and the demonstrations of CCS technologies.

While there is clearly an indication that DOE is progressing towards the program goals, the immediate deliverables within the reach of the DOE programs will never be able to achieve those “commercial grade” goals. Research and pilot testing, such as that at the NCCC, if brought to commercial level, may reduce the incremental levelized cost of electricity (LCOE) attributable to CCS or the cost of CO_2 capture to the level of DOE’s goals. However, industry does not have sufficient information to measure the progress of individual projects or the DOE program as a whole towards achieving those goals.

In addition to the quantitative changes in the goals, there have been two structural changes. First, the early goals were presented in terms of a reduction in the cost of the technology expressed as the cost of electricity (COE), while later goals were presented in terms of cost of CO_2 capture. In 2012, the goals were presented in both terms. [105] Second, in 2013 and 2014, the goals were segregated into the phases of 2nd Generation and Transformational technology. While the cost goals were intended to show progressive improvement over time, eventually leading to cost parity with conventional technology, the time frames have moved well into the future. Cost parity is now an objective for 2035.

Regardless of how they were expressed, it is clear that the goals have become less optimistic over time. There may be at least two reasons for this. One is simply that power plant construction costs have increased even more quickly than general inflation, with a particularly large jump in the mid 2000s. Although the energy penalty represents a significant fraction of carbon capture costs, it also impacts the capital cost component of the capture system. Therefore, a cost goal expressed in absolute terms, like $/ton CO_2 captured, may well increase over time, although a relative goal, like the percent increase in LCOE, may not.

A second possible reason for the less optimistic goals is that in the early years there was less understanding of CCS technology in power generation applications. Thus, early goals may not have completely accounted for the energy penalty that contributes to the higher cost of CCS. As the program has progressed and more knowledge has been acquired, the goals have been adjusted accordingly.

Assessing progress against the DOE's carbon capture goals is problematic, because they are couched in terms of the cost and performance of full scale, commercial, NOAK facilities. Therefore, until such facilities are built and their cost and performance known, there is no objective way to determine that the goals have been met. However, it is clear from the fact that the goals have become less ambitious over time that the DOE has not concluded that any of the those long term goals have been met to date. Technical progress has been made, but comparison of interim research results to such broadly stated cost goals is not possible. Also, as history has shown, the time targets of DOE goals appear to be overly optimistic, even taking into account the fact that DOE goals are not based on commercialization of a technology, but rather, only on having a FOAK technology design available for demonstration.

[105] To put these numbers in perspective, in a DOE study (Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity , Revision 2a, September 2013 , DOE/NETL-2010/1397) the LCOE of a coal-fired power plant with 90% CO2 capture using current technology is 80% greater than for a supercritical PC plant without CO2 capture. This equates to a CO2 capture cost of ~$60/ton.

In summary, the DOE CO_2 capture program goals are not the kind of goals that would be set by the private sector, which must envision a path through to commercial application within a reasonable timeframe in order to justify a return on investment. At best, the DOE programs are intended to bring technologies to the point of large scale demonstration, although it's unclear that adequate funding will be available through existing budgets to bring individual technologies much beyond small pilot scale, such as those tested at the NCCC. The project milestones and successes of individual projects within the program may be understood internally within DOE, but are difficult for outsiders to assess. It is particularly difficult to understand, with the necessary precision, how much these goals contribute to meeting the overarching program goals described above.

Carbon Storage Program Goals

The quantitative goals of the carbon storage segment of the program are to achieve 99% storage permanence and to be able to determine the storage capacity of a sequestration site to within +/- 30%.[106] DOE often uses an estimated cost of $10/ton for CO_2 transportation and storage. The DOE CO_2 storage plan frequently mentions cost effectiveness and does include modeling work to estimate cost, but it does not appear to contain any quantitative goals for transportation and storage cost. The program also has qualitative goals to develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness, and to develop best practices manuals. As with the carbon capture goals, these storage goals pertain to the performance of future commercial sites, and, therefore, it is difficult to assess progress against them.

The RCSP program does provide some metrics that allow an assessment of progress against objectives for that very important component of the CCS program. The formation of the seven partnerships, spanning essentially all of the country, with broad participation by government, industry, and academia was a singular accomplishment. Further, the structure of the program with its three phases of Assessment, Validation, and Development provides an objective way to measure progress. The partnerships have all progressed through the first two phases, and most have moved into the Development phase, involving larger scale injections tests.

[106] Clean Coal Research Program, United States Department of Energy, Carbon Storage Technology Program Plan, September 2013.

6. Accomplishments of the DOE CCS/CCUS Program

Post Combustion Carbon Capture

Post combustion carbon capture has been a major part of DOE's CCS program since 2008 when it was first delineated under the "Innovations for Existing Plants" program, with the idea that post combustion capture could be retrofit to existing pulverized coal plants. In 2014, the budget for post combustion capture was $80 million compared to $12 million for pre combustion capture. The emphasis on post combustion capture is appropriate given the large amount of existing combustion capacity in the U.S. and throughout the world. If cost effective capture technology can be developed and retrofit to these units, a significant reduction in CO_2 emissions could be achieved without waiting to replace existing combustion units with new CCS equipped units over time.

What is unclear is when the DOE research on post combustion capture will move beyond the bench and small pilot scale and into commercial availability. It appears that the current budget is spread among a number of smaller projects as shown in Figure C.2 above. This has the advantage of moving many ideas forward to maximize the prospects of some successes. However, it also appears that many of these projects are being undertaken by smaller entities that may not have the means to move such technologies beyond bench scale without the involvement of commercial vendors. It's improbable that these projects can advance through large pilot scale within the current DOE funding opportunities. Additionally, it is unclear from an industry perspective whether there are technologies in the DOE program that will be ready for commercial demonstration by 2025, as stated in the DOE goals.

The National Carbon Capture Center (NCCC) provides a valuable resource for the DOE program and developers utilizing the NCCC.[107] The NCCC is providing data that can be used by DOE and developers to assess technical and economic potential of pre and post combustion technologies. The Center provides an opportunity to advance the development of technologies beyond lab scale into small scale pilots by testing them in a controlled environment that allows for comparison against other technologies under similar conditions. What is less clear is how these results are being analyzed and what progress they represent in meeting DOE's long term goals. Developers from around the world are seeking opportunities to test their systems at the NCCC.

[107] The National Carbon Capture Center, http://nationalcarboncapturecenter.com

There has also been some success in advancing amine scrubbing, which has benefited from DOE sponsorship and which appears to be a candidate for commercialization in the 2020-2025 timeframe. Notably, the MHI amine scrubbing process was used at Southern Company's Plant Barry to remove CO_2 from a slipstream (25 MW scale) from that coal fired power plant. The CO_2 was used by the SECARB regional partnership in one of the RCSP Development Phase injection tests. The SECARB injection program, managed by the Southern States Energy Board, has been extended to facilitate integrated CO_2 capture, transportation, and storage testing during 2015. DOE provided funding to Southern Company for a series of efficiency enhancements to the capture system, which will provide additional operational data at a scale necessary to understand the technology for commercial applications. As a result, the MHI technology is now slated for use in the NRG Parish commercial demonstration project which is receiving funding under the CCPI program, and is projected to be lower cost and have significantly less energy penalty than earlier amine scrubbing systems.[108]

Another post combustion capture technology that has advanced is Alstom's chilled ammonia process, which was tested at AEP's Mountaineer plant by removing CO_2 from a slipstream (20 MW) for storage in a saline aquifer. The Mountaineer project was proposed for a 250 MW demonstration under CCPI Round 3, but did not go forward due to lack of approval for rate recovery through two state Public Utility Commissions (PUCs), a source of revenue which was necessary to advance the project.

Pre Combustion Capture

DOE has done warm gas cleanup work at the 50 MW scale through testing at TECO's 312 MW IGCC Polk Power Plant in Florida.[109] In 2010, DOE awarded TECO funding from ARRA for the addition of CCS to the existing warm gas cleanup (WGC) project at TECO. The WGC project removes sulfur and trace contaminants. Tying in CCS required the addition of a shift reactor and a syngas cooling capability. The CO_2 removal is with activated methydiethanolamine and is testing the ability to capture 90% of the available CO_2 in a syngas 50 MW slipstream. The plant began capturing CO_2 in April 2014. The plan originally included the injection and geologic sequestration of up to 300,000 tons CO_2 under a Class V permit. Unfortunately, due to funding and timing constraints, the CO_2 will not be sequestered. Project funds must be utilized by September 2015 under ARRA requirements. Many projects with ARRA funding may be in jeopardy.

[108] "From Lubbock, TX to Thompsons, TX: Amine Scrubbing for Commercial CO2 Capture from Power Plants", Gary T. Rochelle, International Conference on Greenhouse Gas Technologies: GHGT-12, Austin, TX, October, 2014
[109] "Polk Station Warm Gas Cleanup & CCS", SECARB, 6th Annual Stakeholders Meeting, March, 2011

Carbon Storage Program

The most evident progress in the carbon storage program can be seen in the Regional Carbon Sequestration Partnership (RCSP) program. The program was structured in three phases: 1) to assess carbon storage potential throughout the U.S., 2) to validate this potential with small scale storage projects, and 3) to then demonstrate storage potential with larger scale injections. Of the seven partnerships, all but one have or are expected to have, progressed to the demonstration stage. The RCSP program is recognized as a world leading effort, having been acknowledged as such through an independent peer assessment by the IEA.[110] The IEA concludes that "from an international perspective there was unanimous agreement that the RCSP is a world leading initiative that is generating valuable results and experience." The RCSPs have also been instrumental in DOE's construction of the NATCARB atlas of carbon storage potential and a series of eight "best practice manuals" covering a wide range of CO_2 storage topics[111].

While the program has been successful in developing a knowledge base regarding CO_2 storage, there have been some limitations to the program. The CO_2 demonstration projects were originally envisioned as eventually injecting one million ton of CO_2 or more in total (in Phase III). Only two have reached that level. One industry source stated that the reason was that the funds budgeted by DOE were insufficient to pay for the amount of CO_2 that would be required to reach that injection rate. Another consequence of these budgetary limitations is that only two of the demonstration projects to date are injecting CO_2 into a saline aquifer, and only one of those will reach one million tons of total injection (over three years). The others are using the CO_2 directly or indirectly for CO_2 EOR. CO_2 EOR may well be the reservoir of choice for early CCS projects, but non CO_2 EOR injections will ultimately be more important if volumes of captured CO_2 increase, and if CCS is to be done in locations throughout the world that do not have access to CO_2 EOR fields and at the scale needed to meet international CO_2 emission reduction goals.

Another comment on the RCSP program is that some of these consortia are led largely by non commercial entities, and, as a result, may lack the "institutional push" to move beyond research into a more commercial mode of operation. While the RCSPs have been very successful at research endeavors, it has been industry's recommendation for a number of years that there is a major need to move beyond the research phase and do characterizations by commercial service companies of a number of power plant scale, non CO_2 EOR storage sites (i.e., sites capable of receiving ~3 million ton/year of CO_2 over 30 years). Such an exercise would help to clarify many of the legal, technical, and insurance issues that would face a developer contemplating a full scale CO_2 capture project, and provide a better estimate of the cost of developing a full scale injection field.

[110] "IEAGHG 2013 Peer Review of US RCSP Phase III Projects", Public Summary Report: 2014/TR2, May 2014
[111] http://www.natcarbviewer.com/pdf/NatCarbUsersGuideAtlasV.pdf

Advanced Combustion

In addition to pre and post combustion CO_2 capture, the DOE program is developing advanced combustion technologies that, when coupled with CO_2 capture, are projected to be highly efficient energy conversion platforms that have significant potential for reducing the energy penalty and costs when capturing CO_2. Such technologies include oxy-combustion (including pressurized) and chemical looping. Oxy-combustion, in particular, appears to be relatively advanced, with a number of projects underway or planned worldwide. DOE NETL's efforts included providing project support to small companies, such as the project with Jupiter Oxygen for development of high flame temperature oxy-combustion with carbon capture.[112] Jupiter Oxygen now has a letter of intent for a China demonstration project, and demonstration project initiatives in several countries. DOE will receive part of the revenue from patents developed during the project with Jupiter Oxygen.

Large scale boiler manufacturers began working on the potential for oxy-combustion boilers in the 1990s. This progressed through several stages, with invaluable support from DOE. Babcock & Wilcox (B&W) technology development, while not part of the original DOE program, is now planned for use in the FutureGen 2.0 project.

In the early 2000s, the DOE supported a 3 MW testing of oxy-CFB (circulating fluidized bed), as well as in extensive technical/economic studies of oxy-combustion power plants evaluated against alternate CCS approaches.[113] Starting in 2008, a comprehensive program was launched with the DOE that focused on utility scale oxy-combustion power plants based on tangentially fired boilers. This program featured testing of five coals of differing rank at a 15 MW oxy-combustion, tangential boiler simulation facility which included air quality control systems and CO_2 processing and compression. This program also included extensive numerical modeling, development of design and operating guidelines, and 350 MW and 900 MW reference design development.[114] These efforts complemented several other demonstrations at the 30 MW scale. The knowledge base gained through the DOE support has now led to the White Rose Project in the UK, a 462 MW ultrasupercritical, oxy-combustion, commercial scale power plant with full CCS. The plant is now in the engineering and design phase with projected commercial operation in 2018-2019.[115] (See Chapter B for details.)

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[112] Schoenfield, M., et al, "Oxy-Combustion Burner and Integrated Pollutant Removal Research and Development Test Facility Final Report", 2012

[113] DOE's Greenhouse Gas Program or Greenhouse Gas Emissions Control By Oxygen Firing In Circulating Fluidized Bed Boilers: Phase 1 – A Preliminary Systems Evaluation, Final Report includes the following volumes: Volume 1 – Evaluation of Advanced Coal Combustion & Gasification Power Plants With Greenhouse Gas Emission Control Volume 2 – Bench-Scale Fluidized Bed Combustion Testing, Cooperative Agreement No. DE-RFC26-01NT41146, Submitted May 15, 2003, Phase I Performance Period: Sept 28, 2001 – May 15, 2003

[114] DOE's Recovery Act Oxy-Combustion Technology Development for Industrial-Scale Boiler Applications Final Report includes the following volumes: Volume 1 – Executive Summary, Volume 2 – Experimental Program, Volume 3 – Modeling and Validation, Volume 4 – Reference Oxy Boiler Designs, DOE Contract Number NT0005290, Submitted July 29, 2014

[115] MIT Carbon Capture and Sequestration Technologies, http://sequestration.mit.edu/index.html

One important aspect of the Advanced Combustion Systems Program is that it has attracted the participation of major vendors who have the corporate ability and desire to move these technologies to the commercial market. If the work continues, they expect to be doing large scale tests of second generation oxy-combustion and chemical looping by 2025. However, these projects will require substantial government funding. That funding is not included in the current DOE budget. In any event, it is unlikely that these early demonstrations will meet the cost goals laid out by DOE for NOAK commercial plants.

Progress is also being made in the development of chemical looping and pressurized oxy-combustion technologies, with recent awards being made to pilot Alstom and B&W/Ohio State University's chemical looping technologies and Aerojet Rocketdyne's pressurized fluidized bed technology to scale up those technologies to small pilot scale testing. Assuming the tests are successful and that both continued support and funding is made available to enable the advancement of these technologies through commercial demonstration, it is possible they could be available in the time frames proposed by DOE, but their success and capability in achieving the DOE cost goals are currently less clear. However, at this time it does not appear that existing annual budgets for the CO_2 capture program or the Advanced Combustion Systems Program would be sufficient to support the advancement of these particular technologies into large scale pilots and commercial demonstrations.

CCS/CCUS Demonstration Programs

There is currently only one commercially operating CCS/CCUS demonstration project of one million tons/year capacity supported by DOE: the Air Products Port Arthur (Texas) project under the Industrial CCS (ICCS) program. In June of 2014, Air Products announced that it had successfully captured more than one million metric tons of CO_2 at Port Arthur for use in CO_2 EOR. While this project is important in advancing the commercialization of CCS/CCUS from a storage perspective, it does not represent the platform for demonstrating CCS comparable to the DOE program goals on the basis of LCOE or cost of CO_2 for power generation applications. Most of these demonstration projects have come from the Clean Coal Power Initiative (CCPI). Only the Kemper County Energy Facility and NRG Parish are currently in construction with start dates expected in 2016.

As illustrated in Table C.4, the CCPI program does not appear to have a high success rate with 10 of the 18 projects that initially received funding never breaking ground and with only four completed projects to date.[116] In a 2003 presentation, the DOE identified several technical, economic, and market challenges facing awarded projects that are still valid today.[117] These include securing the minimum 50% private sector cost sharing for FOAK (high risk) technologies, resolving public/private intellectual property issues, uncertain mid and long term market conditions (e.g., energy prices, environmental regulations), permitting issues, and long term liability issues.

Status	**Number of Projects**
Complete	4
Active	4
Withdrawn	7
Discontinued	2
Negotiations Ceased	1
Total	18

Table C.4. Status of CCPI Projects

Another observation regarding the CCPI program is that historically, only a small number of submitted project applications are selected for funding as shown in Table C.5.

	Applications Submitted	Applications Selected
Round 1	36	8
Round 2	13	4
Round 3	36	6

Table C.5. CCPI Applications Submitted and Selected

[116] Based on DOE-NETL Status Report on CCPI Round 1 Activities, August 26, 2003: http://www.netl.doe.gov/publications/proceedings/03/ccpi/CCPI_R1status.pdf; CCPI Round 2 Project Selection Announcement, October 2004: http://energy.gov/fe/ccpi-round-2-selections; DOE/NETL Major Demonstration Program Update, August 2011: http://www.netl.doe.gov/publications/proceedings/11/co2capture/presentations/4-Thursday/25Aug11-O%27Neil-NETL-CCS%20Major%20Demo%20Projects.pdf.

[117] DOE-NETL Clean Coal Power Initiative (CCPI), Demonstration Projects: Overview, Business & Management, Benefits, March 12, 2003: http://www.alrc.doe.gov/technologies/coalpower/cctc/ccpi/pubs/clearwater/clearwater_ccpi_final.pdf.

DOE has also identified the primary reasons that submitted project applications are rejected: not proposing a commercial demonstration, not addressing the goals of the solicitation, not being clear on how the project would offer significant advancement over current state of the art technology, being too conceptual in nature (i.e., lacked detailed information), proposing an unsupported “low cost” claim, lacking sufficient data, presenting data without context, failing to provide adequate site definition and documentation (e.g., California is not a site), and not defining what work was to be performed.

Unlike earlier CCT/CCPI projects that demonstrated technologies such as SOx or mercury control, the central technologies being demonstrated for CCS are not ancillary to power plant operation and must be fully integrated to achieve reasonable cost and performance. The technical risk of the earlier CCPI funded demonstrations of environmental control technologies was not as great. Vendors had a market for their products, and most of the demonstrations were limited to a period of operation, and, thus, were not expected to keep running to meet financial obligations. In the case of integrated CCS demonstrations, the central technologies must operate in order for the plant to function and also generate revenue for commercial operation. Thus, the developer has both a technological risk and a financial risk for the project.

The benefits derived from completed projects have high potential. The 3 Round 1 projects met the goals of the solicitation and demonstrated the technical viability of the technologies and their potential applicability to coal units across the fleet. With regards to CCS, the 4 projects from Rounds 2 and 3 remain active. At this time, their viability and applicability to the existing fleet has not yet been demonstrated. The anticipated success of each of these projects, as well as FutureGen, will mark major milestones in the development and practical application of CCS/CCUS technology. While none of the projects are expected to achieve the cost goals set by DOE for the program, their experiences will help to clarify what realistic targets are for the cost and performance of future CCUS systems, and will provide the learning necessary to support future demonstrations of integrated CCS systems.

It has proven challenging to understand the true cost of FOAK CCS systems for each of demonstration these projects. Cost estimates for all projects grew over time both as a result of inflation and as the details of the final projects evolved. One reason for such cost growth is demonstrated by the significant design changes that occurred at both Kemper and FutureGen as they progressed from their initial embodiments to their current designs. What became the Kemper project was originally proposed and designed as an IGCC without CCS to be located in Orlando, Florida.[118] It is now an IGCC facility with CCS located in Kemper County, Mississippi.

[118] MIT Carbon Capture and Sequestration website: https://sequestration.mit.edu/tools/projects/kemper.html

FutureGen was originally a greenfield IGCC project to be located in Mattoon, Illinois with a dedicated and surveyed saline storage site. It is now an oxy-combustion repowering project located in Meredosia ,Illinois.[119] Cost increases are also compounded by delays that have resulted from lengthy project permitting and lawsuits. Importantly, the costs are not merely a function of technology, but also schedule, permitting, manufacturing, labor availability, and project development issues as well.

Three of the 5 surviving CCPI projects are IGCC projects: Kemper (Southern Company),Texas Clean Energy Project (Summit), and HECA. All three projects employ different gasifier technologies: TRIG™ by Southern and KBR, Siemens for Summit, and Mitsubishi for HECA, respectively. However, each project employs either Selexol or Rectisol pre combustion capture processes, which are well known, commercially available processes designed for high pressure gas streams. These processes were not developed through the DOE CCS program, nor are they applicable to the existing fleet of pulverized coal plants. While these projects are demonstrating the integration of CCS with power generation, the capture technologies are not novel. Additionally, HECA and TCEP are polygeneration facilities, both producing fertilizer as well as power, which are very specific designs that are not easily nor likely to be replicated.

Thus, what started out as a CCS program, and was funded as such, ultimately became, in effect, a demonstration program comparing gasifier technologies, with no new contribution to the technology of carbon capture and with no clear indication as to whether future replications of these technology configurations will make economic sense (i.e., how much urea can be produced before the price collapses and the anticipated revenue does not materialize?).

Industry recognizes that for CCS to be successful, experience must be gained from the integration of CO_2 capture, transport, and storage even through current industrial CO_2 capture technologies, particularly when integrated with CO_2 storage in a saline aquifer. The two post combustion capture projects, if successful, will provide necessary operational experience to advance post combustion capture technology development and advance a better understanding of the integration of CCS/CCUS technology with power generation systems.

Other Issues Impacting Progress in DOE CCS/CCUS Program

There are several other factors that directly or indirectly impact the ability of the DOE to make progress towards achieving the goals of the program. First, as consistently stated throughout this report, the level of federal funding provided to the CCS program is not sufficient to achieve the aggressive goals of the program. From the point of view of industry, there are several reasons for this. Each newly elected President and DOE Secretary and changing leadership within the DOE program brings different technology priorities that have impacted how much funding the program has received and how those funds are spent on “in vogue” technologies. For example, in the middle of the last decade, IGCC was championed by the Administration and Congress as the technology that would cost effectively and efficiently reduce carbon emissions.

[119] MIT Carbon Capture and Sequestration website: http://sequestration.mit.edu/tools/projects/futuregen.html

At the direction of Energy Secretary Chu (2009-2013), post combustion capture was heavily supported to address emissions from the global fleet of existing coal plants. With diminishing federal budgets for energy across the board, there has been extreme competition among the DOE programs for funding, and, as a result, the program has seen declining budgets instead of growing budgets which are necessary for DOE to successfully meet its program goals.

Additionally, industry does not see an immediate market for CCS technologies, particularly in the U.S., which indirectly affects the prospects of DOE success in achieving its CCS program goals. Developers of the technology must make an internal business case for investing in CCS. Advanced energy and CCS technologies require long lead times to develop (upwards of 20–30 years), with no immediate or foreseeable return on investment. This makes it difficult for companies to justify the investment needed for technology development, even when cost shared with DOE. However, if there is to be a worldwide effort to reduce CO_2 emissions from new and existing combustion sources, CCS ultimately will be necessary for both coal and natural gas combustion sources.

Thus, there is a policy imperative for DOE to invest in CCS/CCUS technology development. It follows that the federal budgets to support that development must be sufficient to ensure industry also invests resources necessary for commercial scale development of the technology. In the absence of any near term market for CCS, significant federal financial support will be necessary to develop and deploy it. There are many potential forms of support including direct grants, feed it tariffs, production credits, tax incentives, CO_2 reduction credits, and "contract for differences". Other forms of creative financing would be welcome as well. Further, CCS must be recognized as a legitimate GHG reduction technology and be treated equally with other GHG reduction systems. In addition, a viable permitting program will be necessary, with some degree of regulatory certainty.

Education and Outreach

Education and outreach play a significant role in the U.S. DOE RCSP. Each Partnership has an outreach coordinator who leads the development and implementation of outreach plans to various stakeholder groups in support of large scale CO_2 injection projects. Information included for each partnership typically includes:

- General information about the RCSP and its region; the project team, its partners, the RCSP's lead organization; announcements and technical reports as they are published.
- -General information about carbon storage, climate change, and CO_2.
- Access to the national or regional atlas of CO_2 sources and emissions in the region; information on geologic CO_2 storage potential in the region; and regulatory and permitting information.
- Detailed information about the Validation and Development Phase storage projects.
- Information and educational products developed by the RCSP, including fact sheets, briefing materials, links to the latest carbon storage news stories, and links to scientific topical reports.
- Links to photographs, video clips, and other multimedia resources.

- Access to a "Frequently Asked Questions" page.
- Links and resources with additional information.
- Links to educational resources and pages to help school age children learn more about the climate and the weather, potential climate change, and the greenhouse effect through online games, climate animation, and other activities.

Outreach coordinators also participate in an Education and Outreach Working Group to share information, experiences, and best practices. This material has been published in a Best Practice Manual summarizing lessons learned.[120] The manual is a key publication to assist project developers understand and apply best outreach practices for storage site permitting and operation and provides practical, experience based guidance on how to design and conduct effective public outreach activities. Never the less, some projects have been opposed by public activists and environmental groups and proactive engagement in every stage of a project is needed.

7. Review of Federal Authorizations and Budgets for CCS

Transparent budgets for CCS activities within the DOE program budgets (in the Clean Coal/CCS & Power Systems program budget) date back to 2001, although funding had been allocated to CCS R&D in some DOE programs dating back to 1997 to support initial investigations into CCS. This section summarizes both the Congressional authorizations for CCS related R&D activities at DOE, and the federally enacted budgets for CCS programs at DOE.

<u>Authorizations for CCS/CCUS RD&D</u>

The first Congressional authorization specifically for a CCS program was provided in the Energy Policy Act of 2005, and in later bills enacted in 2007, as noted in Table D.1 in Appendix D.[121] However, federal funding for these programs has never been appropriated at the levels authorized by Congress. In 2009, the American Recovery and Reinvestment Act (ARRA) provided significant funding for CCS/CCUS development and demonstration activities at DOE, but to date, only a portion of those funds have actually been spent and nearly half of ARRA funding obligated to projects has been returned to the Treasury due to project cancellations and Congressional rescissions.[122] There has been no other legislation that has passed in recent years authorizing additional funds for CCS RD&D programs.

<u>Federal CCS Budgets</u>

The federal funding data (see Appendix E for data tables) for the DOE CCS R&D programs included in this report and as illustrated in Figure C.6 reflects the enacted annual appropriations for CCS programs dating back to 2001[123].

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[120] http://www.netl.doe.gov/File%20Library/Research/Carbon-Storage/Project-Portfolio/BPM_PublicOutreach.pdf
[121] P.L. 109-58 at Page 119 STAT. 891 http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/html/PLAW-109publ58.htm and P.L. 110-140 at Page 121 STAT. 1704 http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm.
[122] See Page 15 of 2014 Congressional Research Report at http://www.fas.org/sgp/crs/misc/R42496.pdf and Page 5 of 2012 Congressional Budget Office Report at http://www.cbo.gov/sites/default/files/43357-06-28CarbonCapture.pdf.
[123] FY 2001 P.L. 106-291 at Page 114 STAT. 975, available at http://www.gpo.gov/fdsys/pkg/PLAW-106publ291/html/PLAW-106publ291.htm;

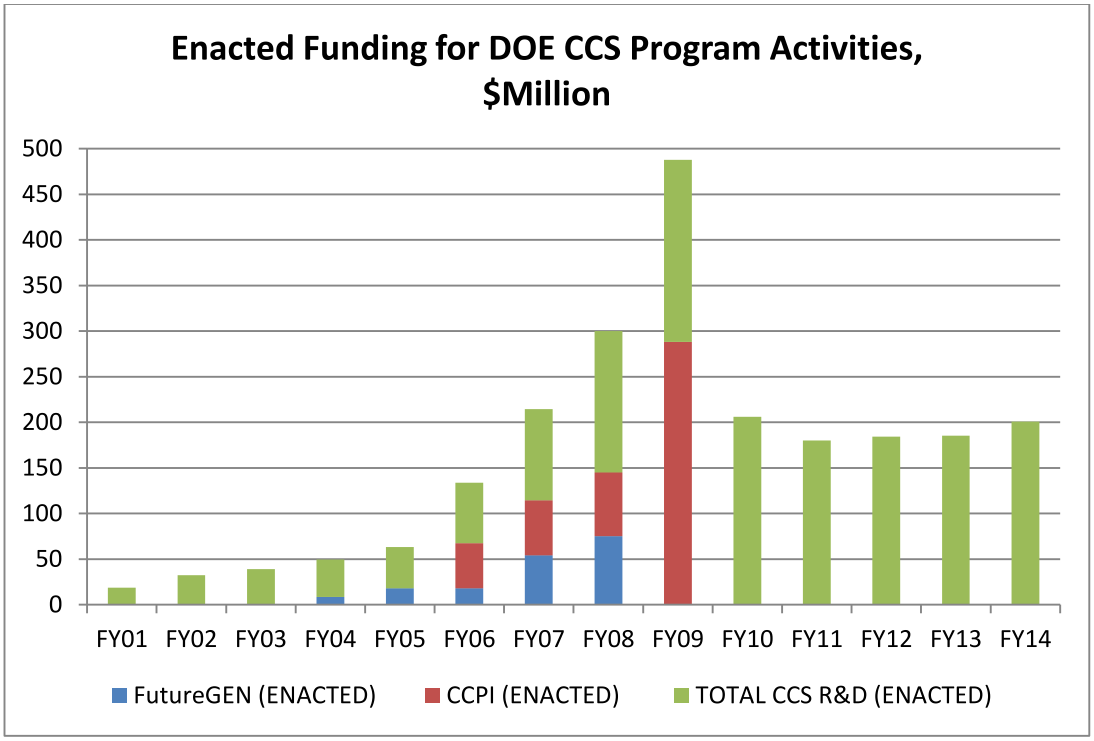

Figure C.6. Federal Funding for DOE CCS Program Activities

FY 2002 P.L. 107-63 at Page 115 STAT. 453, available at http://www.gpo.gov/fdsys/pkg/PLAW-107publ63/html/PLAW-107publ63.htm;
FY 2003 P.L. 108-7 at Page 117 STAT. 258 http://www.gpo.gov/fdsys/pkg/PLAW-108publ7/html/PLAW-108publ7.htm;
FY 2004 P.L. 108-108 at Page 117 STAT. 1290 http://www.gpo.gov/fdsys/pkg/PLAW-108publ108/html/PLAW-108publ108.htm;
FY 2005 at P.L. 108-447 at Page 118 STAT. 3081 http://www.gpo.gov/fdsys/pkg/PLAW-108publ447/html/PLAW-108publ447.htm;
FY 2006 P.L. 109-103 at Page 119 STAT. 2270 http://www.gpo.gov/fdsys/pkg/PLAW-109publ103/html/PLAW-109publ103.htm;
FY 2007 P.L. 110-5 at Page 121 STAT. 19 http://www.gpo.gov/fdsys/pkg/PLAW-110publ5/html/PLAW-110publ5.htm;
FY 2008 P.L. 110-161 at H. R. 2764—114 http://www.gpo.gov/fdsys/pkg/BILLS-110hr2764enr/pdf/BILLS-110hr2764enr.pdf;
FY 2009 P.L. 111-8 at Page 123 STAT. 615 http://www.gpo.gov/fdsys/pkg/PLAW-111publ8/html/PLAW-111publ8.htm and P.L. 111-5 at Page 123 STAT. 139 http://www.gpo.gov/fdsys/pkg/PLAW-111publ5/html/PLAW-111publ5.htm;
FY 2010 P.L. 111-85 at Page 123 STAT. 2862 http://www.gpo.gov/fdsys/pkg/PLAW-111publ85/html/PLAW-111publ85.htm;
FY 2011 P.L.112-10 at Page 125 STAT. 12 http://www.gpo.gov/fdsys/pkg/PLAW-112publ10/html/PLAW-112publ10.htm;
FY 2012 P.L. 112-74 at Page 125 STAT. 868 http://www.gpo.gov/fdsys/pkg/PLAW-112publ74/html/PLAW-112publ74.htm;
FY 2013 P.L.112-175 http://www.gpo.gov/fdsys/pkg/PLAW-112publ175/html/PLAW-112pu112publ175.htm
FY 2014 P.L. 113-76 at Page 128 STAT. 165 http://www.gpo.gov/fdsys/pkg/PLAW-113publ76/html/PLAW-113publ76.htm.

At that time, funding was initially allocated only to the early DOE Carbon Sequestration R&D Program, a program focused on both carbon capture and carbon sequestration R&D activities. In 2008, DOE was directed by Congress to transition work in the Innovations for Existing Plants program to focus on post combustion CO_2 capture activities. Beginning in FY 2011, the DOE reorganized the Coal R&D program and established two new line items in the budget, one for a program called "Carbon Capture" which included separate subprogram budgets for both pre and post combustion activities, as well as a second line item program budget for Carbon Storage.

Since 2001, other DOE programs have undertaken carbon capture technology development, such as the IGCC program which supported pre combustion capture R&D, and in later years, the Advanced Combustion Systems Program, which included development work on advanced post combustion capture concepts, oxy-combustion, and chemical looping. Unfortunately, the budgets for those activities were not transparent prior to FY 2011 and, therefore, are not accounted for in the budgets illustrated in the tables and graphics that follow until FY 2011. The development efforts are, however, significant in their contributions towards the program and the progress made to date to advance CCS R&D.

Funding for DOE CCS demonstration scale activities are reflected in the CCPI program and begin with FY 2006 through FY 2009 annual appropriations. Funding also reflects the annual funding made available to the FutureGen project prior to the $1 billion appropriated to the project in FY 2009 through ARRA, and recognizes the contribution of ARRA funds to meet the federal budget obligations to the projects.

While the $3.4 billion allocated for CCS in the American Recovery and Reinvestment Act (ARRA) of 2009 was a good start in providing the kind of federal funding assistance needed for CCS technology development, much of those funds were returned to Treasury due to canceled projects. Because CCS projects are more complex and carry higher risk, several of the projects that received ARRA funding awards have had challenges achieving financial close. ARRA funding falls short of what will be needed to successfully commercialize and support widespread deployment of CCS technology. It is unlikely that the September 2015 deadline for funds expenditure will be met by any project.

DOE supported incentive programs, such as the Clean Coal Power Initiative (CCPI) and loan guarantee program, can only be successful if the level of funding provided and the loan (or other incentive) address both the technical and financial risk associated with FOAK and early deployments of CCS. While the DOE loan guarantee program is intended to help bridge the gap for new technologies, it has significant limitations. Other federal programs outside the scope of DOE are designed to incentivize deployment of CCS by also addressing financial risk, including investment tax credits and carbon sequestration credits. Many of the current CCS projects under development have applied for federal grants, federal loan guarantees, and tax credits. Even with the combination of some or all of these incentives, they have yet to reach financial close.

FY 2009 appropriations were significantly higher than in other years as a result of the emphasis to stimulate the economy through the federal budget. Funds were provided to advance first generation CCS technologies into large scale projects. Funds for CCS projects were also provided in anticipation of possible enactment of climate change legislation. As a result, the FY 2006 to FY 2009 annual CCPI funds were pooled together and combined with nearly $800 million in funds appropriated to CCPI through ARRA to enable a 3rd Round CCPI RFP soliciting demonstration scale CCS projects.

What is most telling about Figure C.6 is the distribution of federal funding for CCS related activities in the DOE program. Annual federal funding has historically supported budgets for R&D activities, but has not supported the significantly larger federal budgets necessary for demonstrations and large scale projects such as FutureGen, which are necessary to advance CCS towards commercial deployment. Federal funding for the CCS R&D program since 2001 has totaled over $1.6 billion, but has been widely distributed to small R&D scale projects supported by the DOE CCS R&D program. More than half of the $1.6 billion funded through the R&D program has been allocated to the CO_2 sequestration program and the RCSPs, yet the budgets for that R&D program are still not sufficient to support the large scale demonstrations contemplated at one million tons/year that are needed to advance to the next phase of geologic storage on the path towards commercial operation.

There is clear recognition that significant funding has been provided to advance CCS. However, it does not measure up against what industry has consistently recommended is needed from the federal government for CCS technology development and demonstration activities. Figure C.7, from the CURC-EPRI road map, provides an industry perspective on the level of funding believed necessary for CCS technology development and demonstration. [124]

[124] Ibid

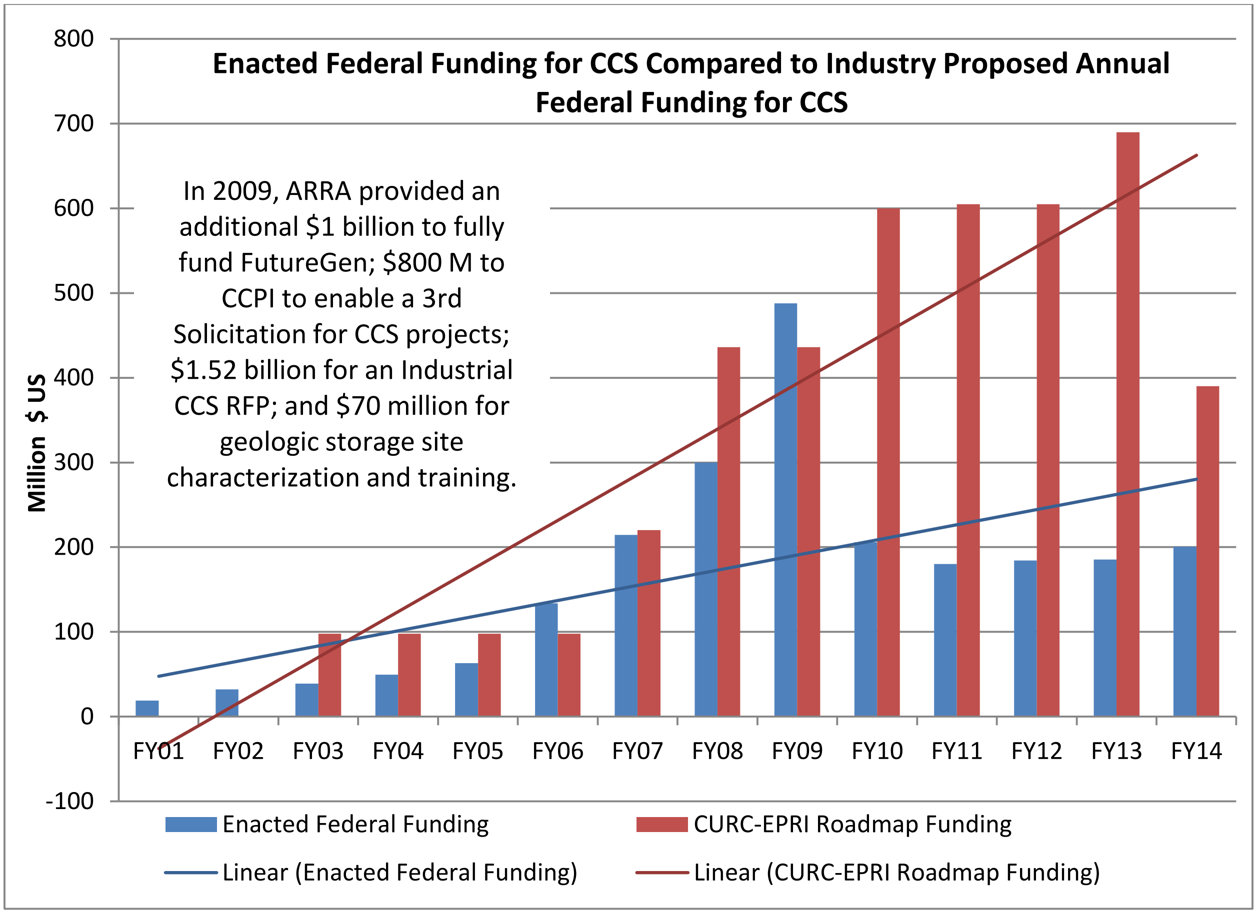

Figure C.7. Federal Funding vs Industry Recommended Funding

This industry perspective is provided by the Coal Utilization Research Council (CURC)[125] through the recommendations made in an Advanced Coal Technology Roadmap ("Roadmap") developed by CURC and the Electric Power Research Institute (EPRI), last updated in 2012 and as provided in earlier versions of the Roadmap published in 2008 and 2003. The Roadmap is a plan that defines the research, development, and demonstration ("RD&D") necessary to ensure that the benefits of coal utilization in the U.S. continue into the future, and identifies coal technology advancements that will achieve specific cost, performance, and environmental goals, similarly expressed to the goals and objectives of the DOE program. The Roadmap also identifies the funding necessary to develop the technologies in order to successfully achieve the goals and objectives within the timeframes identified.[126]

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[125] CURC is an organization of coal using utilities, coal producers, equipment suppliers, universities and institutions of higher learning, and several state government entities interested and involved in the use of coal resources and the development of coal based technologies (see www.coal.org).

[126] Funding in the CURC/EPRI Roadmap for CCS R&D includes funding necessary for both geologic sequestration and CO_2 capture R&D activities, pre and post combustion as well as oxy-combustion and new energy conversion systems such as chemical looping or using supercritical CO_2 as a working fluid. The Roadmap includes funding for CCPI demonstrations and includes support for both small and large pilot scale testing, component demonstrations, and integrated commercial demonstrations. Funding for these activities slowly starts to ramp up in FY 2007 to enable the R&D work on second generation and transformational technologies to scale up into small and large

While significant ARRA funding was provided for CCS demonstrations (for the CCPI, FutureGen, and ICCS programs) in 2009 as noted, Figure C.6 illustrates only the funding recommendations for those activities supported by the annual budget, which, outside of ARRA,[127] has been the only source of DOE funding for CCS related RD&D activities. This graphic illustrates how the annual budgets for CCS are unable to support the larger budgets deemed necessary for scale up of existing R&D efforts on second generation and eventually transformational technology developments within the program. Despite the significant level of funding provided by ARRA, much of the $3.4 billion for CCS has yet to be utilized, and much of it has been returned to Treasury. In 2009, ARRA provided full funding for FutureGen so that out year annual budgets would not be necessary to support the project. ARRA also provided $800 million to support a 3rd Round CCPI solicitation. However, the total $1.541 billion made available to CCPI Round 3 was spread thinly among the six selected projects, which has the impact of reducing the cost share and diluting the value of the federal grant on a per project basis.[128]

Table C.6 shows the breakdown of the CCPI funding provided to each surviving project in comparison to current total project cost.[129] As can be seen, the ratio of the grant to the project is 5% to 18% of total project cost from the federal government, which is simply not enough to enable these projects to be financially stable in securing debt or other project financing. Despite this, DOE is only authorized by statute to provide up to 50% cost share for demonstration projects.

Project	Total Federal Funding	Total Project Cost	Federal Cost Share
Hydrogen Energy California	$408 M	$4 B	10%
Summit Texas Clean Energy	$450 M	$2.5 B	18%
NRG Energy	$167 M	$1 B	17%
Southern Kemper Energy	$293 M	$6.1 B	5%
Totals	$1.752 B	$13.6 B	13%

Table C.6. Cost Breakdown of Surviving CCPI 3 Projects

pilots, and is incorporated in later years (FY 2010 and beyond) into larger budgets to pool annual funds for integrated system demonstrations of CO_2 capture and storage of second generation and transformational funding.

[127] ARRA funding is considered an anomaly in the federal budget for CCS, although if the remaining ARRA funded projects are successful, ARRA supported projects will significantly advance first generation CCS technology development.

[128] CCPI Round 3 Project Selection Announcement, December, 2009: http://energy.gov/fe/clean-coal-power-initiative-round-iii

[129] Ibid. Information for current project costs retrieved from the following sources: http://www.bakersfieldcalifornian.com/business/kern-gusher/x552954144/Oxy-spinoff-delays-proposed-energy-plant; http://www.summitpower.com/story/cps-energy-reconsiders-plan-to-purchase-power-from-texas-igcc-project/; http://www.powermag.com/commercial-scale-carbon-capture-project-starts-construction-in-texas/; http://www.clarionledger.com/story/news/2014/10/02/again-costs-rise-and-completion-delayed-at-kemper/16613487/.

Over $850 million in federal funds are tied up in other smaller projects, and over $250 million of CCPI funds have been returned to Treasury from two projects that were canceled. Even with limited ARRA funds, industry has consistently recommended significantly more funding to develop CCS. To date, the CCS development and demonstration programs at DOE have not reached critical mass.

8. Research and Development

DOE support is essential in the endeavor to commercialize CO_2 capture and storage technologies because for profit companies, particularly publicly traded for profit companies, have constraints on research budgets and a relatively low risk tolerance. With the current uncertainty in CO_2 regulations and corresponding CO_2 emissions control market, private enterprise will be hard pressed to justify the investment in expensive technologies without some reasonable certainty of future sales and necessary return on investment. At the present time, there is no reasonable discount rate that would justify the large expenditures needed to commercialize CCS. For technologies at the scale required for widespread CCS/CCUS deployment, the time scale of research, development, refinement, and commercially guaranteed deployment will be measured in decades. Given the duration and requirement for lengthy investment before any return is realized, DOE support is critical for private sector investments. If deployment of CCS/CCUS technology at a reasonable cost is deemed a public necessity for energy security and reduction of environmental impact, then federal support and leadership is necessary.

Federal R&D investments enable a wide variety of private enterprises and public institutions to facilitate investigations across a range of technologies, fostering competition. Competition will improve technology offerings as well as lead to selection of the most promising technologies, which can then be deployed in the pilot and commercial demonstration phases.

In order for technology to be developed, initial concepts proceed from fundamental understanding, to lab scale testing, bench scale testing, pilot scale evaluation, commercial scale demonstration, and final commercialization. It is unlikely that any one single entity will be able to successfully navigate this path without support. As a result, DOE support for CCS is necessary to advance technologies through the development pipeline which includes university research, university collaboration, small business growth and development, and large EPC and OEM firms' engagement which is ultimately necessary to carry out commercial scale demonstrations.

Pilot Scale Programs

Pilot scale testing is critical for validation and development to move to commercial scale, but the current DOE program structure does not support large scale pilot projects. While initial laboratory scale data is relatively low cost, it does not accurately represent mechanisms and operations present at pilot and commercial scale, under real operating conditions, such as wall effects, mass transfer, heat transfer, fluid dynamics, etc.[130] It is absolutely necessary to test technology at a wide range of scales. Fundamentally, CO_2 capture depends upon gas separations. Heat and mass transfer, kinetics, gas flow, and thermodynamics are the dominant mechanisms which must be investigated. The importance and rate limiting steps of these mechanisms may change as scale is increased and such effects must be well understood. A previous emissions control example that is well understood and highlights such disparities is NO_X control with Selective Non Catalytic Reduction (SNCR). Initial laboratory and bench scale testing revealed 80-90% reagent utilization and effectiveness for NO_X reduction at commercial scale. In reality, 40-60% has proven to be the practical limit.[131]

Importantly, pilot work can be an order or orders of magnitude more expensive than laboratory scale and is considered a high risk endeavor both technically and financially due to the uncertainty in scaling technologies out of the laboratory. Furthermore, a technology which is to be tested at pilot scale would be expected to treat somewhere in the range of 1 MW equivalent of flue gas. At the DOE goal of 90% capture, this corresponds to capturing approximately one ton of CO_2/hour. The gas handling equipment required for such flows, as well as the need to produce experimental materials or processes to facilitate such testing is expensive. Processes must be run continuously for long durations to determine the reliability and robustness of a technology. This requires continuous staffing of skilled operators, scientists, and engineers. As a result, many projects in this size range have budgets in the tens of millions of dollars. Such investment is cost prohibitive for small technology development companies and will not be palatable for larger firms uncertain of the return on investment.

[130] Due to the fundamental laws of scaling, a laboratory or bench scale apparatus will have a much different surface area to volume ratio than a pilot or commercially sized unit. For example, a laboratory vessel which is 0.1 m x 0.1 m x 0.1 m will have a surface area of 0.06 m2 and a volume of 0.001 m3. Meanwhile, a full scale vessel 10 m x 10 m x 10 m will have a surface area of 600 m2 and a volume of 1,000 m3. This represents a 100x difference in surface area to volume ratio between laboratory and full scale vessels. Clearly, different flow patterns, mass transfer, wall effects, and other phenomena will be observed at different scales. This is also the source of economies of scale.

[131] J.E. Hofmann, J. Bergmann, D Bokenbrink, and K. Hein, "NOxControl in a Brown Coal-Fired Utility Boiler", Joint EPA/EPRI Symposium on Stationary Combustion NOx Control, San Francisco, March 6-9, 1989.

9. Loan Guarantee Program

Overview

The DOE Loan Program was authorized by the Energy Policy Act (EPAct) in July 2005 to –

> "*Support innovative clean energy technologies that are typically unable to obtain conventional private financing due to high technology risks*. In addition, the technologies must avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases. Technologies we will consider include biomass, hydrogen, solar, wind/hydropower, nuclear, advanced fossil energy coal, *carbon sequestration practices/technologies,* electricity delivery and energy reliability, alternative fuel vehicles, industrial energy efficiency projects, and pollution control equipment." [132]

Title XVII also specifies that DOE must receive either an appropriation for the "Subsidy Cost" or payment of that cost by the borrower. The Subsidy Cost is the expected long term liability to the Federal government in issuing the loan guarantee. Therefore, the borrower (the sponsors) of a project approved to receive a loan guarantee pursuant to the first solicitation must pay this cost, which defeats the purpose of the loan guarantee and only compounds the high capital cost hurdle.

Status of Loan Guarantee Solicitations and Projects

To date, the DOE Loan Program office has issued more than $34 billion in "conditional commitments" in the form of either direct loans or loan guarantees, including $8.3 billion in one deal for the Vogtle nuclear plant in Georgia (owned by Southern Company), and $8.5 billion on six loans in automotive manufacturing. No advanced fossil projects have received a loan. Figure C.8 shows a summary of the loan program.[133] Most of the remainder was committed to wind and solar projects under the Section 1705 program (promulgated in the 2009 Recovery Act), where the government covered the credit subsidy cost of the loan.

[132] Section 1703 of Title XVII of the Energy Policy Act of 2005; Energy Policy Act of 2005, P.L. 109-58; http://energy.gov/lpo/services/section-1703-loan-program

[133] De Rugy, V. "Who Benefits From the DOE's Loan Guarantee Program?", Mercatus Center, George Mason University, June 19, 2012

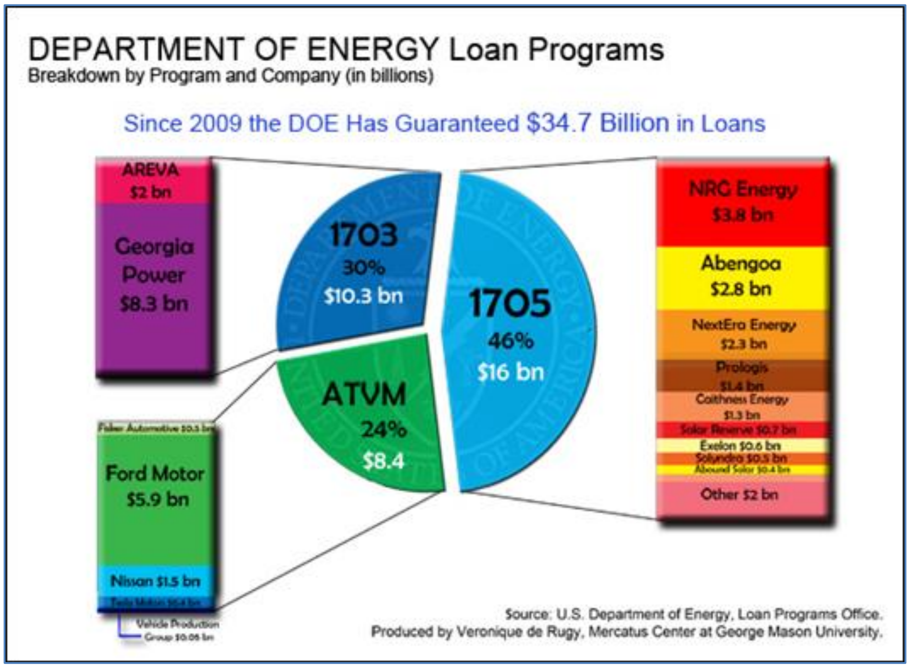

Figure C.8. DOE Loan Guarantee Program Summary

To date, 4 rounds of RFPs have been issued by the Loan Program Office soliciting projects from different energy categories based on the authority to issue loan guarantees in those categories as provided by Congress. (See Appendix F for an historical summary of all of solicitation rounds of the Loan Guarantee program.)

For projects fueled by coal or fossil fuels with advanced technology ("Advanced Fossil" projects), two solicitations have been issued under Section 1703: the first in July 2008 for $8 billion in total credit capacity. No loans or guarantees were offered on projects from that solicitation, so another solicitation was issued in December 2013 for the same amount. The current solicitation for Advanced Fossil projects calls for projects in four broad areas of technology:

> Area 1: Advanced Resource Development (coal bed methane (CBM) recovery, advanced drilling, methane capture)
> Area 2: Carbon Capture (power and industrial process systems)
> Area 3: Low-Carbon Power Systems (e.g., fuel cells using fossil fuel sources)
> Area 4: Efficiency Improvements (combined heat and power systems, etc.)

Mechanics of the Loan Program

There are a few specific features required for a project to be eligible under Section 1703:

- Located in the U.S. (even with foreign ownership).
- Employs "new or significantly improved technology that is *not* a commercial technology" (deemed less than four deployments in the U.S. in the same general application as in the proposed project for at least five years).[134]
- Meets Davis Bacon labor requirements.
- Submits to a federal NEPA review whether on federal land or not.

EPAct allows loans for up to 80% of total project cost. No project in the DOE portfolio entails more than 70% of project costs, meaning at least 30% in equity was provided. Under conventional lending terms, projects with innovative technologies cannot get financing without federal credit support. Table C.7 shows a sample comparison of terms.

	Conventional Commercial Finance	DOE Loan (estimate; based on negotiation)
Deal structure	50% debt – 50% equity	65% debt – 35% equity
Loan tenor	10 – 20 years	20 – 30 years
Interest rates	8% - 12%	4% - 6% (Treasuries)
Equity return expected	12% - 16%+	8% - 12%
Other terms	Complex inter-creditor agreements	Loan guarantee with DOE in senior position
Upfront points	Varies	Credit subsidy cost
Fees	Varies	1% Facility Fee
Underwriting	Credit rating; little tech risk	Credit rating; innovative project

Table C.7. Comparison of Commercial Terms with DOE Loan Attributes

It must be noted that actual cash disbursed or loaned by the federal government is less than the commitment in a direct loan. The loan value is not drawn all at once with signing. Instead, the loan funds are drawn in tranches based on specific technical and equity funding milestones. Hence, some of the loans actually drawn against committed amounts on renewable energy deals that did not meet those milestones ran less than the commitment levels by more than 50%. This has reduced actual losses in the program. These points came to light, in part from the program review conducted as of late November 2011.[135] On roughly $35 billion in commitments, less than $3 billion in "losses" or unpaid loans have been recorded to date.

[134] This is a different definition of "commercial" than used by industry.
[135] Allison, H., "Report of the Independent Consultant's Review with Respect to the Department of Energy Loan and Loan Guarantee Portfolio", January, 2012, White House Mandate, www.whitehouse.gov.

Incentivizing CCS through the DOE Loan Program

Figure C.9 illustrates the technical and cost risk for each phase of technology development programs that support advancement of the technology through to commercialization.[136]

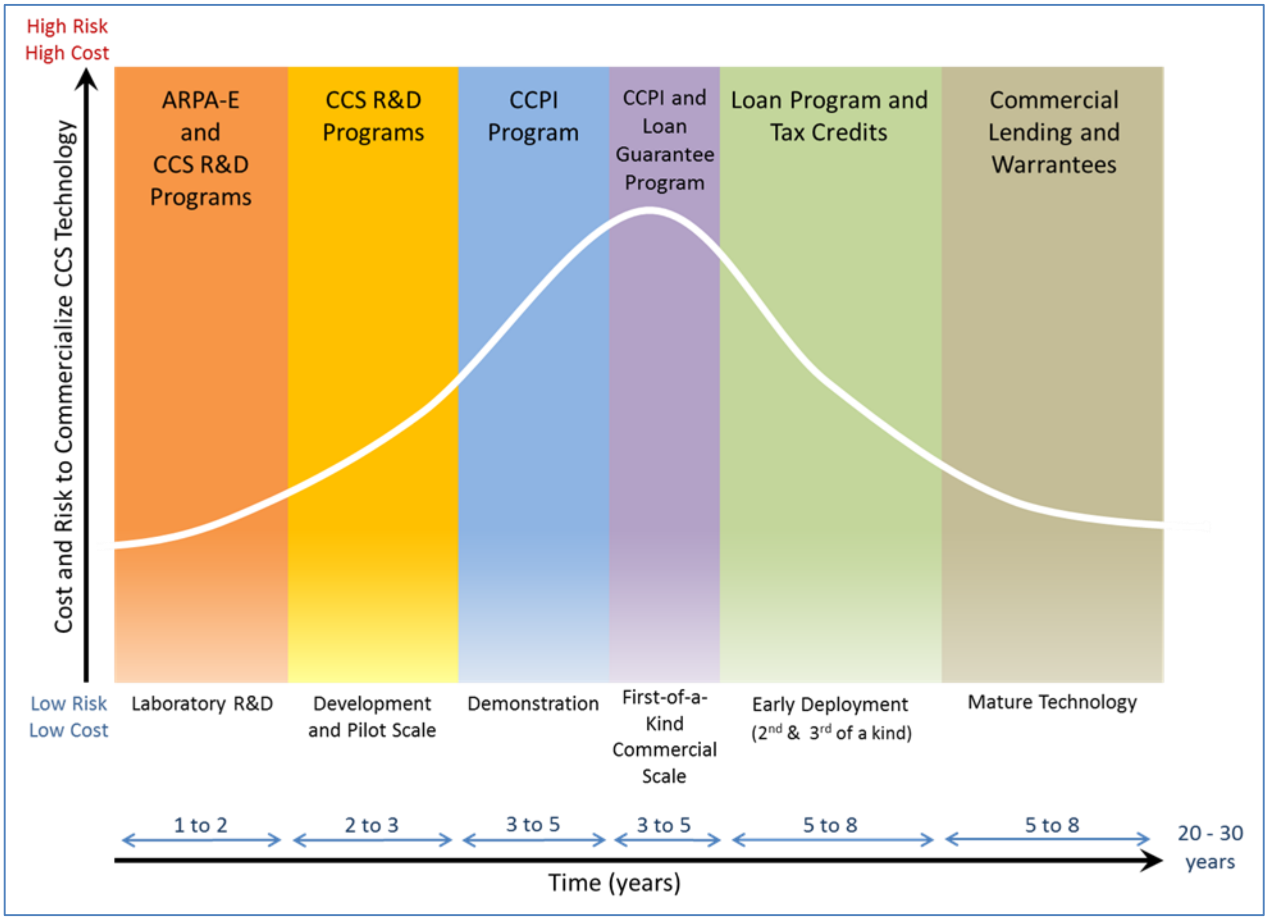

Figure C.9. Energy Technology Development Spectrum to Commercialize Technology for CCS

While the Loan Guarantee program provides significant assurance financially and will certainly lower borrowing cost, the Loan Guarantee program does not cover technology risk or performance risk. These risks need to be satisfied to bring in conventional bank financing and normally require the contractor/developer to provide a wrap guarantee, possibly a parent guarantee, or guaranteed off take agreements, which are troublesome to provide until the technical risk has been overcome. Providing guarantees has proven troublesome on projects to date and has been a leading cause of the inability to finance certain projects, resulting in significant and costly delays.

[136] Adapted from EPRI TAG

Existing studies make the point that government incentives could make a greater difference than they currently do in helping certain technologies address the barriers and risks associated with the commercialization stage.[137] Applying for a DOE loan, particularly for commercial scale Advanced Fossil projects which typically exceed $1 billion in financing, has significant disincentives built into the process. Previous applicants have asked for more clarity in the due diligence process with less duplication on the DOE side for independent underwriting (e.g., an external credit rating, independent engineering review, emissions savings calculations, etc.). Applicants are not asking that such steps be eliminated, only that less duplication in review and legal composition would lead to a more streamlined process. Likewise, NEPA reviews for Advanced Fossil projects pose some uncertainties and could be better coordinated with state regulatory actions that cover most of the same points. In any case, a detailed risk analysis is conducted by reviewers that entail consideration of public policy incentives and siting decisions, in addition to the negotiation of multiple key private agreements. Figure C.10 shows some of the details.[138]

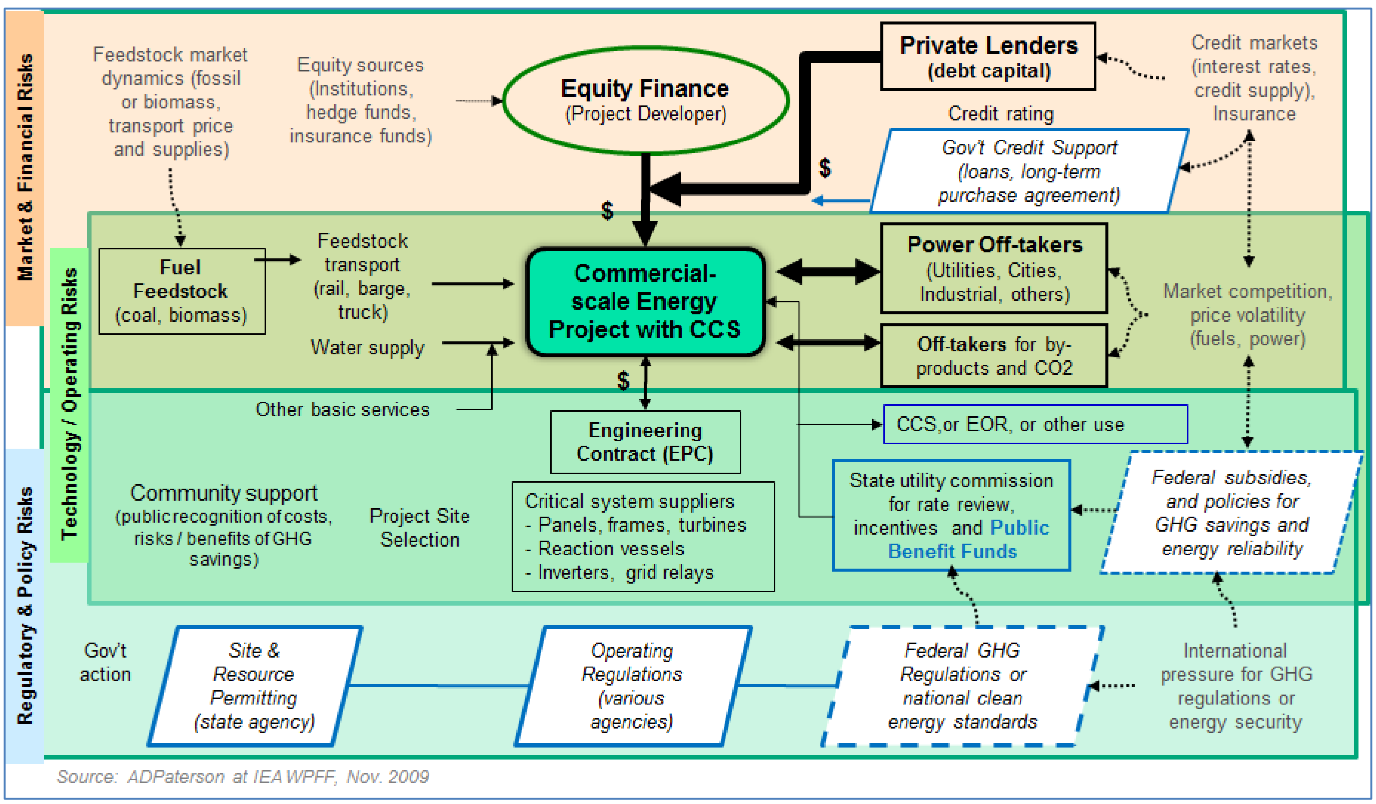

Figure C.10. Risk-based Project Analysis employed in Commercial Scale Underwritings

[137] This point has been made in a number of prior studies, including a report authored by John Deutch for the MIT Joint Program on the Science and Policy of Global Change in May 2005: "What Should the Government Do To Encourage Technical Change in the Energy Sector?".
[138] Paterson, A. D., IEA WPFF, Nov. 2009

Unlike grants or tax credits, underwriting of loans entails a much more extensive analysis of technical, policy, and market factors *over the life of the loan* than do grant applications, which focus primarily on technical milestones and objectives.

Given ongoing constrained capital market conditions, the DOE Loan program remains vital, particularly for Advanced Fossil projects. The DOE Loan Program is one of at least two DOE programs currently in place to support the continuum for moving from early research to FOAK demonstration projects (supported by the CCPI program) through to early deployments of 2nd and 3rd of a kind projects (supported by the DOE Loan Guarantee program). However, the FOAK CCS projects currently being supported by DOE exhibit both technical and financial risk. Although the intent of the loan program as authorized by Congress is to "support innovative clean energy technologies that are typically unable to obtain conventional private financing due to high technology risks," the loan program to date has not supported this intended objective for new and innovative technologies such as CCS. Since the loan program has not met this objective, it needs to be reviewed and restructured accordingly.

10. Training Programs

A skilled workforce is critical to DOE's goal to enhance CCS commercial viability. Yet various specialties needed for deployment are currently underrepresented in the U.S. The need for CCS education and workforce training was highlighted in two prominent reports: Report of the Interagency Task Force on CCS and the National Academy of Sciences report on Emerging Workforce Trends in the U.S. Energy Industry.[139]

The Interagency Task Force on CCS recognized the need to integrate public information, education and outreach throughout the lifecycle of CCS projects. The Task Force further detailed specific CCS training and workforce capacity challenges:

> "…widespread, cost effective deployment of CCS will require hiring, training, and retaining a large workforce of highly skilled professionals in the private sector to design, build, and operate facilities."

The National Academy report concluded, "…unless student recruitment into the geosciences can be sustained, the lack of a strong geosciences workforce could limit CCUS implementation" and recommends:

> "…DOE, industry, institutions of higher education, and other involved organizations consider continuing support for DOE initiated training programs for CCUS."

[139] http://www.epa.gov/climatechange/Downloads/ccs/CCS-Task-Force-Report-2010.pdf and http://www.nap.edu/catalog.php?record_id=18250

Over the past decade, DOE has taken a number of actions to address potential CCS workforce capacity issues. These include the Research Experience in Carbon Sequestration (RECS) program and the Regional Carbon Training Centers.

Founded in 2004, the RECS is a first of its kind field training program and career network designed for graduate students and early career professionals. RECS is building a CCS workforce pipeline and has an active alumni network comprised of over 300 young scientists, engineers, and other professionals as well as a faculty of leading CCS experts from industry, academia, national laboratories, and NGOs. RECS trains participants in all aspects of CCS from science, technology, and policy to public engagement, communications, economics, and financing. The program combines classroom instruction with group exercises, CCS field site visits, and hands on training.

RECS is a national program that has been based in different parts of the U.S. to showcase various DOE supported CCS demonstration sites. Most recently, RECS has been held in partnership with Southern Company, Southeast Regional CO_2 Sequestration Training Program (SECARB-Ed), the CCUS Research Coordination Network, and EnTech Strategies. Each year up to 30 participants are competitively selected, including a few representatives from countries with which DOE maintains a strategic bilateral CCS activity. This international engagement provides DOE with a global reach, enhances bilateral cooperation, and furthers the CCS program goals.

Source: Research Experience in Carbon Sequestration

DOE initiated seven regional CCS training centers with funding from ARRA that augment and supplement outreach activities in the Regional Carbon Sequestration Partnerships (RCSPs). Training activities focus on applied CCS engineering and science for site developers, geologists, engineers, and technicians. It also provides a platform for CO_2 storage technology and knowledge transfer.

Source: Research Experience in Carbon Sequestration

Chapter D: CCS/CCUS Deployment Challenges

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1. Key Findings

- The infrastructure for transportation and storage of massive quantities of captured CO_2 does not exist. Without this infrastructure, it is difficult to imagine that CCS/CCUS can be commercialized.
- Financing power plants with CCS is a major issue. Power plant projects are large and costly. The means to monetize the entire CCS/CCUS process has not been identified.
- Legal and regulatory issues still remain unresolved. Currently proposed regulations have not been helpful in promoting CCS/CCUS. The confusion and uncertainty makes the long process of planning, permitting, financing, constructing, and operating a plant that much more difficult.
- Public acceptance is still an issue. While there are some regions of the U.S. that might accept a CCS project, many others will not. There is a parallel public perception association between fracking and CCS that should be more closely observed. Some regions have banned fracking. They might also ban injection and storage of CO_2.
- First generation technologies are costly. Second generation technologies offer some potential, but are still at the early stages of development. Continued R&D at all stages is needed to help reduce costs.
- General Equilibrium Models can be helpful as tools to provide guidance, but should be used with caution as neither the economy nor the climate are truly at equilibrium.
- CO_2 utilization can improve the economics of early adopter plants. However, the magnitude of the amount of CO_2 that must be captured to meet CO_2 emission reduction goals is much greater than the potential economic uses. For the most part, utilization is able to handle millions of tons, leading to perhaps some modest total of billions of tons. Reduction requirements will be in the thousands of billions of tons. Utilization must be considered as a storage option.
- There is a policy mismatch between CCS/CCUS technology funding and other DOE energy programs. Policy parity would provide more energy options for the U.S.

2. Scale of CO_2 Capture and Utilization

The capture, storage, and/or utilization of CO_2 on a global basis will entail enormous challenges at the scale at which technologies would need to be deployed to mitigate these emissions. This problem is primarily due to the scale of CO_2 emissions. Global CO_2 emissions were 36 billion tons in 2013 and grew at a rate of 2.1% for that year, down slightly from 2.2% the year before.[140] Using the 2.1% growth rate out to 2050, the calculated, cumulative total of CO_2 emissions would be 2062 billion tons. Of these, the International Energy Agency (IEA) estimates that only 884 billion tons could be safely emitted to meet its chosen goals.[141] By contrast, the highly successful Title IV SO_2 cap and trade program in the U.S. targeted to reduce SO_2 emission from 10 million tons/year down to 5 million tons/year.

The sheer amount of CO_2 to be captured, stored, and/or utilized exceeds the largest production industries in the world. For example, world coal production was 7.8 billion tons in 2013.[142] World oil production was 4.2 billion tons in 2013.[143] Just to transport nearly 30 billion tons/year of CO_2 would require a massive undertaking in pipeline capacity. The scale of the problem represents one of the greatest deployment challenges in modern industrial history. Since this is a global problem, international collaboration will be needed, a fact which poses additional major problems. While it is possible to imagine global cooperation, it is also readily apparent that there are major social and economic impediments to cooperation throughout the world.

Taking each of the capture, storage, and/or utilization issues in turn, the capture technologies have been utilized at small scale (20 – 30 MW) relative to the size needed for widespread commercialization on large scale utility (500 – 900 MW) and industrial applications. The oil and gas industry has been capturing CO_2 from natural gas production facilities for decades. Most of this CO_2 has been vented to the atmosphere. Never the less, the size of these plants has been relatively small. As noted in Chapter B, the total of worldwide carbon capture and storage (CCS) projects currently amounts to 40 million tons/year of captured CO_2, far short of the IEA proposed requirement.

The AES Shady Point power station in Panama, Oklahoma installed a monoethanolamine (MEA) CO_2 scrubbing system on a slip stream from this 350 MW plant, equivalent to about 30 MW, in 1990. The captured CO_2 is used for dry ice production. It was the largest CO_2 capture plant in the world in terms of equipment size. There are other CO_2 post combustion capture systems including advanced amine scrubbing systems, the chilled ammonia process, and oxy-combustion. All have been demonstrated at the 25–30 MW level. Getting to the next size level has been a significant challenge. A number of larger projects have been cancelled for a variety of reasons including cost, financing, and public acceptance. Without adequate demonstration at scale, there can be no commercialization.

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[140] Global Carbon Project, "2014 Global Carbon Budget", www.globalcarbonproject.org
[141] International Energy Agency. Technology Roadmap: Carbon Capture and Storage, 2013
[142] World Coal Association, "Coal Statistics", 2013, www.worldcoal.org
[143] BP, "Statistical Review of World Energy 2014", Oil Production, www.bp.com

A review of every major new technology introduced into the power industry since the 1950s shows that commercializing a new technology is both time consuming and costly. These technologies include supercritical steam generation technology, nuclear technology, gas turbine technology, SO_2 scrubbing technology, fluidized bed combustion technology, and integrated gasification combined cycle (IGCC) technology. While the commercialization of IGCC technology has been limited due to its high costs, fluidized bed combustion technology has been installed at a substantial number of plants around the world and has been operating since the 1970s. In spite of this success, fluidized bed technology is only just now starting to be installed in plants in the 500–600 MW size range, some 40 years after the initial, smaller demonstration plants went into operation.

The typical development and commercialization of a new technology in the power industry generally progresses through the following steps:

1) Invention and laboratory conceptual stage
2) Small sub pilot and pilot testing phase
3) Small, slip stream field testing stage
4) Field demonstration stage
5) Early commercial deployment

Each of these stages, or phases, can take at least 5-10 years, in some cases longer. In this scheme, commercialization is defined as being that point where either the new technology claims 10% of the installed base or at least 50% market share of new installations for several years. This definition may be viewed as somewhat conservative, but, if anything, due to the large capital expenditure involved in building a power plant and the risks involved in securing a financial return on that expenditure, power plant owners have only gotten more conservative in the last several decades.

Attempting to “short cut” these steps has generally led to a negative reputation for the technology in question, as well as excessive cost to the developer and the early adopter. Scrubbing technology for SO_2 emissions ran into technical difficulties in the 1970s. A long period of time was necessary for this technology to become the “accepted standard.” These points were also made by utilities and the financial community at the DOE/CURC 2014 Workshop. [144] Short circuiting technology development sounds good in theory, but in practice has no attractiveness for either utilities or investors. These entities want proven assurances that can only be achieved with adequate demonstration and testing as described above.

For this study, “commercially viable” is intended to be different from “commercially available.” Commercially “viable” would mean that a technology has achieved at least TRL 7 or 8 and has been evaluated to have the potential to be commercially “available.” A technology can be deemed “available” if it meets the following criteria:

[144] Brian Brau, Private Communication, Dec. 2014, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/workshop-2014/1-2.pdf

1) One year of operation with 70% availability at scale within 5 years after start up
2) Reasonable cost and performance
   - Meets the proforma requirements of the facility's balance sheet
   - Project wrap performance guarantees are available
   - Reasonable insurance policies are available
   - Risks to ratepayers are minimized (i.e., cost over runs, under performance)
   - Risk of prudency type reviews downstream are minimal
   - Performance objectives are met (i.e., heat rate, availability, reliability, market and grid dispatch, flexibility, emissions criteria)
   - Project finance can be obtained without the need for a consortium

From these criteria, it is clear that carbon capture technology is not "available" for use in the power industry (utility or industrial) as it has not been demonstrated at scale and does not meet the reasonable cost and performance criteria. While there are a few demonstration projects planned or underway, they are heavily subsidized. There are no truly commercially available carbon capture projects at significant scale presently in operation.

Never the less, capture technology is not the most significant stumbling block for the large scale commercial application of CCS technology. Storage remains the primary hurdle with respect to the commercialization of CCS. Put simply, there is no point in capturing CO_2 from utility and industrial sources if there is no place to put it. Storage of CO_2 will require the resolution of a number of commercial, technological, financial, legal, safety, insurance, and public acceptance issues.

From a commercial point of view, the infrastructure necessary to move the captured CO_2 from its source to the accepted storage location does not exist on the scale needed to transport and store billions of tons of CO_2. In addition, fully characterized and publicly accepted storage locations do not exist. There are potential storage locations, but these have not been sufficiently characterized in terms of their storage capacity, likely movement of CO_2, ownership of the CO_2, potential for leakage, insurability, liability aspects, pore space ownership, regulatory framework, safety requirements, and ultimate public acceptance criteria. Without adequate characterization, CO_2 cannot be captured, transported, and stored routinely and reliably at large scale.

Further, none of this process has been "monetized" to the extent that a potential industrial entity can envision a means to be profitable providing the necessary services and equipment that would be needed to make this system a reality. Indeed, a major contribution from the U.S. DOE could very well be in articulating the means for creating and developing this infrastructure. On the one hand, CO_2 has been captured from natural gas processing facilities for decades. Most of that CO_2 is vented to the atmosphere. One could argue that this CO_2 is essentially "free." On the other hand, carbon markets have been established in some parts of the world. Never the less, very little CO_2 has been captured and sequestered (or utilized). Without adequate demonstration and available storage and transportation, this technology will not be commercially deployed.

In the shorter term, utilization of CO_2 will help to offset the cost of capturing the CO_2 from a given source. CO_2 EOR has been the favored application since it already exists commercially, provided that CO_2 can be delivered to the target oil reservoir at a reasonable price. Stimulation of certain oil fields by CO_2 injection has been practiced for over 30 years. There are more than 3,500 miles of CO_2 pipelines that transport nearly 50 million tons of CO_2 annually to over 120 different oil fields. Much of that CO_2 is naturally produced.

From the oil producer's point of view, CO_2 that stays in the field is "lost" (incidentally stored), while CO_2 that comes up with the oil can be recovered and reused. The CO_2 that stays in the field is "stored". Ultimately, over 99% of the CO_2 that is purchased by the oil field operator ends up "incidentally" stored in the field.[145]

There is sufficient technical and regulatory experience available to consider CO_2 EOR to be a mature technology. There are no specific technological barriers that would prohibit a CO_2 EOR operation from becoming a CO_2 storage operation. The main reason that there is not considerably more utilization of CO_2 for CO_2 EOR is the lack of reasonably high purity CO_2 at a price that would make such projects economical as well as a lack of the transportation infrastructure to deliver the CO_2 to where it is needed. Commercial CO_2 EOR operations are driven by profit and market forces. The goal of such operations is to maximize oil production while minimizing the purchase of CO_2. For commercial CO_2 EOR applications, CO_2 is treated as a commodity; if the cost of the CO_2 is too high, oil cannot be produced at competitive market prices. Industry has spent $1 billion on 2,200 miles of CO_2 transmission and distribution pipeline infrastructure to support CO_2 EOR in the Permian Basin.[146] The purchase price for CO_2 will depend upon the current price for oil, with higher oil prices allowing for higher CO_2 prices.

3. Survey Results

In order to gain additional input into the opportunities and challenges associated with CCS technology development, a survey was devised and sent to individuals in the coal industry, the power industry, academia, and other knowledgeable stakeholders. The survey was sent to 250 people, of which 48 responded, or 19%. Roughly half of the responses were from power generators and half were from technology providers. About half of the respondents received some form of DOE support or assistance on CCS/CCUS projects. Of these, 59% achieved their project goals. Some 33% did better than average on their project goals. Only 8% did not achieve their goals. Roughly 67% of respondents indicated that DOE assistance was very helpful in achieving the goals (highest response), while the rest indicated DOE assistance was only somewhat helpful.

[145] DOE NETL CO_2 Enhanced Oil Recovery, http://www.netl.doe.gov/file%20library/research/oil-gas/small_CO2_EOR_Primer.pdf, pg. 24
[146] Ibid. pg. 11

Respondents receiving assistance were asked to rate their projects with regard to achieving their stated project goals, advancing CCS/CCUS overall, advancing CCS, advancing CCUS, and advancing public acceptance, safety, technical operations, and cost. The ratings were based on a scale of 1 -5, with a rating of 1 representing DOE being a key factor and 5 being DOE was not a factor. A rating of 3 represented DOE being somewhat of a factor. The results are shown in Table D.1.

Main element	Sub Element	Key Factor	Somewhat key	Not a factor
CCS/CCUS		40%	49%	11%
	Combustion Tech	49%	47%	4%
	Gasification Tech	49%	42%	9%
	Transportation	11%	72%	17%
	Storage	51%	42%	7%
	Capture	71%	27%	2%
	Efficiency	26%	54%	20%
CCS		47%	47%	6%
	Operations	31%	62%	7%
	Safety	28%	65%	7%
	Cost	33%	60%	7%
CCUS		40%	49%	11%
	Operations	20%	67%	13%
	Safety	16%	75%	9%
	Cost	23%	58%	19%
CCS/CCUS				
	Public Acceptance	18%	73%	9%
	Safety	20%	78%	2%
	Cost reduction	14%	79%*	7%
	Operations progress	18%	75%*	7%

The star (*) for the last two items indicates that the result was for below average.

Table D.1. Survey Results –
Was DOE assistance a factor in achieving your CCS/CCUS project goals?

Respondents were asked to identify key barriers to the commercialization of CCS/CCUS. The following factors were cited:

- Costs
- DOE lack of funding support
- Capture technology
- Commercial complexity
- Efficiency impacts, including performance, balance of plant, and auxiliary power
- The need for large scale projects
- Public acceptance
- Regulatory issues
- Liability
- Markets
- Financial drivers
- Safety
- Technology

A number of respondents indicated that natural gas was a barrier to progress on the application of CCS/CCUS to coal on the grounds that low priced natural gas would replace coal in both new and existing installations. This trend would reduce interest in applying CCS to coal, at least in the U.S. However, as already pointed out, CCS will be needed on natural gas installations as well. Note also, that the lack of a carbon price was not listed as a barrier.

Lastly, respondents were asked when they felt that either CCS or CCUS would become commercial. The results are shown in Table D.2.

	By 2020	By 2025	By 2030	By 2035	By 2040	Longer
CCS	5%	39%	32%	0%	7%	17%
CCUS	29%	44%	0%	18%	0%	9%

Table D.2. Commercialization Date –
Survey respondents' projections on when CCS/CCUS would become commercially available

From the above results, it can be seen that DOE has been instrumental in advancing CCS/CCUS technology on the long road to commercialization. Areas that can benefit from more emphasis include cost, efficiency, and operations progress, all aspects that can benefit from more demonstration plants.

4. First Generation Technologies: Deployment Challenges

First generation technologies include MEA scrubbing, chilled ammonia scrubbing, oxy-combustion, and IGCC with CO_2 capture. The MEA scrubbing process has been the most studied for CO2 capture from flue gas due to its long term utilization in the oil and gas industry for gas processing. It has been demonstrated at the 25–30 MW scale. Scale up studies have estimated the cost for this technology at utility scale of 550 MW_e. For an NOAK plant, the capital cost increase compared to a conventional power plant with the same output is estimated to be about 67%. The resulting increase in cost of electricity (COE) is estimated to be about 63%. The estimated cost of CO_2 captured is $58/ton. The estimated cost of CO_2 avoided is $78/ton.[147] The cost of CO_2 captured can be considered when the CO_2 is to be sold for utilization. The cost of CO_2 avoided is more useful in thinking about overall reductions in CO_2 emissions. The avoided cost takes into account the loss of efficiency in generating power when applying CCS to a power plant.

The cost estimates for oxy-combustion and chilled ammonia are, in general, similar to the MEA process. The IGCC process with CO_2 capture capability was hoped to be somewhat less expensive. However, the most recent plants (Kemper County and Edwardsport) have experienced substantial cost increases. These are both large utility power plants at scale (520 MW). Of these, only Kemper County includes carbon capture and utilization, in this case, at the 65% level. The captured CO_2 will be piped and sold for CO_2 EOR applications. Even so, the cost of these plants has been more than double the cost of conventional, coal fired technology without CO_2 capture. These high costs have been a barrier to further commercialization. In order to overcome these cost disadvantages, second generation technologies are being developed.

5. Second Generation and Transformational Technologies: Deployment Challenges

According to the November 2011 presentation at the Carbon Sequestration Leadership Forum (CSLF), the IEA projects that by 2050, use of biomass based sources for transportation fuels will grow significantly.[148] The projected use of bio-fuels as estimated by the IEA would increase from a 2% today to approximately 27%, thus avoiding 2.1 billion tons per year of CO_2 emissions. Technologies using biomass include bio-energy carbon capture and storage (BECCS) and gasification with Fischer Tropsch (XTLE) systems. Some technologies such as converting CO_2 into cement, minerals and plastics, enhanced fixation into biomass, and using CO_2 as feedstock for chemicals, are at various stages of development.

[147] U.S. DOE, National Energy Technology Laboratory, 2014 DOE/NETL-2007/1281, Cost and Performance Baseline for Fossil Energy Plants, Volume 1, Bituminous Coal and Natural Gas to Electricity, Revision 4

[148] Position Paper, Carbon Sequestration Leadership Forum, November, 2011

Use of CO_2 As Feedstock For Chemical Industries

This application pertains to the use of CO_2 in chemical processes to produce valuable carbon containing products. CO_2 can be converted into building block chemicals and used as a source for commodity chemicals. CO_2 is already used for the synthesis of organic compounds, such as urea (nitrogen fertilizer), antacids, a pharmaceutical ingredient, methanol, cyclic carbonates, and plastics. Global CO_2 demand for urea amounts to over 115 million tons of CO_2 per year. For every ton of urea produced, approximately 0.75 tons of CO_2 can be utilized. CO_2 can also be converted into inorganic minerals that can be used in building materials through electro-chemical reactions. Overall, the potential usage of CO_2 is difficult to determine due to the large potential product portfolio. VDI recently estimated that the global future CO_s demand for polymers could be about 84 million tons/year.[149] Again, while this amount of CO_2 utilization is small relative to the large tonnages that are needed, any revenue from such utilization could help get a demonstration project started.

CO_2 Use in Cement and Concrete Structural Materials

The U.S. National Energy Technology Laboratory (NETL) is investigating efficient techniques to integrate CO_2 into cement and other products.[150] Initial estimates indicate that if 10% of the world's building materials were replaced by the use of this technology, this process would consume approximately 1.6 billion tons of CO_2 annually. Global cement production was 3.3 billion tons in 2010.[151] This application could also abate the CO_2 emitted during the production of cement.

Other Advanced CCS/CCUS Technologies

Several CCS/CCUS technologies are in their early stages of development. These include chemical looping technology, algae cultivation, microbial activities, and renewable methanol.

Chemical Looping. This advanced technology relies on combustion or gasification of fuels in a nitrogen free environment. The chemical looping processes being developed utilize either a metal oxide or calcium sulfate as an oxygen carrier to transfer O_2 from air to the fuel. Chemical looping splits combustion into separate oxidation and reduction reactions. In the fuel reactor, the oxygen carrier releases O_2 in a reducing atmosphere and the oxygen reacts with the fuel to form a concentrated stream of CO_2. The carrier is then recycled back to the air reactor, or oxidation chamber, where it is regenerated by contact with air. Because air is not introduced into the fuel reactor, the products of combustion are primarily CO_2 and water.

[149] Inag/en/do, Energy Policy Consulting, Carbon Capture Use and Storage, 2013.
[150] U.S. Department of Energy. DOE/NETL Advanced Carbon Dioxide Capture R&D Program. May, 2013.
[151] The Statistical Portal, www.statisca.com/219343/cement-production-worldwide

Similar to more conventional oxy-combustion, the primary advantage of the chemical looping process is that the CO_2 is concentrated, and not diluted with nitrogen. Further, since both reactors are operated at temperatures higher than traditional or contemplated steam temperatures, any inefficiency in these reactors provides heat for steam generation, thus greatly reducing the energy penalties associated with CO_2 capture systems. A DOE NETL report states that while chemical looping combustion demonstrates good potential, additional technology development is needed to prepare the technology for demonstration scale testing. Never the less, the estimated costs for chemical looping, both capital and operating, are significantly less than the estimated costs for first generation capture technologies.[152] A recent EPRI review of the chemical looping technology drew similar conclusions.[153]

Algae Production. Biological mitigation of CO_2 is based on photosynthesis. Algae use CO_2, water, and energy provided by sunlight to produce biomass. The resulting biomass can be used for electricity generation or for the production of transportation fuels and chemicals. Microalgae have a high biomass productivity compared to terrestrial crops, and can be cultivated on non-arable land. On average, algae will absorb approximately two tons of CO_2 per ton of biomass, and release oxygen in the process. Current global fuel production from microalgae is 10,000 tons per year, indicating that this technology is in its infancy. Land requirements for algae cultivation are considerably lower than for traditional biofuel crops, but are still very significant. Microalgae can produce an average of about 10,000 gal/acre/year of biodiesel fuel.[154] Current global fuel use is roughly 1 trillion gal/year.[155] Complete replacement would require 100 million acres to be devoted to this process. Land and water use requirements may limit the application of this technology. Duke Energy is hosting a project in Kentucky to demonstrate an algae based system for CO_2 mitigation from one of its coal fired power plants.[156] This project will focus on studying the production of biofuels from algae to demonstrate economic feasibility.

[152] Andrus, H., et al, "Alstom's Chemical Looping Combustion Prototype For CO2 Capture", Phase IV A, Final Report, US DOE NETL, DE-NT0005286, Dec. 2012
[153] "Assessment of Chemical Looping", EPRI Report #3002003620, Dec. 2014.
[154] Elmaragy, M, and Farag, I. H. "Biojet Fuel Production From Microalgae: Reducing Water and Energy Requirements for Algae Growth", International Journal of Engineering Science, Vol.1, Issue 2, Sept., 2012, pp 22 - 30
[155] BP, "Statistical Review of World Energy 2014", Oil Production, www.bp.com
[156] Duke Energy Report on Carbon Capture and Storage with CAER and University of Kentucky, Algae CO_2 Capture at the University of Kentucky, September, 2013

Micro organisms. Research endeavors have started to gain some momentum in this area. Current work has identified five different types of bacteria capable of assimilating CO_2.[157] These micro-organisms could be potentially developed further into industrial scale bioprocesses, using waste water treatment technology as an example. These micro-organisms offer the potential to produce useful chemicals. Typically, these processes plan to utilize captured CO_2 and hydrogen to produce organic compounds, such as fuels. One of the advantages is that the microbes can be tailored to produce a particular type of compound, such as jet fuel, for example. Most of these processes are still at the small lab stage (i.e., a few liters of material to test which microbes are suitable). Economics still need to be verified by pilot scale testing at minimum.

Renewable methanol. This technology uses electrolysis of water to produce hydrogen. The hydrogen is then combined with captured CO_2 over a catalyst to produce methanol and water. This concept has been broadly discussed in Germany as a possible option to store and conserve renewable energy. The energy efficiency of the process is still poor. Energy conversion efficiency of the electrolysis process itself is around 60% at 850 C.[158] The electricity to run the electrolysis process must be generated and the energy needed to capture the CO_2 must be supplied.

Enhanced Geothermal Systems (EGS). EGS are engineered reservoirs created to produce energy from geothermal resources that are otherwise not economical due to lack of water and/or permeability. EGS technology has the potential for accessing the earth's vast resources of heat located at depth An EGS is a man made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS, fluid, such as CO_2, is injected into the subsurface under carefully controlled conditions, which cause preexisting fractures to reopen, creating permeability. Increased permeability allows fluid to circulate throughout the now fractured rock and to transport heat to the surface where electricity can be generated. While advanced EGS technologies are young and still under development, EGS has been successfully realized on a pilot scale in Europe and now at two DOE funded demonstration projects in the United States.[159]

CO_2 Enhanced Water Recovery. CO_2 storage in deep saline formations can potentially run into pressure limitations. One means to reduce the pressure is to produce the saline water to the surface. Then by using one of various desalination techniques, the saline water can be purified to recover fresh water. As water resources become more stressed, this technology offers a combined solution to CO2 storage and water resources. The recently announced project with China and the U.S. is an example of this type of project.

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[157] Carbon Dioxide Capture and Utilization Using Biological Systems. Opportunities and Challenges. Journal of Bio-processing & Bio-techniques Volume 4, Issue 3, 2014.
[158] Badwal, SPS; Giddey S; Munnings C (2012). "Hydrogen production via solid electrolytic routes", Energy and Environment 2 (5).
[159] DOE Fact Sheets, http://energy.gov/sites/prod/files/2014/02/f7/egs_basics_0.pdf

As stated above, these advanced CCS/CCUS technologies currently are primarily in the R&D and sub pilot stages. Further development into multi-MW demonstrations to enable application to large fossil plants would require major investments in money and time. To move these technologies into near commercial stage would require substantial financial support. It is critical to begin weeding out those processes that cannot meet the DOE cost and performance goals at the TRL 4-5 level

6. Legal Issues

The capture, transportation, and storage of massive quantities of CO_2 present many legal and regulatory issues including ownership, liability, insurability, jurisdiction, and permitting concerns. Many of these issues have been discussed in earlier NCC reports (See Appendix H). As evidence continues to emerge of the growing potential for use of CO_2 in industrial processes, it is likely that captured CO_2 will be sold for value, mainly for the production of oil through CO_2 EOR. This approach is sensible, both because getting value for the CO_2 is preferable to paying for its storage, and because CO_2 EOR is a well established industrial activity and, therefore, has a known risk profile.

DOE has a vital role in promoting an understanding among federal and state regulators, who in their turn play key roles in devising and implementing the legal framework, regarding both the future landscape for CCS/CCUS and the impacts of regulations that are being considered. The legal issues discussed below are not intended as a comprehensive list, but as examples of high consequence issues confronting CCS/CCUS.

Proposed Regulation of GHG Emissions from New Sources - 111(b) Rule

CCS as a "Best System of Emission Reduction . . . Adequately Demonstrated"

On January 8, 2014, the U.S. Environmental Protection Agency (EPA) proposed CO_2 emission limits for new fossil-fueled electric generating units. EPA has proposed a standard for coal-fired units – 1,100 lbs./MWh – which would necessitate CCS.[160] To do so, EPA must reasonably find that CCS is a "best system of emission reduction . . . adequately demonstrated."[161] CCS does not yet meet this best system of emission reduction (BSER) standard, because it has not yet been adequately demonstrated.

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[160] The emission standard proposed for new coal-fired power plants is 1,100 lb CO2/MWh gross over a 12-operating month period, or 1,000-1,050 lb CO2/MWh gross over an 84-operating month (7-year) period. "Standards of Performance for Greenhouse Gas Emissions From New Stationary Sources: Electric Utility Generating Units; Proposed Rule," January 8, 2014, 79 Fed. Reg. 1430, at 1502.

[161] 42 U.S.C. 7411(a).

As discussed above, there does not exist today anywhere in the world an operating power plant deploying full scale CCS. None of the 158 carbon capture and advanced energy system projects funded through DOE's National Energy Technology Laboratory (NETL) have, on the 9 level TRL scale, reached a level of 7, the level at which a prototype of a technology has been demonstrated, at which final design is virtually complete, and at which the design has undergone large scale pilot testing.[162] The Boundary Dam project has just started up in Canada. This 110 MW retrofit project will transition from TRL 6 to TRL 7 with sufficient operation and testing.

A representative of Alstom, one of the world's leading energy technology manufacturers, testified to Congress that a technology cannot be considered "available for installation on new plants" until there has been a demonstration at full commercial scale. "It is critical to be at commercial scale to define the risk of offering the technology. . . . This is the first opportunity that we have to work with the exact equipment in the exact operating conditions that will become the basis of contractual conditions [and] becomes the first opportunity to optimize the process and equipment to effect best performance and, very importantly, seek cost reduction."[163]

The two full scale U.S. projects that are cited to support the "adequately demonstrated" conclusion – Southern Company's Kemper County Energy Facility and Summit Power's Texas Clean Energy Project – both received substantial funding from DOE. Not only does this demonstrate the importance of DOE funding, but it causes the proposed rule to run afoul of Section 321 of the Energy Policy Act of 2005, which prohibits EPA from basing a standard solely on projects funded by DOE. In addition, neither of these projects is in operation.

If the assertion that CCS is BSER stands, it could be harmful to the vital research that DOE is continuing to pursue. It may become more difficult to attract partners in the research necessary to fully commercialize a suite of CCS technologies, as companies could be expected to invest in generation resources with more proven technology and less regulatory risk. Furthermore, Congress may question why continued funding support for DOE research is necessary if the technology already is "adequately demonstrated". Given the need described above for greater funding, this represents a significant challenge.

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[162] U.S. Department of Energy, Office of Fossil Energy, Technology Readiness Assessment, "Pathway for Readying the Next Generation of Affordable Clean Energy Technology – Carbon Capture, Utilization and Storage," December 2012, p. 3.

[163] Testimony of Robert Hilton, Subcommittee on Environment and Subcommittee on Energy of the Committee on Science, Space and Technology, March 12, 2014.

It also should be noted that EPA historically has applied the section of the Clean Air Act under which the rule was proposed to regulated facilities, not to "outside the fence" actions to mitigate emissions. The "storage" portion of CCS is anticipated in most cases to be undertaken remotely from the regulated facility. Thus, it is unclear how the rule may impact the storage issue. DOE should bring attention to the conclusions of this report showing that DOE research has been valuable but is far from finished.

Subpart RR Reporting

CO_2 EOR represents a potential option for beneficial use of captured CO_2 emissions and to provide revenue to first mover CCS projects. The 111(b) rule includes existing Underground Injection Control (UIC) program rules[164] and the Mandatory Reporting for Greenhouse Gases Rule[165] to establish reporting and verification requirements for coal fired plants implementing CCS.[166] Facilities would be required to report CO_2 emissions to the EPA under a regime known as Subpart RR, if CO_2 is received from a facility regulated under the proposed rule. Subpart RR requires the facility operator to file a monitoring, reporting, and verification plan with the EPA, subject to a notice and comment process, and to continue monitoring after CO_2 EOR operations have ceased. It also would require reopening the plan any time a significant operational change is made, which is very frequently in an CO_2 EOR operation. Some have argued that this proposal could cause CO_2 EOR operators to be in violation of state laws, some of which prohibit oil and gas field developers from encumbering a property in a manner that could preclude future resource recovery. It also could require renegotiation of hundreds of land use contracts. Some EOR operators have said they will refuse to take CO_2 from a regulated source rather than attract these legal problems.

Class II – Class VI Transition

Draft guidance for Class VI (geologic sequestration) UIC wells proposes that when CO_2 is injected in a Class II oil or gas well "for the primary purpose of long-term storage," the owner or operator must apply for a Class VI permit "when there is an increased risk to USDWs compared to Class II operations."[167] This regulation is vague, and raises the specter that oil wells may summarily be subjected to the much more onerous Class VI regulatory structure, raising risk for CO_2 EOR operations.

[164] 40 CFR pt 144
[165] 40 CFR pt 98
[166] 79 Federal Register, 1482
[167] 40 CFR 144.19(a).

There are nine criteria for the implementing regulator to consider in determining when a well exhibits "increased risk" compared to Class II operations. For example, the regulator must consider whether there is a "decrease in reservoir production," or an "increase in carbon dioxide injection rates." There are two main problems that put CO_2-EOR at risk. First, the vagueness of these terms gives too much latitude to the regulator to shift to an inappropriate regulatory structure, potentially even in cases where the activity is commonplace industry practice shown by decades of experience not to pose a significant threat to drinking water (protection of which is the purpose of the UIC program). Second, EPA has assigned this interpretive task to the Class VI regulator, which as of today is the EPA in all 50 States. The EPA does not have the experience to make this assessment. The task should instead be left to Class II regulators, who have long and deep experience overseeing oil and gas operations. This type of regulatory risk will serve to diminish the likelihood that demonstration projects can realize the potential value of captured CO_2 for EOR applications.

RCRA Conditional Exclusion

On January 3, 2014, EPA issued a rule conditionally excluding CO_2 injected in a Class VI UIC well from hazardous waste regulation under the Resource Conservation and Recovery Act (RCRA).[168] Hazardous waste injected underground is subject to Class I – hazardous regulation, generally the most stringent requirements in the UIC program.

While this conditional exclusion provides helpful clarification, it has given rise to the inference that CO_2 injected in a Class VI well is a waste, though not a hazardous waste. This has caused some to question whether CO_2 injected in oil fields for EOR could also be considered by EPA to be a "waste," even though in the context of CO_2 EOR, the CO_2 is not being disposed of, but is an essential tool for additional oil production. The potential uncertainty is unnecessary and could be seen by some as a deterrent to CCS/CCUS, as the stigma of dealing with a "waste" complicates land use arrangements and public acceptance. There could also be implications for the fuel being produced from such a well as also being considered as a "waste" by association. Under the MACT rules, the combustion of **any** "waste" would classify the combustor as an incinerator, subjection to more stringent rules. Precedents have been established that provide the basis for excluding from RCRA altogether CO_2 when used for CCS or CO_2 EOR, by deeming CO_2, in such circumstances, to be an "uncontained gas," which is not included in RCRA's definition of a waste.

[168] Federal Register, Vol. 79, No.2, Jan. 3, 2014, Rules and Regulations

Infrastructure Development

Industrial infrastructure – particularly linear infrastructure such as pipelines and transmission lines – has over time become more difficult to site and build in the U.S., due to the large number of applicable federal, state, and sometimes local laws and regulations. In addition to the standard environmental reviews, approvals, and permitting required under the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Clean Water Act (CWA), and other statutes, CCS/CCUS presents more difficult infrastructure development issues than a typical utility projects in two ways that could complicate its development and deployment:

- CO_2 pipelines associated with a CCS/CCUS project may or may not be eligible for eminent domain so that rights of way through private property can be obtained when needed. Availability of eminent domain authority differs by state, and turns on such factors as whether the constructing entity is a public utility, whether the facilities are needed to serve end-use customers in the state, or whether the facility is for public use.[169]

- Rights must be obtained for injection of CO_2 in a geologic formation, whether an oil or gas formation for production of energy resources or a saline or other formation for pure CO_2 storage. In many states, ownership of "pore space" where CO_2 would be injected is not clear, though a number of states have enacted clarifying laws.

DOE should maintain circumspection and provide input during the interagency review process regarding proposed changes in federal regulations that could further complicate CCS/CCUS infrastructure development.

Slowness of Regulatory Approvals

The regulatory structure applicable to CCS/CCUS is in flux, and, regarding CCS, is immature. Project developers and regulators alike are still determining how this new and complicated regulatory structure will be applied.

- The first permits for injection of CO_2 into Class VI UIC wells have been issued within the last few months, first to the FutureGen 2.0 project in Illinois, and more recently to the Archer Daniels Midland (ADM) Decatur project, also in Illinois. In the case of the ADM permits, applications were pending for more than three years before being issued. The length of time and complexity of the review process will be a signal to other potential Class VI applicants, none of whom are in queue to our knowledge. Both permits are now being challenged by environmental groups.

[169] See "Study of Legal Issues Relating to Risk and Liability in Connection with Carbon Capture and Storage," p. 46, CCS Alliance, July 23, 2008, accessed September r 29, 2014 at http://www.huntonfiles.com/files/webupload/CCS_liability_report_7.23.08.pdf .

- On June 21, 2013, North Dakota became the first (and still the only) state to apply for Class VI "primacy," under which the state would administer the Class VI permitting program in place of the EPA. After a lengthy pre-application process and more than 15 months after submitting the application, North Dakota is still awaiting final approval from the EPA. This may deter other states from applying to operate the Class VI program.

These legal issues, along with the relative immaturity of the technology have made it difficult to develop demonstration projects, even when funding has been made available.

7. Review of the Experience in Developing and Financing DOE Demonstrations

This review covers the experiences in developing and financing the original group of DOE projects under the CCPI program. These projects included Southern Company Kemper County, AEP Mountaineer, Summit/Texas Clean Energy Project (TCEP), Hydrogen Energy California LLC (HECA), NRG Parish, Basin Electric, and FutureGen. Kemper, Mountaineer, TCEP, HECA, and Basin Electric were awarded in 2009. Parish was awarded in 2010. The original FutureGen was awarded in 2003.

The Kemper Project was originally granted a CCPI award of $270 million in 2004. The project was for a 285 MW IGCC to be built in Florida. However, due to uncertainties in Florida state regulations, the project was withdrawn. In 2008, DOE agreed to reinstate the project as restructured and moved to Kemper County, MS. The project was estimated at $2.67 billion, including the coal mine and the 582 MW net IGCC plant with 65% CO_2 capture. The DOE grant remained at $270 million. The project received permits in late 2010 and proceeded to construction. The project encountered delays in construction and cost over runs. It is now expected that the project as designed will commence operation in 2016. The gas turbines started operation on natural gas in August of 2014. The current cost estimate for the project is $6.1 billion.[170] The project, internally financed by Southern Company, includes the original DOE grant, tax incentives, and a 19% rate increase for the ratepayers in Mississippi. Southern Co. agreed to a cost cap of $2.88 billion for rate making purposes.[171]

AEP Mountaineer was planned as a 235 MW post combustion capture and sequestration project to follow on the earlier American Electric Power (AEP) 20 MW demo of the Chilled Ammonia Capture technology. AEP was to receive a grant of $334 million for the project.[172] AEP, through its subsidiary Appalachian Power, filed with both the Virginia Public Service Commission and the West Virginia Public Service Commission for cost recovery of an additional $334 million for the project under an R&D allowance. Ultimately both states denied the rate application (Virginia first) on the basis that they could not grant the recovery of funds for R&D for which there was no regulatory mandate. Without cost recovery, AEP abandoned the project.

[170] Patel, Sonal (October 29, 2014). "Kemper County IGCC Project Costs Soar to $6.1B", Power
[171] www.globalccsinsitute.com/project/kemper-county-energy-facility
[172] MIT Carbon Sequestration Initiative, ttp://sequestration.mit.edu/tools/projects/aep_alstom_mountaineer.html

TCEP is a polygeneration project which will utilize gasification to produce power (400 MW), urea, and CO2 for EOR. The project received its permits in 2010 from Texas. The project cost was estimated at $3 billion with a $450 million grant from DOE. The project has been delayed primarily due to financing. Unable to find financial closure domestically, TCEP signed an agreement with Sinopec and the Chinese EXIM bank in 2012 to proceed with the project. After performing an additional FEED study with escalating cost, Sinopec backed out of the project. In January of 2014, the power purchase agreement was withdrawn. In July of 2014 TCEP announced an MOU with China Huanqui Contracting & Engineering Corporation, Huaneng, and Chexim to allow the project to proceed. Financing is expected to close around April 2015. Operation is expected in 2018.

HECA was originally a project of BP and Rio Tinto. However, in 2011, the project was sold to SCS Energy. The project is also a polygeneration facility producing power, urea, and CO_2 for EOR. The project has a DOE grant of $408 million. The project's estimated cost is about $4.028 billion.[173] The project was still negotiating offtake agreements and equipment pricing in 2014. Construction and financial close are estimated at late 2014 or early 2015. Operation is currently forecast for 2019. The project will be performed by Mitsubishi Heavy Industries (MHI) with financing led by the Japanese Export Bank.

NRG Parish was originally a 60 MW post combustion process when DOE selected the project and granted it $167 million. The objective was to demonstrate CO_2 capture and subsequent use for CO_2 EOR. Not long into the project, it was recognized that 60 MW would not produce enough CO_2 for a significant EOR application. NRG then announced that the project would be run by its Petra Nova subsidiary and was expanded to a 240 MW slipstream from a 650 MW unit. The project cost is now estimated to be a total of $1 billion. [174] There will be an 80 mile pipeline to the oil field. Petra Nova has taken the additional step of adding a natural gas combined cycle (NGCC) plant in 2013 to the Parish project to provide steam for the amine process. Petra Nova has also acquired an interest in the oil field that will use the captured CO_2 in order to receive revenue from the oil to make the project financially acceptable. Financial close happened in mid 2014 with the start of construction at the same time. Operation is forecast for 2016.

Basin Electric was granted $100 million for a post combustion capture project estimated at $338 million total. The project would capture CO_2 from a 120 MW slip steam at the Antelope Valley Plant and send it through the existing Weyburn pipeline for CO_2 EOR. Basin had two different capture suppliers in the project consecutively. In 2010, Basin withdrew the project as unacceptable financially.

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[173] http://sequestration.mit.edu/tools/project/heca.html
[174] http://sequestration.mit.edu/tools/projects/wa_parish.html

FutureGen was originally selected in 2003 as a 275 MW IGCC demonstration project. The project was to add a shift reactor to the gasification process to produce hydrogen as a fuel for the combined cycle plant, thus increasing the CO_2 captured in the acid gas cleanup system. It was granted $1 billion against a total estimated project cost of $1.65 billion. After a series of problems and cost escalations, DOE cancelled the project in 2008. The DOE reinstated the project in 2010 using ARRA funding. Later in 2010, DOE restructured the project as FutureGen 2.0 and changed the project from an IGCC to a 162 MW oxy-combustion project with CCS. A new project site was selected as a retrofit of an existing plant at the Ameren Meredosia plant. The new project was estimated at that time at $1.25 billion. The project cost is currently estimated at $1.75 billion. These cost over runs and other delays have caused the start of construction to be late 2014 with operation in late 2017 or 2018.

Morgan County, IL will be the site of the injection for sequestration. The State of Illinois has agreed to provide liability coverage for the sequestration and has also provided the equivalent of a power purchase agreement at slightly above the current and projected Illinois power rate. A Sierra Club lawsuit has claimed that the project represents a "major modification" and must undergo New Source Review (NSR) and Prevention of Significant Deterioration (PSD) permitting. The Illinois Pollution Control Board rejected the Sierra Club claim pointing out that the project was properly approved. The Sierra Club has filed a state court appeal of the Board's decision. This lawsuit has held up financial commitments. The FutureGen Alliance has argued that the plant does not need a PSD permit.[175] The project must spend the awarded ARRA funds by a September 2015 expiration date.

In reviewing these projects, the most obvious observation is that nearly all of the projects' costs were under estimated from the start. None of the projects, as selected, retained the same scope from the start as engineering, permitting, and estimating evolved. Also, the time for permitting and development was under estimated for all projects. These are perhaps normal risks for FOAK technologies. Further, in reviewing the projects that are currently proceeding, only those with a major funding source for the entire project are moving forward. Thus, financing, even with significant DOE funding, is still a major barrier to advancing the commercialization of CCS/CCUS.

[175] Tomich, J., Midwest Energy News, "FutureGen Officials Say Sierra Club Suit Jeopardizes Project", 8/8/2014, E&E Publishing, LLC

In regard to financing, this report has pointed out that funds and incentives have been insufficient to drive very many projects through the entire process of planning, permitting, financing, constructing, testing, and ultimately operating large scale power plants with CCS/CCUS. Yet, as previously pointed out, coal fired power plants provide about 40% of electricity generation in the U.S. In terms of financing, other technologies receive much greater funding opportunities with much less generation potential. In particular, residential rooftop solar PV receives on the order of $8 billion/year in various subsidies from federal, state, and local entities, while providing on the order of 0.43% of U.S. electricity generation.[176,177] A significant number of large scale CCS/CCUS demonstration plants can be built for $8 billion/year. Similarly, funds for renewable projects under ARRA were $20 billion (See Appendix E). This would appear to be a policy mismatch. Policy parity would allow the U.S. to retain the option to utilize CCS/CCUS to achieve both environmental and energy resource goals.

8. Public Acceptance

It is important to underscore that effective community engagement is measured by the success of the engagement process and is not contingent upon agreement on the outcome or the design of a CCS project.[178] In some cases, effectively engaging communities can help move projects forward with constructive relationships between the developers and communities. Such constructive relationships can help ensure that the FOAK CCS demonstrations, and any later commercial projects, advance in such a way that respects local economies, values, ecosystems, and residents. Two recently published resources on this topic are the DOE "Best Practices for Public Outreach and Education for Carbon Storage Projects" (2010), and the World Resources Institutes' "Guidelines for Community Engagement on CCS Projects" (2010).[179,180]

The political context for CCUS has shifted dramatically over the last few years as indicated by, among other things, failure to pass climate change legislation, access to abundant and cost-competitive natural gas, and potential regulations for CO_2 reductions. Arguably, this shift has also affected the public perception of issues related to CCUS projects. Where a few years ago, the conventional wisdom (and political and market drivers) expected the implementation of many large scale CCUS projects utilizing saline formations for storage, today has transitioned to a belief that it will be more of a niche application where CO_2 captured at large industrial facilities and select power plants is preferentially used for CO_2 EOR and ancillary storage in oil formations. Assuming this conventional wisdom, there are two levels of public perception to consider: project level and national policy level.

[176] MIT CEEPR, private communication with C. Bozzuto

[177] US Energy Information Administration, Table 1.1.A. Net Generation by Other Renewable Sources: Total (All Sectors), 2003-July 2013, Table 1.1. Net Generation by Energy Source: Total (All Sectors), 2003-Dec2013, Sep 2014

[178] World Resources Institute, http://www.wri.org/publication/guidelines-community-engagement-carbon-dioxide-capture-transport-and-storage-projects, Nov. 2010

[179] NETL's *Public Outreach and Education for Carbon Storage Projects* BPM assists project developers in understanding and applying best outreach practices for siting and operating CO_2 storage projects. It provides practical, experience-based guidance on designing and conducting effective public outreach activities.

[180] http://www.wri.org/publication/guidelines-community-engagement-carbon-dioxide-capture-transport-and-storage-projects

At the project level, it will likely to be easier and/or less expensive to build public support for projects in, or near, oil fields than has been the case for projects in saline formations. The reasons for this relate to the increased local experience with subsurface activities, the potential for direct benefits in the form of royalties for individual landowners, and increased tax receipts for communities. In addition, CO_2 EOR is currently allowed under Class II permits of the Underground Injection Control (UIC) program and, thus, faces a different hurdle than projects that need to obtain a new Class VI permit, one that also has less public involvement in the permitting process.

At the national policy level, many of the same concerns still apply. However, the emphasis is changing. Two competing trends seem to be influencing this: ambivalence towards climate change and competitive alternatives to CCS/CCUS. Public views regarding climate change are mixed enough that there is no unified driver for climate legislation that requires significant cuts in CO_2 emissions. Polls suggest that a majority of Americans think climate change is happening.[181] However, there is not a lot of agreement about the cause (whether natural or manmade), the impacts, or the benefits of reducing emissions.

For many people, the issue of climate change competes for attention with many other more immediate concerns such as the economy, crime, schools, public safety, and family. These factors tend to leave many Americans unmotivated to address climate change and, therefore, CCS/CCUS is not even on the radar screen.

In the recent political election, it was hard to escape the ads calling on voters to elect officials that would repeal Clean Air Act rules that make electricity more expensive. These ads were a poignant reminder that one alternative to CCS/CCUS is simply doing nothing. However, there are a number of other costs to consider. These include the deployment of renewable energy in greater numbers, the re-permitting of existing nuclear energy, and natural gas as a “clean” energy source. Nuclear power and natural gas alternatives for electric power are somewhat less expensive than current CCS technology, even if natural gas is only a temporary and insufficient solution to reduced CO_2 emissions.

One interesting challenge posed by the rise of natural gas is that power companies benefit from the reduced fuel costs and also become less likely to support further CO_2 reductions on new gas units. To these companies, the cost of CCS/CCUS is too large to support wide scale deployment, as evidenced by the withdrawal of several CCS/CCUS projects that could not be completed for economic reasons, as noted above.

[181] Pew Research Center, “Climate Change: Key Data Points from Pew Research”, Jan. 27,2014

Interestingly, some of the eNGOs that have been modestly supportive of CCS/CCUS have shifted their focus to natural gas production (i.e., fracking and methane emissions). However, the eNGO Network on CCS still continues to advocate for CCS development globally and in May, 2014 issued policy recommendations to accelerate the deployment of CCS in the U.S.[182] Ambivalence about whether or how to address climate change in the U.S. is further muddied by concerns that China, India, and other countries will not do their "fair share" to reduce emissions.

At the national level, there are some safety concerns that influence general perceptions of subsurface activities and seem to carry over to CCS/CCUS. In particular, the public seems to easily confuse subsurface activities, including fracking and CCS/CCUS. The alleged water quality problems reportedly associated with fracking and the induced seismicity reportedly associated with waste-water disposal from natural gas production are all problems associated with CCUS. Couple this confusion with a common distrust of companies to "do the right thing" and government to "know what the right thing is", and concern over specific permits, and general policies to expand CCS/CCUS projects can come under fire.

Finally, at the national level, environmental activists have been successful in promoting anti coal sentiment. Many link this to the need to wean ourselves from fossil fuels altogether. Where earlier CCS/CCUS was often characterized as a bridge technology to some ill defined future without fossil fuels, there is now less support because the technology has not been implemented and is considered by many to be too late to be a bridge.

The projects that have moved forward have learned from earlier projects and generally have built positive relationships with the community. Such examples include the Illinois Basin – ADM Decatur Project, Southern Company's CCS pilot and demonstration projects, FutureGen, and in Canada, Boundary Dam, Weyburn, Quest, and Aquistore. The best practices cited in 2010 by the NETL manual remain relevant and provide a useful framework for approaching new projects. Never the less, more can be done to educate the public on the need for CCS and the safety of its application.

[182] ENGO Network on CCS, http://www.engonetwork.org/NEWSRELEASES/Boundary_Dam_Final.pdf, and http://www.engonetwork.org/engo_perspectives_on_ccs_digital_version.pdf

9. General Equilibrium Models

Much of the projected climate impacts from projected CO_2 emissions are based on general equilibrium models that couple economic forecasts with climate forecasts. These models attempt to estimate the impacts of various policies on future economic and climate scenarios, starting with a "business as usual" case (BAU) and working through various policy scenarios to investigate the impacts. The difficulty with general equilibrium modeling is that neither the economy nor the climate is truly at equilibrium. Further, both economics and climate science are extremely complex with so many variables that the results are essentially reflective of the assumptions rather than a true representation of reality. As economist John Mauldin has stated,

"Something as complex as the economy of the United States, or even a relatively small system, cannot be adequately modelled, as there are just too many variables in play (many of them unknown). Further, economies are never in equilibrium, so even a multivariate dynamic equilibrium model assumes a relatively static, and by definition closed, economy (though many economists would argue vehemently that that is not the case)."[183]

That being said, models can be useful in providing guidance in what would otherwise be intractable problems. The point to be made is that models are not the "gospel truth," but rather an indication of what might be expected in the future. One only has to look at the U.S. economy or the shale revolution to know that whatever models might have been used, they did not predict accurate scenarios going forward.

With that preface, models are the best tools available and they are improving. They can provide insight into trends and directions. If one understands the limits of the assumptions being made and the construction of the model, useful information can be obtained. In this light, some potential uses of the models with regard to CCS/CCUS can be contemplated.

As an example, recently the DOE has informed various contractors working on CCS/CCUS development projects that the goal is essentially cost parity with present day, commercial, coal fired power plants without carbon capture. This goals can be achieved by the development of two transformational technologies: 2nd generation carbon capture technologies (e.g., chemical looping) and advanced power cycle technology (e.g., supercritical CO_2 cycles). The 2nd generation capture technology has the potential to reduce the cost of capture from the current level of a 63–65% increase down to less than a 20% increase. The advanced power cycle technology has the potential to improve the overall efficiency by 20–25%, which will, in turn, lower the specific capital cost and, hence, the cost of electricity. The goal is to have these technologies ready for commercial deployment by 2035.

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[183] Mauldin, J. , "Thoughts From the Frontline", Mauldin Economics, Aug. 2014

With this information, it should be possible to utilize general equilibrium models to estimate the amount of expected CO_2 emissions through the deployment of such technologies from 2035 onward. The goals are set in the model, while the other provisions of the model are held the same (i.e., costs for everything else, general economic conditions, general constraints on land and water availability and use, etc.). The assumed availability of these technologies could be compared under a number of policy type actions (i.e., regulations, cap and trade, carbon tax, "business as usual", etc.). Furthermore, one could examine what might happen if the commercialization date was delayed by 5 or 10 years. Likewise, one could look at how much additional emissions reductions could be obtained if these technologies could be made available by 2030, or even 2025.

The benefit of this type of modeling is not necessarily the absolute numbers cranked out by the models, but the sensitivities to the various input assumptions being input. There still may be flaws in the underlying assumptions of the models and difficulties with getting all of the variables correctly analyzed and represented. However, by keeping those assumptions constant during the exercise, at least the trends and the order of magnitude of the costs and emissions reductions can be estimated.

From this type of analysis, one could try to understand if the potential contribution to emissions reductions from CCS/CCUS would be sufficient to meet the overall goals. Consider an extreme case. Fossil fuels continue to provide over 80% of U.S. energy needs through 2035. Then the DOE development goals are met and CCS technologies penetrate the market rather rapidly (another assumption). With these technologies, energy costs remain relatively constant (under the cost parity assumption). Thus, over some time period, virtually all plants use these technologies and the capture level is 90% (another assumption). From then on, the CO_2 emissions from the U.S. power sector are 10% of what they used to be. With that level of reduction, can the CO_2 concentration goals be attained? If not, how much of the rest of the world would have to adopt these technologies?

CHAPTER E: Gap Analysis

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1. **Key Findings**

- The current DOE CCS/CCUS program does not include any budget or plan to fund demonstrations of 2nd generation CO_2 capture technologies. Such demonstrations need to be operating in the 2020-2025 timeframe in order to foster widespread deployment of CCUS on power plants in the 2030s. For demonstrations to begin operating in the 2020-2025 timeframe, financial commitments need to be made in near future (2015-16).

- At the same time, DOE needs to continue to "feed the pipeline" by sponsoring early stage R&D on transformational technologies for CO_2 capture as well as technologies which can improve the efficiency of CO_2 compression.

- While the DOE should be justifiably proud of its CO_2 storage program, in its current form it will not be sufficient to reach the desired endpoint. DOE's goal should be to have 5-10 GW of CCUS projects operating by 2025. In addition, DOE's program needs to address the risk a CCUS project developer faces of not finding a suitable site for CO_2 storage in a timely and economic fashion. This can be addressed by carrying out a program to identify and certify at least one reservoir which is capable of storing a minimum of 100 million tons of CO_2 at a cost of less than $10/ton in each of the seven regions covered by DOE's Regional Carbon Sequestration Partnership (RCSP) program.

- Control of greenhouse gas emissions is a global problem in need of global solutions. DOE has undertaken important steps to form international collaborations, but more will be needed.

- In the past several years, no federal funding has been made available for commercial scale demonstrations of CCS/CCUS technology. The existing DOE loan guarantee program for CCS/CCUS projects will not be sufficient to move these projects forward. There is a need to find creative mechanisms to finance CCS/CCUS projects.

2. Introduction

This chapter defines what should be the desired endpoint of DOE's CCUS R&D program and compares that endpoint to DOE's stated goals. The chapter then evaluates whether DOE's existing R&D program will get the nation to the desired endpoint by 2035. Where it is determined that the existing program will fall short, the magnitude of the "gap" is identified and ways to close the gap are recommended.

This gap analysis assessment is based on each primary link in the CCUS "chain": capture, transportation, and storage/utilization. There are also additional insights provided on the need for international collaboration and opportunities for such collaboration, the relevance of DOE's ongoing Quadrennial Energy Review (QER), as well as the President's Export and Manufacturing Initiatives, to its CCUS program, and workforce issues.

Finally, because the overall assessment is that DOE's current CCUS program will fall short of reaching the desired endpoint, the need for creative financing approaches, which could help advance CCS/CCUS development goals, is laid out along with some examples of approaches that could be taken.

3. CO_2 Capture

<u>What is the desired endpoint?</u>

As described in Chapter A, to meet international carbon management objectives CCUS must begin to be widely deployed in the decade of the 2030s. In order for this to occur, CO_2 capture technology must be ready for commercial deployment in the decade before that date. As noted in Chapter D, the benchmark for being commercially available is for a technology to have operated reliably at full commercial scale for at least one year with reasonable cost and performance so that it can be commercially insurable and financeable. Reaching that benchmark should be the desired endpoint for DOE's CCUS program.

<u>DOE's stated goal for its CO_2 capture program</u>

DOE has established multiple goals for its CCUS program which have evolved over the past ten years. The 2008 goal was to develop technology which would capture 90% of CO_2 emissions while limiting the increase in the LCOE for combustion based coal power plants by no more than 35% and gasification based power plants by no more than 10% (Note: the baseline costs for these two types of plant vary). Later this was changed to developing a combination of power plant and CO_2 technologies that would be ready for demonstration in the 2020–2025 timeframe (with commercial deployment beginning in 2025) that could capture CO_2 at a cost of less than $40/tonne of captured CO_2. (See Chapter C for a discussion on the CCS goals.)

There was a companion goal of developing "transformational" technologies[184] that would be ready for commercial deployment in 2035 that could capture CO_2 at a cost of <$10/tonne of captured CO_2. Those goals were recently modified and now DOE is calling for "2nd generation" technology to be ready for demonstration in the 2020–2025 timeframe that could capture CO_2 at a cost of approximately $40/tonne of captured CO_2, and transformational technology ready for demonstration in 2030-2035 timeframe that would deliver costs of less than $40/tonne of captured CO_2. This revised timeline is depicted in Figure E.1.

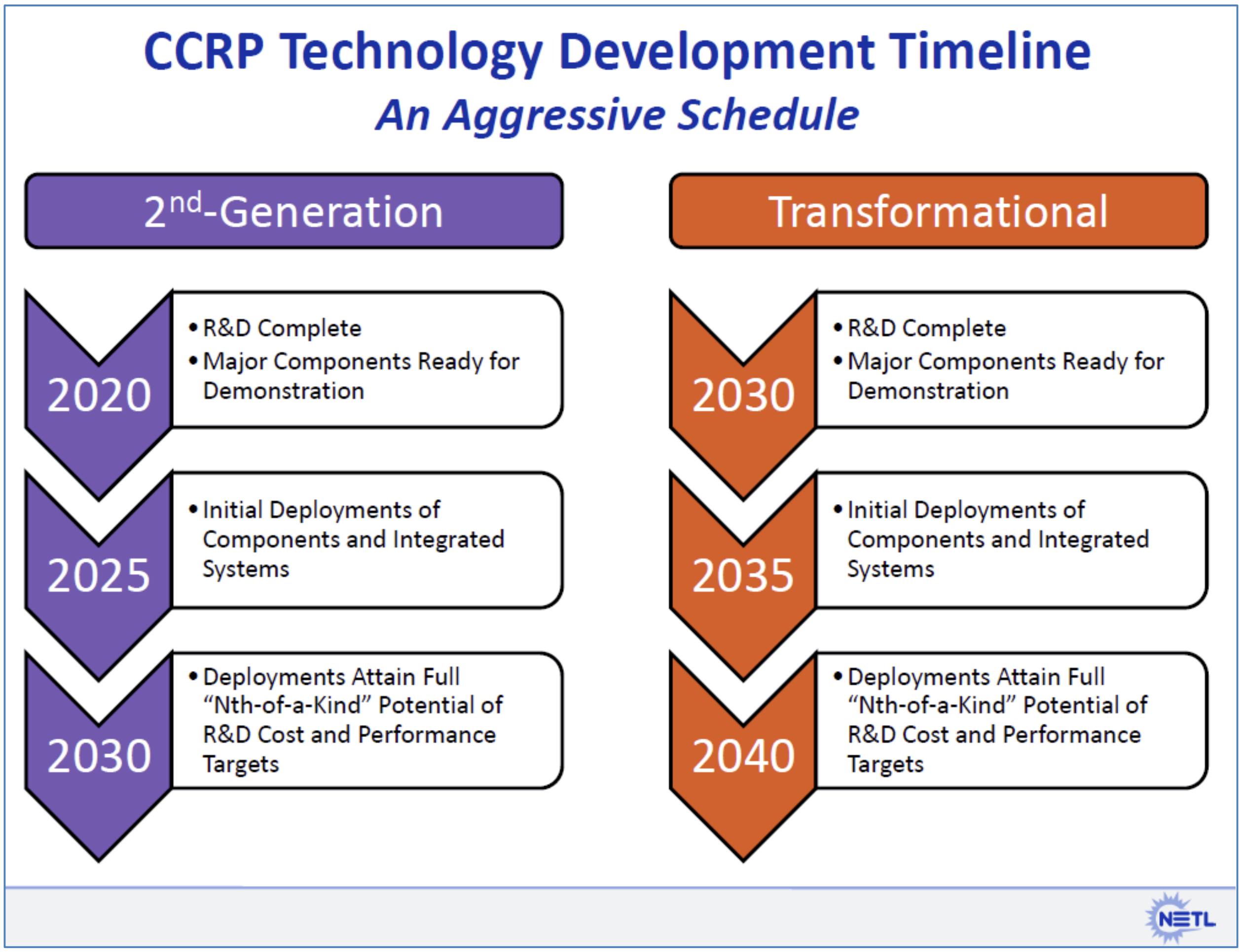

Figure E.1. DOE's CO_2 Capture Research Timeline[185]

[184] DOE considers "transformational" technologies to be those which will not complete their R&D activities until 2030 and will not reach "nth of a kind" commercial deployment until 2040. Examples DOE has given of transformational technology currently in the DOE R&D portfolio are chemical looping, direct power extraction (e.g., MHD), and pressurized oxy-combustion.

[185] Gerdes, K, "New Coal Power R&D Goals", CO_2 Capture Technology Meeting, Pittsburgh, PA, July 2013.

It should be noted that when DOE cites cost goals, they are for greenfield plants, not retrofits. Also, the costs are for NOAK, not FOAK plants. This means the costs incurred by the first several commercial scale demonstrations of this technology will very likely be higher than the stated goal. Historically, it has taken more than several plants to introduce a brand new technology into the power industry. The cost goals are for the first year of plant operation, and include compression to 2215 psia but exclude CO_2 transport and storage costs. The cost of capture is relative to a new advanced ultrasupercritical pulverized coal (A-USC PC) plant without CCS.

Will DOE's current program get to the desired endpoint?

DOE believes the cost goal for "2nd generation" technologies (e.g., any that meet the cost goals) should be sufficient to allow coal power plants that can sell captured CO_2 for CO_2 EOR to be economically competitive with a coal power plant (A-USC) that does not capture CO_2 (assuming a new coal plant could be built without limits on CO_2 emissions). In other words, DOE projects that the captured CO_2 could be sold for more than $40/tonne to an EOR operator. If that is true, and DOE's CO_2 capture demonstration program resulted in a commercial scale CO_2 capture system operating reliably for more than one year, one could argue that DOE's program would reach the desired endpoint of delivering technology which is ready for commercial deployment by 2030.

However, the mismatch between FOAK costs and NOAK costs means DOE's current program will fall short. If a DOE subsidized demonstration project operates at or near commercial scale in the 2020-2025 timeframe and shows promise of delivering $40/tonne of captured CO_2 in an NOAK unit, the next plant built with this technology will still incur costs significantly higher than $40/tonne. Since there is no program in place or proposed to help subsidize either the initial or operating cost of "first movers", those plants will not be economically competitive and therefore will not be built. The NOAK costs will never be reached if the 1st, 2nd, 3rd, etc. commercial scale plants are never built.

An even greater concern is that the current DOE program has no budget or plan to fund demonstrations of 2nd generation CO_2 capture technologies. How will these technologies be demonstrated at or near commercial scale in the 2020-2025 timeframe? Keeping in mind the fact that commercial scale CO_2 capture projects will take at least five years, or more, to be designed, permitted, and built, in order for a demonstration to beginning operating in 2020, the commitment to fund it must be made in 2015.[186]

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[186] DOE's current commercial scale CCUS demonstration projects provide the most applicable examples of design and construction timelines. The Kemper County IGCC was granted its Clean Coal Power Initiative award in January 2006 and is expected to begin commercial operations in 2016. The W.A. Parish post combustion capture project received its CCPI award in May 2010 and is now expected to start operating in 2016. Given these examples, a five year timeline may be optimistic, but the point remains that if demonstrations are to occur in the 2020-2025 timeframe, funding commitments must be made soon.

How can the gap be closed?

From the above discussion it is clear that what is missing is a major demonstration program for CCS. A suite of programs will be needed to take the 2nd generation and transformational CO_2 capture technologies which DOE is now nurturing from pilot scale (~1 MW) to commercial scale. This must include demonstration projects at or near commercial scale which receive sufficient government subsidies to allow them to at least break even as well as mechanisms to help first movers cover the gap between the cost of "single digit serial number" commercial scale projects and NOAK project costs.

In addition, it is critical for DOE's program to continue to "feed the pipeline" by sponsoring early stage R&D on transformational technologies. ARPA-E has abandoned that space, but no one has yet come close to developing a CO_2 capture technology which approaches the theoretical minimum energy for separating CO_2 from flue gas, so there is much opportunity for improved concepts to be discovered. DOE could fund a program to help bring those concepts forward. In addition to improved solvents, sorbents, and membranes, DOE should continue its efforts to nurture more efficient CO_2 compression technologies.

4. CO_2 Transportation

What is the desired endpoint?

In order to begin widely deploying CCUS in the 2030s, it will be necessary to have technology which can transport CO_2 at commercially relevant volumes (i.e., millions of tons per year) over distances of hundreds of miles.

DOE's stated goal for its CO_2 transportation program

The DOE CCUS program does not have any R&D goals related to CO_2 transportation. However, it has conducted analyses on CO_2 transportation. DOE Fossil Energy and National Energy and Technology Laboratory researchers recently released a CO_2 transport cost model for public use.[187] This model calculates the cost to transport a metric ton of captured CO_2 by pipeline. It includes all aspects of a pipeline project including construction, operation, and financing costs.

Will DOE's existing program get to the desired endpoint?

Today there are more than 5000 km (>3000 miles) of commercial CO_2 pipelines in the U.S. Some of these pipelines have been in service since the 1970s. They have proven to be highly reliable and safe. Also, DOE's transport cost model has shown that transportation costs for CO_2 traveling through a 100 mile pipeline will be on the order of $1/ton using today's technology. In short, this is commercial technology, and DOE's current program is adequate. Permitting can still be a problem and more public outreach will be needed to address that issue.

[187] http://www.netl.doe.gov/research/energy-analysis/analytical-tools-and-data/co2-transport

5. CO_2 Storage and Utilization

What is the desired endpoint?

In order to begin widely deploying CCUS in the 2030s, it will be necessary to demonstrate economically viable CO_2 utilization options which could consume gigatons per year of CO_2 or commercial scale geologic storage of CO_2 must be proven to the extent it is accepted by both the public and by CO_2 producing industries as a low risk option for locking up CO_2.

DOE's stated goal for its CO_2 Storage and Utilization program

DOE has the following four major goals for its CO_2 storage program:

- Develop and validate technologies to ensure 99% storage permanence
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- Support industry's ability to predict CO_2 storage capacity in geologic formations to within +/- 30%
- Develop Best Practice Manuals for monitoring, verification, and accounting (MVA); site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.

In addition, DOE's "Core R&D" program within its CO_2 Storage program includes an effort focused on "carbon use and reuse." While there are no high level goals established for this effort, DOE is currently sponsoring projects focused on polycarbonate plastics, mineralization and cements, and chemicals produced from CO_2. Even ignoring economics, it is simply very difficult to find products that could be made from CO_2 that are in high enough demand to have a meaningful impact on U.S. CO_2 emissions. For example, the 750,000 tons/year of urea that would be produced from CO_2 captured from the proposed 200 MW Texas Clean Energy Project would provide 20% of the urea currently produced in the US. Building four other similar projects would saturate the market, and yet 1 GW of power represents only one third of one percent of the installed coal power in the nation.

Will DOE's existing program get to the desired endpoint?

DOE's CO_2 storage program is the best in the world. Even so, it is still inadequate to support the large scale deployment that will be requires. No other national or transnational effort has come close to DOE's RCSP program. The RCSP has been a three phase effort spread across seven regions of the U.S. All parts of the nation are included in at least one region, with the exception of the six New England states which generally do not have geology conducive to CO_2 storage.

The first phase of DOE's program, conducted principally between 2003 and 2005, characterized each region's geological resources and the magnitude of CO_2 which potentially could be stored in that geology. The second phase, conducted primarily between 2005 and 2013, implemented a series of small scale CO_2 storage projects meant to validate both the ability of a given geological resource to store CO_2 and the monitoring, verification, and accounting (MVA) technology and techniques required to prove that CO_2 was permanently stored. The third stage, which began in 2008 and is expected to continue through at least the end of this decade, has focused on carrying out large scale CO_2 storage projects in which at least 1 million tons of CO_2 is stored. Table C.2 (Chapter C) provides an overview of these third stage, or development phase, projects. [188]

While the DOE should be justifiably proud of its CO_2 storage program, in its current form it will not be sufficient to reach the desired endpoint. DOE's current four goals each must be achieved in order for industry to widely deploy geologic storage of CO_2, but that will not be enough to gain widespread acceptance by the public. CO_2 storage suffers from a not under my back yard (NUMBY) problem. Until it has been demonstrated in multiple parts of the country that large scale geologic storage is safe, it is unlikely that this relatively unknown concept will be embraced by an often skeptical public, as pointed out in Chapter D.

An equally important aspect is that geologic storage must be embraced as a low risk option by the risk adverse CO_2 producing industries. DOE's current program will help quantify the risk of geologic CO_2 storage including potential issues associated with leaks and induced seismicity, which may make the industries, and their insurers, more willing to accept the long term liability that U.S. federal regulations place on the owner of the CO_2. A greater number of large scale storage projects would do much more to build confidence.

There is a separate class of risk which will not be addressed sufficiently by DOE's current program, and that is the risk of not finding a suitable site for CO_2 storage in a timely and economic fashion. Currently no company offers CO_2 storage as a commercial service. There are companies which will conduct site characterizations via 3D seismic surveys and which will drill test wells to verify the suitability of a reservoir for CO_2 storage, but those types of activities require considerable time and money and come with no guarantee that the result will be satisfactory.

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[188] DOE Carbon Storage Program Plan, http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/Program-Plan-Carbon-Storage.pdf

The ZeroGen project in Australia provides an example of what can go wrong for an organization hoping to build a power plant with CCS. Previous geologic survey work conducted in Queensland had identified a region called the Northern Denison Trough as an area which had deep saline formations that could be suitable for CO_2 storage. The ZeroGen organization spent three years and $100 million Australian (approx. $95 million USD) on CO_2 storage exploration, drilling, testing, and studies only to conclude that the chosen location could not sustain the required injection rates for their planned 390 MW IGCC project.[189] That was a principal reason the project was canceled.

The Queensland government issued a case history of the ZeroGen project this year and one of their "top five" lessons learned was:

> "A large amount of expensive data gathering should be expected and while success rates *might* be higher than in the oil and gas exploration sector, failure rates and costs and delays are likely to be significant".[190]

Power plant developers are not willing to take on a $100 million bet and wait three years to find out whether they've hit "pay dirt" in terms of finding a suitable CO_2 storage site. Instead, they are likely to follow more certain paths such as building natural gas combined cycle plants, which under proposed New Source Performance Standards (NSPS) regulations can be built without CCS.

DOE's storage program does not appear to be aimed at addressing this situation. There is the goal to support industry's ability to predict CO_2 storage capacity in geologic formations to within +/- 30 percent, but that is not the same as supporting industry by assuring that sufficient storage capacity has been appraised and is ready for a power plant developer (or third party) to use in a commercial CCS project without the need to undergo a large amount of expensive data gathering.

DOE has conducted 9 "site characterization" projects for CO_2 storage as part of the ARRA. However, the budgets for these projects were a factor of 20 less than what ZeroGen spent, and several of these projects were simply reviews of existing seismic and other geologic data and did not include drilling of wells or test injections. Another of the ZeroGen case history's "top five" lessons learned was "desktop analyses are inadequate, it is likely that a significant drilling, testing and seismic program will be required and these will be *funds at risk*."[191]

[189] http://www.globalccsinstitute.com/publications/zerogen-project-case-study
[190] State of Queensland, 2012, University of Queensland, 2014, "ZeroGen Case History", http://www.uq.edu.au/energy/docs/ZeroGen.pdf
[191] ZeroGen IGCC with CCS: A Case History, The State of Queensland, 2012, http://www.uq.edu.au/energy/zerogen-igcc-with-ccs-a-case-history

In contrast to its storage program, DOE's CO_2 utilization program is very modest and clearly will not reach the desired endpoint of having demonstrated commercially viable gigaton/year options for using CO_2. However, as discussed in Appendix G, there are many reasons to be skeptical that any level of R&D effort will be able to reach the desired endpoint.

How can the gap be closed?

More large scale demonstrations of geologic storage of CO_2 are needed. Two previous reports by the National Coal Council[192,193] as well as the report by the Interagency Task Force on Carbon Capture and Storage[194], all recommended 5-10 GW of commercial scale CCS demonstrations. If one assumes a coal power plant produces 0.9 tons of CO_2 per MWhr of power production, and if the CCS demonstrations all captured 90% of the CO_2, 5-10 GW of CCS demonstrations would capture 4050 to 8100 tons per hour of CO_2. Over the course of a year this would be 28-56 million tons of CO_2 to be stored. DOE's RCSP development phase storage projects which are underway will store a total of 9 million tons of CO_2, and that will occur over several years, not each year.[195] Even taking into account the planned development projects and DOE's other CCS demonstrations such as FutureGen 2.0, the projects will store at most 10 million tons of CO_2 per year. Three to five times that amount should be the goal.

It should be acknowledged that DOE was an early champion of the need to have 5 to 10 commercial scale CCUS demonstration plants. Several of the projects have not moved forward for a variety of reasons including higher than expected project costs (e.g., Basin Electric Antelope Valley), the inability to get approval to pass the cost of the project on to rate payers (e.g., AEP Mountaineer 235 MW post combustion capture), and delays in receiving permits to sequester CO_2 (ADM's ethanol CO_2 storage project in Decatur). DOE and stakeholders in industry need to address the issues which have canceled or delayed DOE's demonstration projects before a new initiative is undertaken to carry out a new round of demonstrations. Among others, this might include requiring a smaller cost share percentage from project developers and creating a mechanism that shares the liability for long term care of the stored CO_2.

DOE could significantly reduce the risk of undertaking a commercial CO_2 storage project by conducting the type of "significant drilling, testing, and seismic program" that ZeroGen cited, or by establishing a program that spurs industry to carry out such an effort. The goal of such a program would be to certify at least one reservoir in each of the seven regions covered by DOE's RCSP program which is capable of storing a minimum of 100 million tons of CO_2 at a cost of less than $10/ton.

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[192] Low-Carbon Coal: Meeting U.S. Energy, Employment and CO_2 Emission Goals with 21st Century Technologies, National Coal Council, December 2008

[193] Expediting CCS Development: Challenges and Opportunities, National Coal Council, March 2011.

[194] Report of the Interagency Task Force on Carbon Capture and Storage, (multiple federal agencies), August 2010. http://www.epa.gov/climatechange/Downloads/ccs/CCS-Task-Force-Report-2010.pdf

[195] Rodosta, T, "Carbon Storage Program Overview", US DOE Carbon Storage R&D Project Review Meeting, Pittsburgh, PA, August 2014

As previously stated, DOE's CO_2 utilization program is not on track to reach the desired endpoint (see Appendix G). However, DOE's efforts to extend knowledge of CO_2 EOR and its investigations of the possible use of CO_2 in "residual oil zones" are efforts that should be continued and enhanced.

6. International Collaboration

The issue of controlling GHGs, especially CO_2, is unquestionably global in scope and requires a global effort. There is little impetus to act alone on CCS/CCUS research, development, demonstration, and deployment if other countries are not willing to deploy the technology. In fact, the DOE has already taken important steps to form international collaborations, but more are needed.

The Current Foundation

The DOE has already fostered partnerships with several organizations around the world to encourage knowledge sharing and advance CCS. For instance, there are several international CCS projects, including:

- Weyburn-Midale (Canada)
- Sleipner (North Sea)
- Otway Basin (Australia)
- FutureGen (U.S.)
- Water Production (China)

These projects have several benefits for all CCS stakeholders. First, technical challenges and solutions can be shared. In addition, each large scale project can be used to convince the public of the safety of CCS.

The DOE has also established several collaborative groups, such as the CSLF that includes participation from countries that represent about 75% of global anthropogenic emissions. Under the broader North American Energy Working Group the North American Carbon Storage Atlas was created.[196] In 2009, the U.S.-China Clean Energy Research Center (CERC) was established, covering research on a broad range of energy issues, including CCS under the CERC Advanced Coal Technology Collaboration (ACTC) with West Virginia University leading the way on the topic of clean coal research.[197] This collaboration includes universities, major corporations, and other research institutions from both the U.S. and China. These collaborative efforts are a promising first step, but as DOE's budget is insufficient to commercialize CCS alone, DOE must continue to seek international opportunities to augment its efforts.

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[196] USDOE, http://energy.gov/articles/energy-department-announces-new-mapping-initiative-advance-north-american-carbon-storage, "Energy Department Announces New Mapping Initiative to Advance North American Carbon Storage Efforts", May 1, 2012

[197] National Energy Technology Laboratory, Global Collaborations, www.netl.doe.gov/research/coal/carbon-storage/cs-global/

Using Low Cost CO_2 to Demonstrate Storage

CCS is advancing at a time when China is developing new sources of low cost CO_2 that could potentially be used for large scale, internationally funded storage demonstrations. Although the geology of CO_2 storage locations is site specific, there are some very strong reasons that it is worthwhile to use China's low cost CO_2 for large demonstrations, including:

- Through co-financing such CO_2 storage projects, foreign governments could gain early access to the lessons learned as well as technology basics. Some challenges will have global implications.
- As there are very limited public sector financial resources, the lowest cost CCS projects offer the "biggest bang for the buck."
- As CO_2 is distributed on a global scale, it does not matter from where CO_2 is captured. Therefore, using the lowest cost CO_2 streams represents a way to tackle the "low hanging fruit" first.

The number of gasification projects, which are responsible for creating the low cost CO_2 streams, is rising rapidly as shown in Figure E.2.[198] The vast majority of this growth is occurring in China. As of 2010, China had about 400 such plants (including those operating, under construction, or being planned) that use coal as the feedstock. When all these plants are up and running, the cumulative nearly pure CO_2 emissions will be about 270 million tons per year.[199]

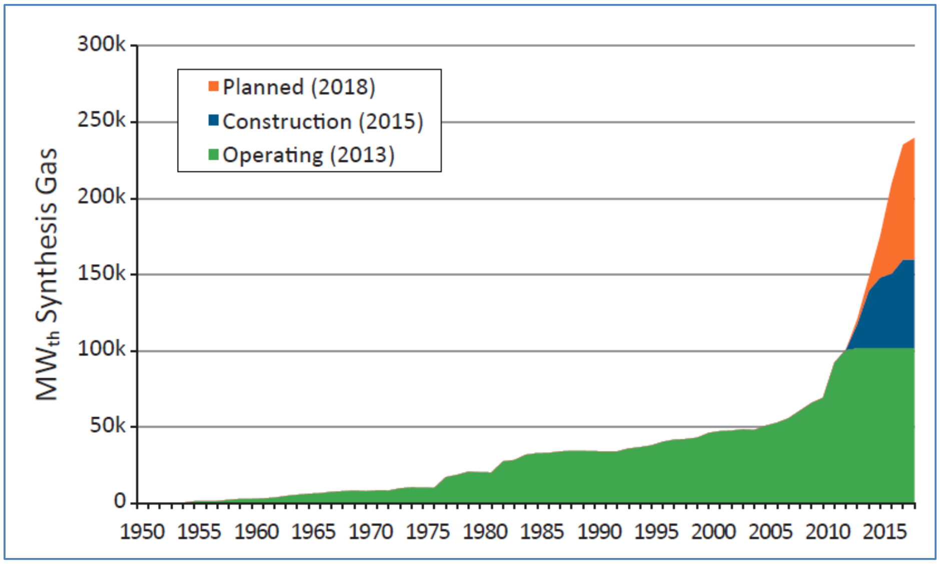

Figure E.2. Global Gasification Projects

[198] Kerster, A. Gasification Can Help Meet the World's Growing Demand for Cleaner Energy and Products, *Cornerstone,* 2(3), 2014.

[199] Zheng, Z., Larson, E.D., Li, Z., Liu, G., and Williams, R.H., Near-Term Mega-Scale CO_2 Capture and Storage Demonstration Opportunities in China, *Energy and Environmental Science*, 3, 1153-1169, 2010.

In a 2010 study, Zheng et al. identified 18 coal to chemicals facilities that were within 10 km of potential saline storage sites and another 8 facilities that were within 100 km. All of these facilities will or are emitting a minimum of one million tons/year. The study also evaluated the NOAK costs, which were generally in the range of $8–12/ton CO_2, with about 75% of the projects 10 year net value costs at $200 million or less.[200]

Although international storage demonstrations should not completely replace the learning through domestic projects, the prospect of relatively low cost CO_2 streams and costs being borne through several public sector funders is appealing when considering the need to advance CCS in the near term. Since the 2010 study, there has been an even greater emphasis on coal based conversion projects in China, specifically to create substitute natural gas. These plants offer an even greater opportunity for international collaboration on CO_2 storage and some collaboration is already underway under the CERC ACTC program.

Demonstrating U.S. Technologies Abroad

Compared to CO_2 storage, demonstrating CO_2 capture technologies is much less sensitive to the site at which it is occurring. There is a strong need to deploy more CO_2 capture projects to reduce the technology costs through learning by doing. There may be a unique opportunity to complete pilot scale (and perhaps demonstration scale) projects in the U.S. first, and then undertake first or second of a kind projects at locations where construction costs are lower and permitting timelines may be shorter. Again, China is an example where such opportunities exist. Further, such U.S. support could be utilized to promote the purchase of CCS equipment manufactured in the U.S.

Demonstrating CO_2 capture at the commercial scale and advancing technology to reduce capture cost is desperately needed to convince power producers and policy makers that CCS is a viable option for the future. For CCS deployment, there are some major advantages in the U.S., including a system that protects intellectual property, the potential for low cost CO_2 transportation, and abundant opportunity for revenue producing CO_2 EOR. However, advancing these technologies to commercial operation may be better served through international collaboration.

Of course, there are many challenges to taking advantage of international collaboration opportunities, not the least of which is how to deal with intellectual property (IP) rights, which would be a major concern for technology developers. The DOE could support the development of a strong IP protection strategy, without which international demonstrations may falter. Fortunately, much of the groundwork around IP protection has been laid through existing collaborations, including CERC. International efforts of this type could support objectives of both the President's Export Initiative[201] and the President's Manufacturing Initiative.[202]

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[200] Zheng, Z., Larson, E.D., Li, Z., Liu, G., and Williams, R.H., Near-Term Mega-Scale CO_2 Capture and Storage Demonstration Opportunities in China, *Energy and Environmental Science*, 3, 1153-1169, 2010.

[201] http://www.trade.gov/neinext/

7. Relevance of QER

The Quadrennial Energy Review (QER) is a federal government wide review of energy policy. President Obama called for a new QER to begin in January 2014 with a focus on infrastructure with the goal of identifying "the threats, risks, and opportunities for U.S. energy and climate security, enabling the federal government to translate policy goals into a set of integrated actions."[203] The current QER is intended to be a four year effort with the first year focusing on electricity transportation and distribution infrastructure. Subsequent years will look at energy supply, supply chains, and end use infrastructure. It is the NCC's recommendation that the infrastructure needs for a comprehensive, nationwide CCUS system be considered in 2015 or 2016.

8. Workforce Issues and Public Acceptance

The President's 2010 Interagency Task Force on CCS noted that "workforce capacity may be a barrier for widespread deployment, including both project related workforce needs (e.g., reservoir engineers, etc.) and permitting related workforce needs at both the State and Federal levels."[204]

These concerns are still valid today, and while DOE's current CCUS program will indirectly help to ease the workforce needs by engaging scientists and engineers on CCUS related topics, more could be done to address the barriers noted by the 2010 Task Force. For example, DOE could hold workshops for state and federal regulators to introduce them to DOE's CCUS demonstrations and also take them to locations where CO_2 pipelines are currently in place so that regulators can talk with people who work on the pipelines and to people who live next to the pipelines. Fostering discussions between regulators in states with DOE CCUS demonstrations and regulators from states that do not yet have CCUS projects would be another capacity building effort DOE could undertake. It would also help with public perception issues.

Finally, DOE's highly successful University Turbine Systems Research program which sponsors R&D projects related to gas turbines at U.S. universities and places engineering students in summer internships with U.S. companies that work with gas turbines could be replicated with a similar program focused on CCUS. This would help "prime the pump" in the development of a workforce with the necessary skills to implement a wide spread deployment of CCUS projects in the coming decade.

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[202] http://www.manufacturing.gov/nnmi.html

[203] http://www.energy.gov/epsa/quadrennial-energy-review-qer

[204] Report of the Interagency Task Force on Carbon Capture and Storage, (multiple federal agencies), August 2010. http://www.epa.gov/climatechange/Downloads/ccs/CCS-Task-Force-Report-2010.pdf

9. Need for Creative Financing

Since FY 2009, no federal funding has been available for commercial scale demonstrations of CCS/CCUS technology, as shown in Figure E.3. Given current budget policies (e.g., budget sequestration process), it is acknowledged that obtaining hundreds of millions, if not billions, of dollars from the federal government to pay for projects which will cost will be difficult. Consequently, there is a need to find creative mechanisms to finance such projects.

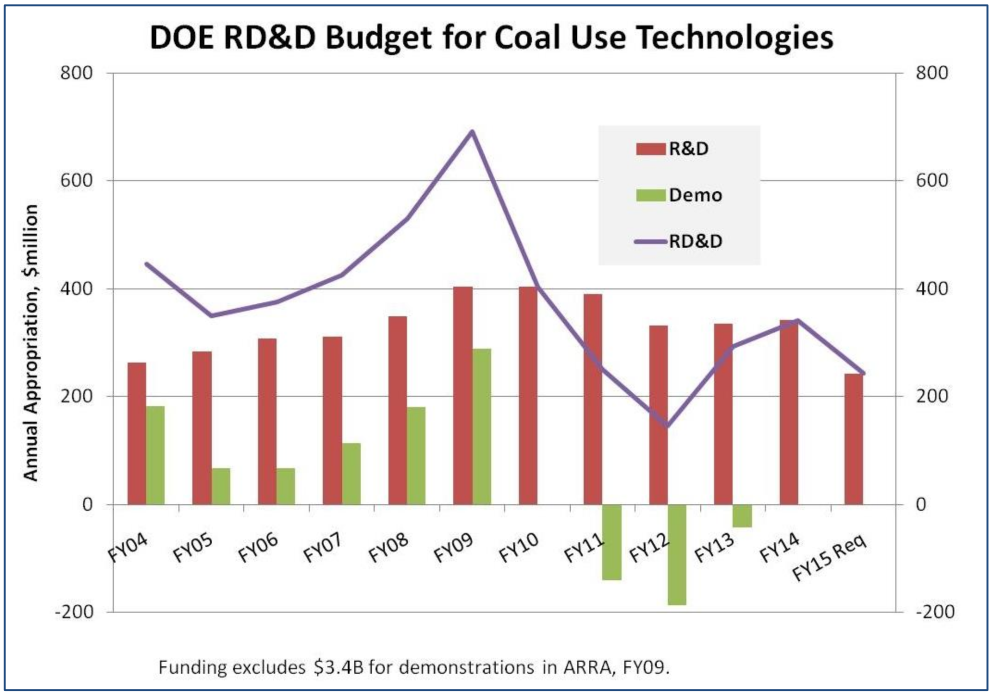

Figure E.3. DOE RD&D Budget[205]

The existing DOE loan guarantee program for CCUS projects will not be sufficient to spur such projects to fruition. A major portion of the cost of a CCUS project on a coal power plant is the increased heat rate due to the loss of net power output. Getting lower cost financing will not help a company overcome those increased operating costs. To put it another way, getting a lower interest rate loan to buy a money losing business only means you will lose less money. Thus, a good loan does not mean a project will make sense financially. This is one reason why DOE has not been successful in getting companies to sign up for their loan guarantee program.

[205] National Coal Council "Reliable & Resilient: The Value of Our Existing Coal Fleet" May 2014.

The U.K. government has proposed using a new concept called the "contract for difference" to assist commercial scale CCS projects in that nation. The contracts would cover the difference between the market price for electricity received by a power plant implementing CCS and the plant's actual cost to generate electricity. In times of high electricity prices (or high prices for CO_2 if it is being sold for CO_2 EOR), the government may not have to provide any subsidy, but if electricity prices are lower than a plant's true costs, a financial backer will have the security of knowing that the U.K. government will make certain the project will not go into the red. While all of the details of this approach have yet to be announced, DOE should monitor the UK experience closely and consider using a similar approach for U.S. projects if warranted.

In 2012, the National Enhanced Oil Recovery Initiative (NEORI) issued a report that proposed the use of a "competitively awarded" federal production tax credit to companies that would capture CO_2 and sell it for use in CO_2 EOR.[206] The NEORI endorsed legislation was introduced in the U.S. Senate (S. 2288) by Senators Jay Rockefeller (D-WV) and Heidi Heitkamp (D-ND) in 2014 that would expand and reform an existing federal tax incentive to deploy capture technology to supply CO_2 for CO_s EOR. NEORI analysis indicated this incentive could lead to production of an additional 8 billion barrels of U.S. oil and store 4 billion tons of CO_2 over the next 40 years. In addition, the tax credit would more than pay for itself over time due to revenues generated from increased domestic oil. This is another concept that DOE could consider as it looks for ways to foster demonstrations of the CCUS technologies in its R&D portfolio. Additional financing options, such as rate recovery, feed-in tariffs, grants, and tax free debt financing should also be evaluated for their potential to expedite CCS/CCUS deployment.

[206] Carbon Dioxide Enhanced Oil Recovery: A Critical Domestic Energy, Economic, and Environmental Opportunity, National Enhanced Oil Recovery Initiative, Feb. 2012. http://www.neori.org/NEORI_Report.pdf

Chapter F: Recommendations
Chapter Lead: **Carl Bozzuto**

The main conclusion from this study is that, despite its successes, the current DOE program has not reached critical mass with regard to the commercialization of CCS in the time frame needed to meet stated U.S. goals for CO_2 emissions reductions. Significantly more CCS/CCUS pilot and demonstration projects are needed in order to commercially deploy the technology. While there have been some notable successes, the urgent need for numerous commercial demonstration units does not appear to be part of the DOE plan. Without adequate demonstration, there can be no commercialization. This fact applies to all aspects of the CCS system including capture, transportation, utilization, and storage. There is no point in capturing CO_2 if there is no place to use it or put it. An estimated 37 million ton/year of CO_2 is captured during the production and processing of natural gas, most of which is vented as there is no place to use it or store it.[207] The key considerations supporting this analysis are as follows:

- In order to achieve CCS deployment at commercial scale, policy parity for CCS with other low carbon technologies and options is required.

- Technology and funding incentives must be significantly better coordinated to be effective.

- DOE program goals need far greater clarity and alignment with commercial technology and funding approaches used by industry.

- Funding for CCS RD&D is limited and must be enhanced and focused.

- Public acceptance continues to be a major hurdle.

- Control of GHG emissions is an international issue in need of international initiatives.

Each of these will be considered in turn.

1. **In order to achieve CCS deployment at commercial scale, policy parity for CCS with other low carbon technologies and options is required.**

- Policy parity for CCS in funding, extending tax credits, and other subsidies provided to renewable energy sources, will facilitate creation of a robust CCS industry in the US, benefiting the American people and leading to the development of the lowest cost, near zero emission energy technology. Such technology would be available for electric generation as well as all fossil fuel dependent industrial applications. The NCC recommends that DOE take a stronger position on the need for policy parity with respect to funding allocations.

[207] Fulton, M., et al, "Comparing Life Cycle Greenhouse Gas Emissions From Natural Gas and Coal", World Watch Institute, Aug. 25, 2011

2. **Technology and funding incentives must be significantly better coordinated to be effective.**

   The current package of incentives combined has not been sufficient to promote and encourage the substantial numbers of demonstration projects needed to commercialize CCS technologies. As pointed out by the GCCSI, "Financial and policy support structures must be provided in the near term to enable the transitioning of the "potential portfolio" of planned projects into an "actual portfolio" of projects by 2020."[208]

The key recommendations proposed to help remedy this situation are as follows:

- The NCC recommends that DOE develop a plan to have a total of 5–10 GW of CCS/CCUS demonstration projects in operation in the U.S. by 2025.

- The NCC recommends that all federal incentives provided by the DOE and other federal agencies for CCS demonstration projects undergo a coordinated review for their combined adequacy and effectiveness in supporting CCS deployment. If necessary, combinations of incentives or new incentives could be utilized to achieve the desired level of demonstration projects. This coordinated review needs to be completed in time to achieve the installation of 5–10 GW of CCS demonstration projects by 2025.

- The NCC recommends that DOE expand its RCSP program to identify and certify at least one reservoir in each region that is capable of storing a minimum of 100 million tons of CO_2 at a cost of less than $10/ton by 2025.

- Given the absence of recent federal funding support for commercial scale CCS demonstration projects and national budget constraints, there is a need to find creative mechanisms to finance such projects. The existing DOE loan guarantee program is insufficient to move these projects forward. The NCC recommends a concerted effort be undertaken by DOE to identify and pursue creative mechanisms to finance CCS/CCUS projects.

The successful accomplishment of these recommendations would put CCS/CCUS well on its way towards commercialization. Demonstration projects would be in operation at scale and storage locations would be available to handle the CO_2 that was captured. The amount of CO_2 that would be captured from these demonstration plants is estimated to be approximately 25 million tons/year by 2025, including Kemper, Petra Nova, and FutureGen 2.0.[209] Assuming another 5 GW could be installed by 2030, about 50 million tons/year could be captured and stored. This level would represent on the order of 2% of the EPA proposed target of emissions reductions by 2030.[210]

[208] "The Global Status of CCS/2014", The Global Carbon Capture and Storage Institute, Ltd. 2014
[209] Calculations by Jeff Phillips, EPRI, Nov. 25, 2014
[210] Calculations by Carl Bozzuto, Alstom, Nov. 26, 2014

Even this scale of demonstration only represents a relatively small contribution to the emission reductions in that time frame. In order to meet a goal of 80–83% reduction in CO_2 emissions by 2050, about 6 billion tons/year of reductions would have to be achieved. If 17% of those emissions reductions were to come from CCS (as estimated by the IEA, See Chapter A), then CCS would need to provide about 1 billion tons/year of CO_2 captured and stored in 2050. This would require the installation of 10 GW/year of CCS plants for the 20 year period of 2031 to 2050.[211] There is a precedent for this level of power plant installation in the U.S., provided that the technology has been adequately demonstrated.

Additional recommendations that would support these key recommendations include the following:

- The NCC recommends that DOE consider waiving the 50% cost share requirements for CCS demonstration projects.
- The NCC recommends that DOE take a stronger position on the need to streamline the regulatory process for CCS demonstration projects. In particular, the recognized state of technology development and deployment needs to be consistent throughout all federal agencies. Requirements such as New Source Review are threatening current retrofit projects and hindering efficiency improvement projects which could contribute to CO_2 emissions reductions .

3. DOE goals need far greater clarity and alignment with commercial technology development and funding approaches used by industry.

Since the initiation of work supported by the DOE on CCS/CCUS, the reported goals have changed several times. Further, these goals were always reported in terms of NOAK plants, making a comparison of results difficult. While it is important to keep in mind the ultimate long term goal, it is necessary to have interim goals that are consistent with industry practices and decision making processes to assure success in eventually meeting the long term goal.

The following key recommendation is intended to support this concept:

- The NCC recommends that DOE and industry convene a task force to clearly define the role and objectives of individual projects in achieving broad program goals. The aim is to better understand industry technology goals and needs and to understand industry criteria for investment in CCS technologies throughout the entire development pipeline. Prioritization of projects is critical to achieving overall goals with limited budgets, consistent with the need to bring CCS technologies up to Technology Readiness Level 9.

[211] Calculations by Carl Bozzuto, Alstom, Nov. 26, 2014

Additional recommendations in support of this consistency enhancing objective include the following:

- The NCC recommends that DOE establish interim goals that are more amenable to testing for scale up of CCS technologies that show promise towards meeting the cost and performance goals of the program.
- Since demonstration is critical to commercialization success, the NCC recommends that a targeted number of projects or GWs be established with dates of operation that are consistent with overall emission reduction targets.
- To the extent that CCS infrastructure needs are not addressed in the soon to be released (2014-2015) Quadrennial Energy Review (QER), the NCC recommends that future QER reports examine said infrastructure needs for a comprehensive, nationwide CCS/CCUS system.
- The NCC recommends that DOE undertake a general equilibrium model study, using the MIT EPPA model, or equivalent, to determine if the goal of CCS cost parity with conventional technology by 2035 is adequate and consistent with the overall CO_2 emission reduction goals (nationally and internationally).

4. Funding for CCS RD&D is limited and must be enhanced and focused.

There will always be limits to funding. The need for demonstration units is a priority from an industry point of view. This need will put some constraints on the level of other projects that can be funded.

This fact leads to the following key recommendations:

- The NCC recommends that DOE continue its strategy of fostering a portfolio of technologies for implementing CCS. It is important to maintain DOE's approach of "priming the pump" with early stage funding for promising concepts, but in recognition of budgetary constraints and the need to move more quickly in getting larger scale CCS projects operating, the NCC recommends that after technologies reach TRL 4, DOE cull its support to only those technologies which show a clear promise of meeting or exceeding DOE's CCS performance goals.

- The NCC recommends that DOE develop a plan for demonstrating second generation and transformational CCS technologies at a scale of 25–50 MW by 2020 and make subsequent budget requests to Congress to carry out the plan. However, these demonstrations should only move forward for technologies which have a clear advantage in cost and performance compared to first generation CCS technologies.

5. Public acceptance continues to be a major hurdle.

The lack of public acceptance for any given project can completely derail the project. Several examples have occurred in the last five years throughout the world. If CCS is to be able to make a major contribution to CO_2 emissions reductions, it will have to be considered reasonably safe and reliable by the public. This means that special efforts will have to be made for CCS demonstration projects, as there will be little to no track record at the time of the first demonstration plants. The key recommendation for this concern is as follows:

- The NCC recommends that DOE increase its existing CCS/CCUS public engagement, education, and training activities. Outreach efforts should target counties and states with demonstration projects and regions that have potential infrastructure developments (e.g., CO_2 pipelines and storage sites). Training activity should build workforce capacity across the CCS/CCUS chain and build U.S. leadership and knowhow to meet potential national and international demand.

In view of the large amounts of CO_2 that would need to be captured and stored by 2050, timely permitting of capture projects, pipelines, and storage projects will be needed. A long and publicly contentious permitting process adds to the cost and uncertainty of developing a project. While CO_2 has been utilized and stored in CO_2 EOR operations for over three decades, the transportation and storage of large amounts of CO_2 still raise concerns over safety and liability issues. More direct efforts are needed in this area.

Additional recommendations include:

- The NCC recommends that DOE create an outreach/education program for state and local regulators that would have jurisdiction over CCS/CCUS projects. This program would provide such regulators with experience from existing projects, including direct discussions with people that operate such projects and those that live near them, as well as regulators from other locations that have issued permits.

- The NCC recommends that DOE create a University Carbon Systems Research Program along the lines of the existing and highly successful University Turbine Systems Research Program, so as to place engineering students in summer internships with US companies that work on CCS/CCUS technologies. This program could help develop a workforce with the necessary skills to implement a wide spread development of CCS/CCUS as well as a community of young people that can assist with public outreach and acceptance.

6. **Control of GHG emissions is an international issue in need of international initiatives.**

It has been pointed out that the U.S. only represents a fraction of global CO_2 emissions and that the increase in U.S. emissions will be neglible compared to the rate of global emissions. Consequently, international efforts are needed. Again, since demonstration projects are important for commercialization, the key recommendations are as follows:

- The NCC recommends that DOE maintain its existing CCS/CCUS international collaboration efforts including the Carbon Sequestration Leadership Forum and the US-China Clean Energy Research Center.
- International partnerships in commerce should also be pursued. The NCC recommends that the DOE explore ways to foster CCS/CCUS demonstrations in developing nations which are rapidly increasing their CO_2 emissions, such as China and India. In particular, conducting CO_2 utilization and storage projects using CO_2 from new and existing coal gasification projects in these countries, could be a low cost means to increase global knowledge and acceptance of commercial scale CO_2 storage.

In support of these key recommendations, the following additional recommendations are made:

- The recently announced collaboration with China on a water producing, commercial scale, CCUS project is an important first step and the NCC recommends that DOE be actively involved with the advancement of this project.
- The NCC recommends that DOE propose an international pool of funds specifically set up for the implementation of CCS demonstration projects at scale.
- The NCC recommends that DOE consider programs and policies to promote the purchase of U.S. manufactured CCS equipment for international CCS demonstration projects.

Fossil Forward - Revitalizing CCS
Bringing Scale and Speed to CCS Deployment

Appendices

Appendix A. Large Scale CCS Projects in Operation or Construction

	Large Scale CCS Projects in Operation							
	Project Name	Location	Primary Industry	Capture	Transport	Storage	Capture (MMtpa)	Year in Operation
1	Val Verde Natural Gas Plants	Texas, U.S.	Natural Gas Processing	Pre-combustion	Pipeline 132 km	EOR	1.3	1972
2	Enid Fertilizer CO_2 EOR Project	Oklahoma, U.S.	Fertilizer Production	Industrial Separation	Pipeline 225 km	EOR	0.7	1982
3	Shute Creek Gas Processing Facility	Wyoming, U.S.	Natural Gas Processing	Pre-combustion	Pipeline 403 km	EOR	7	1986
4	Sleipner	North Sea, Norway	Natural Gas Processing	Pre-combustion	None Direct Injection	Saline	0.9	1996
5	Great Plains Synfuel Plant and Weyburn-Midale Project	Saskatchewan, Canada	Synthetic Natural Gas	Pre-combustion	Pipeline 315 km	EOR	3.0	2000
6	In Salah CO_2 Storage	Wilaya de Ouargla, Algeria	Natural Gas Processing	Pre-combustion	Pipeline 14 km	Saline	0 Injection Suspended	2004
7	Snohvit CO_2 Injection	Barents Sea, Norway	Natural Gas Processing	Pre-combustion	Pipeline 152 km	Saline	0.6-0.8	2008
8	Century Plant	Texas, U.S.	Natural Gas Processing	Pre-combustion	Pipeline 69 km	EOR	8.4	2010
9	Air Products Steam Methane Reformer EOR Project	Texas, U.S.	Hydrogen Production	Pre-combustion	Pipeline 101-150 km	EOR	1.0	2013
10	Petrobras Lula Oil Field CCS Project	Santos Basin, Brazil	Natural Gas Processing	Pre-combustion	Pipeline N/A	EOR	1.0	2013
11	Coffeyville Gasification Plant	Kansas, U.S.	Fertilizer Production	Industrial Separation	Pipeline 112 km	EOR	1.0	2013
12	Lost Cabin Gas Plant	Wyoming, U.S.	Natural Gas Processing	Pre-combustion	Pipeline NA	EOR	0.8-1.0	2013
13	Boundary Dam Integrated CCS Demonstration Project	Saskatchewan, Canada	Power Coal	Post-Combustion	Pipeline 100 km	EOR	1.0	2014

Large Scale CCS Projects in Construction								
	Project Name	**Location**	**Primary Industry**	**Capture**	**Transport**	**Storage**	**Capture (Mtpa)**	**Expected Operation**
1	Kemper County Energy Facility	Mississippi, USA	Power Coal	Pre-combustion	Pipeline	EOR	3.0	2016
2	Petra Nova Carbon Capture Project	Texas, U.S.	Power Coal	Post-combustion	Pipeline	EOR	1.4	2016
3	Illinois CCS Project	Illinois, U.S.	Industry Ethanol	Industrial Separation	Pipeline 1.6 km	Saline	0.8-1.0	2016
4	Gorgon CO_2 Injection Project	Australia	Natural Gas Processing	Pre-combustion	Pipeline 7 km	Saline	3.4-4.0	2016
5	Abu Dhabi CCS Project	Abu Dhabi, UAE	Industry Iron / Steel	Industrial Separation	Pipeline	EOR	0.8	2016
6	Quest	Alberta, Canada	Hydrogen Production	Pre-combustion	Pipeline 65 km	Saline	1.1	2016
7	Alberta Carbon Trunk Line with Agrium CO_2 Stream Project	Alberta, Canada	Fertilizer Production	Industrial Separation	Pipeline 240 km	EOR	0.3-0.6	2016
8	Uthmaniyah CO_2 EOR Demonstration Project	Eastern Province, Saudi Arabia	Natural Gas Processing	Pre-combustion	70 km	EOR	0.8	2016
9	Alberta Trunk Line with North West Sturgeon Refinery CO_2 Stream Project	Alberta, Canada	Oil Refining	Pre-combustion	Pipeline 240 km	EOR	1.2-1.4	2017

Appendix B. Clean Coal Research Program R&D Key Technologies TRL Summary (from 2012 Technology Readiness Overview, DOE/NETL). NOTE that this table includes all technologies in the Clean Coal Research Program and is not exclusive to CCS/CCUS technologies.

CCUS and Power Systems R&D	Technology Area	Key Technology	Number of R&D Projects					Total
			TRL 1	TRL 2	TRL 3–4	TRL 5–6	TRL 7–9	
Carbon Capture	Post-Combustion Capture	Solvents		2	14	2		18
		Sorbents		1	8	4		13
		Membranes		2	8	1		11
	Pre-Combustion Capture	Solvents		1	1			2
		Sorbents		1	3			4
		Membranes		1	5			6
		Subtotal Carbon Capture	**0**	**8**	**39**	**7**	**0**	**54**
Carbon Storage	Geologic Storage Technologies and Simulation and Risk Assessment	Wellbore			1			1
		Mitigation			2			2
		Fluid Flow, Pressure, and Water Management			14	1		15
		Geochemical Impacts			5			5
		Geomechanical Impacts			9			9
		Risk Assessment			3			3
	Monitoring, Verification, Accounting, and Assessment	Atmospheric Monitoring				2		2
		Near-Surface Monitoring			1	2		3
		Subsurface Monitoring			11			11
		Intelligent Monitoring			2			2
	Carbon Use and Reuse	Chemicals			4			4
		Mineralization/Cement			2			2
		Polycarbonate Plastics			1			1
	Regional Carbon Sequestration Partnerships	Clastics (deltaic, fluvial deltaic, fluvial/alluvial, strandplain, turbidite, eolian, and shelf clastic)			1	6	1	8
		Carbonates (shallow shelf and reef)				3		3
		Coal and Shale				1		1
		Subtotal Carbon Storage	**0**	**0**	**56**	**15**	**1**	**72**
Advanced Energy Systems	Advanced Combustion Systems	Oxy-Combustion			5	2		7
		Chemical Looping			2	1		3
		Advanced Materials			11	1		12
	Gasification Systems	Feed Systems			3			3
		Gasifier Optimization and Plant Supporting Systems		1	5	1		7
		Syngas Optimization Systems		1	4			5
	Hydrogen Turbines	H_2 Turbines				2		2
		Oxy-Fuel Turbines for EOR and Power			1			1
		Combustion Systems			6	0		6
		Materials and Material Architectures			6			6
		Aerodynamics and Heat Transfer			7			7
	Coal and Coal-Biomass to Liquids (Fuels)	Advanced H_2 Membranes		2	11			13
		Coal-Biomass to Liquids		1	15			16
	Solid Oxide Fuel Cells	Anode Electrolyte Cathode (AEC) Development			10			10
		Atmospheric Pressure Systems			2			2
		Pressurized Systems			1			1
		Alternative AEC Development			3			3
		Subtotal Advanced Energy Systems	**0**	**5**	**92**	**7**	**0**	**104**

Appendix C. Summary of CCPI Rounds 1 to 3

Round 1 focused on advanced coal-based power generation and efficiency, environmental and economic improvements, announced its intent to award funding to 8 demonstration projects in 2003 under three broad categories: Clear Skies Technologies (3), Higher Efficiency Processes (3) and Clean Energy Technologies (2). Total DOE contribution in Round 1 was $317,000,000 and represented 10-50% of the total project cost. Of the 8 projects, three were completed, three were withdrawn, one was discontinued and another is listed as "negotiations ceased."

Round 2, focused on gasification, mercury (Hg) control and carbon dioxide (CO_2) sequestration, announced its intent to award funding to four demonstration projects in 2004 and included two projects demonstrating advanced integrated gasification combined cycle units and two projects demonstrating multi-pollutant control technologies. Total DOE contribution in Round 2 was $332,500,000, representing approximately 2-50% of the individual total project costs. Of the 4 projects selected, one is active, one was completed and two were withdrawn or discontinued. Only one of these projects, Southern Co.'s Kemper County IGCC, is designed to capture and sequester CO_2 (via CO_s EOR).

Round 3 focused on CO_2 capture and sequestration/beneficial reuse (CO_2 EOR); 6 demonstration projects were selected in 2009 and since then, 3 have been withdrawn and 3 remain active. DOE funding initially totaled $1.64 billion and ranged between 20-50% of the total project cost.

Appendix D. Congressional Authorization Bills

ENERGY POLICY ACT OF 2005

Section and Title	Key Provisions	Funds Authorized	Funds Appropriated
§962 – Coal and Related Technologies Program	962(a)(5) – DOE instructed to conduct research, development, deployment, and commercial application of coal-based power systems including carbon capture and sequestration R&D.	For all activities under 962 (including CCS), the following sums are authorized from the pool of funds in 961: • $367,000,000 for fiscal year 2007; • $376,000,000 for fiscal year 2008; and • $394,000,000 for fiscal year 2009.	FY 2007 = $311 M FY2008 = $350M FY2009 = $404M
§963 – Carbon Capture Research and Development Program	- DOE to conduct a 10-year carbon capture R&D program for new and existing facilities.	The following sums are authorized from the pool of funds in 961 specifically for R&D on capture from existing facilities: • $25,000,000 for fiscal year 2006; • $30,000,000 for fiscal year 2007; and • $35,000,000 for fiscal year 2008.	FY2006 = $0 FY2007 = $0 FY2008 = $36 M
Title IV, Subtitle A: Clean Coal Power Initiative (§§ 401-404)	- §401: General appropriations for CCPI. - §402: CCPI to fund gasification projects that can produce a concentrated stream of CO_2 (70% of funds), and other projects (30%).	$200M per year, FY2006-FY2014 Total = $1.8 Billion	FY2006 = $50 M FY2007 = $60M FY2008 = $70M FY2009 = $288 M ARRA = $800 M Total = $1.268 Billion
Title XVII – Incentives for Innovative Technologies, §1703	- DOE loan guarantee program. - 1703(b)(5) allows guarantees for projects utilizing CCS practices and techniques.	Under 1704, such sums as are necessary.	$8 billion in authority originally authorized in FY 2008 and again with no expiration on use in FY 2009.

ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

Section and Title	Key Provisions	Funds Authorized	Funds Appropriated
Title VII – Carbon Capture and Sequestration. - 702	§702 creates a CCS R&D program at DOE, requiring general R&D activities as well as field validation and large-scale testing at 7 non-FutureGen sites across the U.S.	$240M per year, FY 2008-FY2012	FY2008 = $155 M FY2009 = $200 M FY2010 = $206 M FY2011 = $180 M FY2012 = $184 M
§703 – Carbon Capture from industrial sources	Creates a carbon capture demonstration program for high-percentage capture and sequestration from industrial sources.	$200M per year, FY2009-FY2013	$1.52 B in ARRA
§705 – Geologic Sequestration Training and Research	DOE to create an interdisciplinary program to support CCS science	$1M for FY 2008 for report with National Academy of Science; such sums as necessary for competitive grant program	$20 M in ARRA
708 – University R&D Program	DOE to establish university R&D to study CCS using various types of coal	$10M; no dates indicated.	Unknown
711 – CO2 Sequestration Capacity Assessment	DOE to develop a method and conduct a study of potential sequestration formations in the U.S.	"$30,000,000 for the period of fiscal years 2008 through 2012."	Funds utilized for this activity is unknown; provided in DOE Sequestration Program Budget.

AMERICA COMPETES ACT OF 2007

Section and Title	Key Provisions	Funds Authorized	Funds Appropriated
§5012 – ARPA-E	- DOE authorized to conduct R&D on areas including "reductions of energy-related emissions, including greenhouse gases."	$300M for FY2008; such sums as necessary for FY2009 and 2010.	2 RFPs issued awarding 17 CCS projects, funded at a total of $41,326,651

Appendix E. Subsidies for Renewable Project Deployment in Recovery Act (ARRA 2009) $20 billion

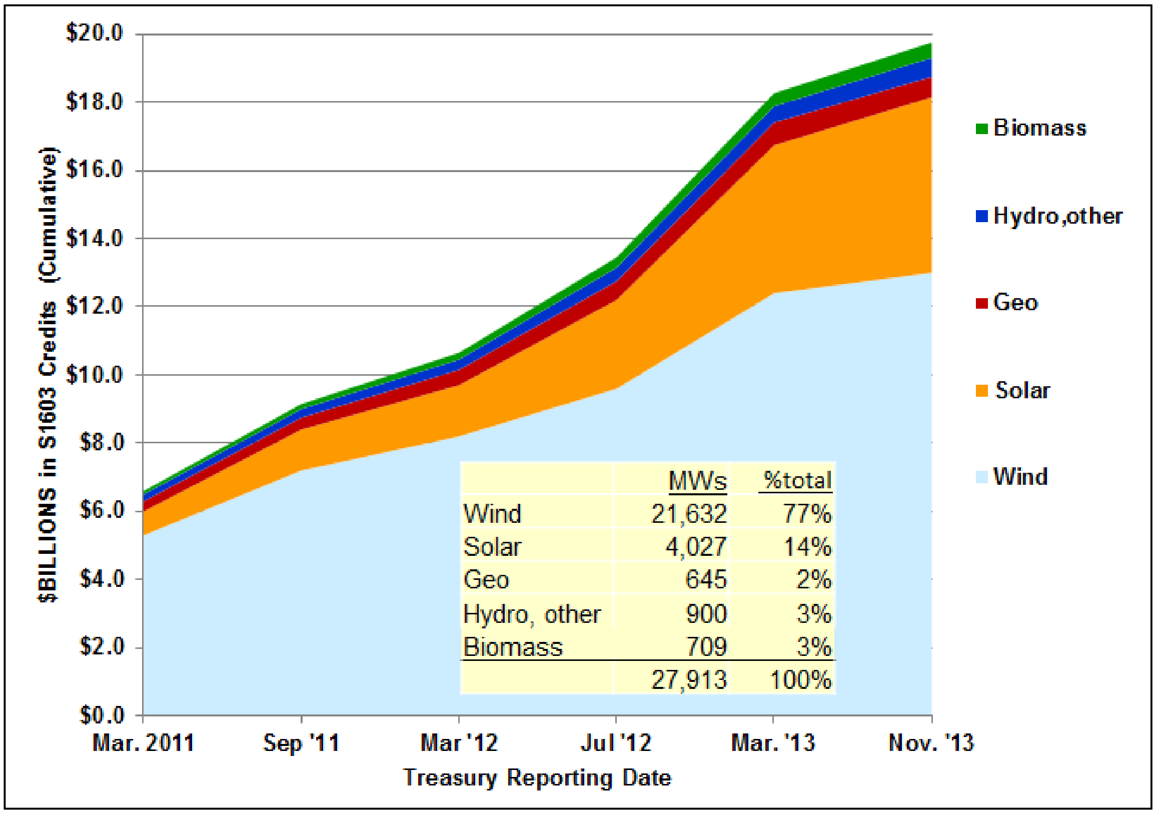

Figure E.1. Treasury Grants (Section 1603 of ARRA), 2009-2013[212]

[212] http://www.treasury.gov/initiatives/recovery/Documents/STATUS%20OVERVIEW.pdf

Appendix F. Historical Summary of Loan Guarantee Solicitations

Round 1 (August 2006 / October 2007; under Section 1703) – The initial loan guarantee solicitation in 2006 covered a wide range of "innovative" clean energy technologies and was limited to $2 billion in credit capacity (but deferred nuclear, which was deemed too large for the initial authorization). An initial solicitation for "borrower pays" (Section 1703) loan guarantees was issued in August 2006 with "pre-applications" due December 31, 2006. No application fee was required with this initial round, and the submittals varied widely in overall quality and readiness for debt financing. A significant number of initial pre-applications (143) were reduced to a shortlist of 16 qualifying projects by 2007[213] In addition, credit capacity for $4 billion in loan value was authorized at that time. The 143 pre-applications sought more than $27 billion in loan guarantee protection with project costs estimated at more than $51 billion, according to DOE figures. However, evaluation of the short listed projects was delayed by a lack of appropriations by Congress for the DOE Loan Program Office (LPO) itself. This lack of specific appropriations hampered staffing and progress for more than a year.

Round 2A/B/C (July 2008; under Section 1703) – Subsequent solicitations in 2008 covered nuclear generation and the front end of the nuclear fuel cycle, plus additional authorization for renewable energy and energy efficiency. These Round 2 solicitations were authorized by the FY 2008 Omnibus Appropriations bill, which allocated $38.5 billion as follows: $20.5 billion for nuclear generation and fuel, $8.0 billion for advanced fossil technologies, and $10.0 billion for renewable energy, energy efficiency, distributed energy, and related technologies.

Rounds 3A/B (July 2009; under Section 1705) – The third round of solicitation encompassed innovative technologies for energy efficiency, renewable energy, and transmission upgrades and was the first solicitation issued under the new provisions of ARRA, which included appropriations from Congress to cover credit subsidy costs, rather than the original "borrower pays" Section 1703 mode.

Round 4 (October 2009; under Section 1705) was also based on ARRA and temporarily expanded the eligible technology universe to include conventional renewable generation, in light of the credit crisis in the financial markets that took shape in 2008. Significantly, the conventional technologies were eligible only for the Financial Institutions Partnership Program (FIPP), which required a minimum of 20% private sector loan exposure.

Depending on the level of credit subsidy required project by project, the Loan Guarantee provisions in ARRA underpinning Rounds 3 and 4 (described below) were thought to create $40 to $80 billion in additional loan or guarantee authority. By example, if projects supported by the $4 billion credit subsidy cost allotment provided by Congress through ARRA were deemed by OMB to carry a weighted average of a 10% subsidy cost, then that amount would support $40 billion in loan capacity. A lower value (higher quality projects, with more equity and stronger credit traits) would expand the credit support DOE could provide. Under the Federal Credit Reform Act (FCRA 1990), DOE must evaluate default exposure annually and report that evaluation to OMB and to Congress.

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[213] The list of the first 16 projects invited to submit full applications by December 2006, covered a wide array of technologies, and were listed on the DOE LGP website: www.lgprogram.energy.gov/press/100407.pdf

Appendix G. Why CO_2 Utilization is Difficult

Recent analysis by EPRI[214] noted that the total amount of CO_2 produced each year by U.S. power plants is six times greater in mass than the sum of the mass of the top 50 chemicals produced in the U.S. Even ignoring economics, it is simply very difficult to find products that could be made from CO_2 that are in high enough demand to have a meaningful impact on U.S. CO_2 emissions. For example, the 750,000 tons/year of urea that would be produced from CO_2 captured from the proposed 200 MW Texas Clean Energy Project would provide 20% of the urea currently produced in the US. Building four other similar projects would saturate the market, and yet 1 GW of power represents only one third of one percent of the installed coal power in the nation.

While CO_2 could be converted to fuels, and there is a large demand for liquid fuel in the U.S., it must be recognized that doing so requires energy that is at least equal to the heating value of the produced fuel. Consequently, CO_2 derived fuels are a form of energy storage. For example, electricity could be "stored" by using it to produce H_2 and O_2 via electrolysis. The H_2 could react with CO_2 to produce formic acid (HCOOH). Formic acid could then be used as a fuel and combusted with air in a power plant to make electricity. However, the "round trip efficiency" of such a scheme is not attractive. Only 10 to 20% of the electricity used in the electrolysis process would be produced by the formic acid fired power plant. Other energy storage schemes have much higher round trip efficiencies (batteries 85%, pumped hydro 75%, hydrogen 45%).

If useful products are not an attractive pathway for CO_2 utilization, perhaps there are products that could be made that simply allow for stable storage of the CO_2. Carbonate rocks would be such an example. However, as noted in the EPRI report, this process usually takes millions of years to occur in nature.

There have been methods suggested for accelerating the natural process of producing carbonate rocks, but the next challenge is to supply enough reagent to react with all the CO_2 being produced by power plants. It is a massive task. As Figure U.1 shows, the annual mass of CO_2 produced by power plants globally is more than four times the sum of the mass of the 50 most produced chemicals in the world. The most widely produced chemical is lime, CaO, but its annual production rate is miniscule compared to the amount of CO_2 produced from power plants. Ignoring the fact that most lime is produced from limestone (CaCO3) and CO_2 is released in the process, it would also require a considerable amount of energy to produce it and transport it to a power plant. Consequently, the EPRI report concluded "the energy for

[214] *Update on Utilization or Storage of CO_2 through Chemical, Biological, or Mineral Conversion*. EPRI, Palo Alto, CA: 2013. 3002001006.

mining, transportation, grinding, and, most importantly, activation along with the time required for the carbonation reaction, make mineralization of CO_2 currently economically unfeasible."[215]

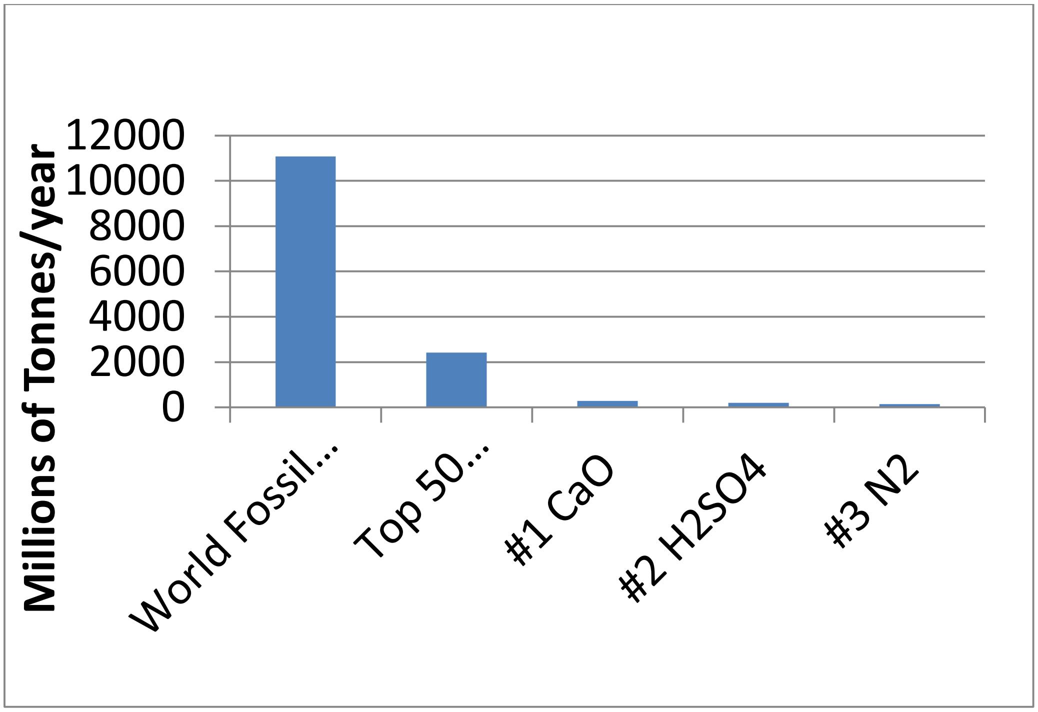

Figure G.1. – A Comparison of Annual CO_2 Emissions from Fossil Fuel Power Plants to the Production Rates of the 50 Most Widely Produced Chemicals Globally.

These conclusions do not mean there are no options for utilizing CO_2 which could be economic, but those will be niche opportunities which, such as the Texas Clean Energy Project, cannot be replicated on a scale that will have a climate changing impact on CO_2 emissions.

[215] *Update on Utilization or Storage of CO_2 through Chemical, Biological, or Mineral Conversion*. EPRI, Palo Alto, CA: 2013. 3002001006.

Appendix H. Review of Prior NCC Reports on CCS/CCUS

Since the year 2000, the National Coal Council (NCC) has prepared numerous studies for the Secretary of Energy regarding carbon management, including:

- May 2000 Research & Development Needs for the Sequestration of Carbon Dioxide
- May 2003 Coal-Related Greenhouse Gas Management Issues
- March 2006 Coal: America's Energy Future (Volumes I & II)
- June 2007 Technologies to Reduce or Capture & Store Carbon Dioxide Emissions
- May 2008 The Urgency of Sustainable Coal
- December 2009 Low Carbon Coal: Meeting U.S. Energy, Employment & Carbon Dioxide Emission Goals with 21st Century Technologies
- March 2011 Expediting CCS Development: Challenges and Opportunities
- June 2012 Harnessing Coal's Carbon Content to Advance the Economy, Environment & Energy Security (CCS-EOR)

Spanning more than a decade, these studies document a consistent set of findings and recommendations to the U.S. Department of Energy on policies and technologies NCC members advocate as a means to advance the deployment of carbon capture, storage and utilization technologies (CCS/CCUS). The NCC has consistently noted the following:

- Enhancing the efficiency of the existing coal generation fleet is a first step toward reducing CO_2 emissions.
- New Source Review (NSR) disincentivizes power plant operators from pursuing efficiency improvements.
- Research and development (R&D) must be pursued simultaneously on numerous greenhouse (GHG) technologies with the aim of developing a portfolio of options suitable for various applications.
- Various CO_2 storage options need to be identified and characterized.
- Monitoring and verification methods for CO_2 storage need to re refined.
- Employ DOE-industry partnerships to demonstrate technologies on a large-scale basis with the aim of reducing technology costs and expediting commercial availability.
- International partnerships are necessary to advance GHG technology solutions and global adoption.
- Technology demonstration projects are critical for the advancement of CCS/CCUS technologies.
- Financial incentives and federal funding support are vital, especially for early mover and first-of-a-kind (FOAK) projects.
- Deployment of CCS/CCUS technologies offers the most impactful opportunity to achieve CO_2 emissions reductions.

Following is a summary of the major findings and recommendations from each of these reports. All are available on the NCC website at www.nationalcoalcouncil.org.

May 2000 - Research & Development Needs for the Sequestration of Carbon Dioxide

Secretary of Energy Bill Richardson requested that NCC recommend research and development needs for management of carbon dioxide (CO_2), identifying carbon sequestration opportunities and recommendations on R&D to bring cost effective, competitive sequestration technologies to the market. The NCC suggested a 3 part management strategy that included:

1. Maximizing the efficient use of fossil fuels in order to minimize CO_2 emissions.
2. Shift to low-carbon and zero emissions technologies.
3. Capture and sequester both CO_2 emissions and CO_2 already present in the atmosphere.

NCC noted that to successfully implement this strategy, research is needed to verify the feasibility of numerous CO_2 sequestration options. Leadership, in the form of a partnership between industry and government was recommended in order to demonstrate technologies on a large scale with the aim of reducing costs so that the technologies could be effectively implemented.

Among the detailed recommendations:

- DOE should evaluate, improve and develop advanced chemical absorption solvents and physical absorbents; develop improved membrane separation devices; conduct research to shorten the processing time and examine the handling demands of the silicate carbonation processes; develop additional technologies for transportation and storage of the product upon successful completion of CO_2 separation and capture.
- DOE should identify potential CO_2 storage reservoirs in saline reservoirs, rock caverns, unminable coal seams and salt domes. These sites should be characterized for their economic viability and from the points of view of environmental protection.
- DOE should refine the monitoring and verification methods for sequestering CO_2 in soil, vegetation, agricultural lands, pastures, tundra, forests and wetlands. Also, the long-term issues of the uses of large tracts of land for carbon storage need resolution.
- DOE should increase R&D on the decarbonization of coal to produce hydrogen rich streams for electricity production and pure CO_2 for industrial use.
- DOE should continue and accelerate its work on achieving the success of super-clean, high efficiency, multi-use electric generation technologies and increase research into zero emissions technologies for coal.
- DOE should accelerate research into the production of chemicals and clean transportation fuels from coal.

May 2003 - Coal-Related Greenhouse Gas Management Issues

Secretary of Energy Spencer Abraham requested that NCC prepare a study of how increased energy efficiency and carbon sequestration could be utilized as part of a greenhouse gas (GHG) management program. In its findings, the NCC noted:

- There has been widespread participation across a range of industries in voluntary programs to reduce GHG emissions. Some GHG reductions have been inhibited by certain regulatory impediments, including New Source Review requirements that discourage power plant operators from making efficiency improvements.
- The Federal government has established domestic and international partnerships to address the technical, environmental and societal challenges to widespread adoption of GHG management technologies.
- Efficiency improvements in electricity generation are an important near-term option for reducing GHG emissions from coal-base power plants.
- CCS could account for more than 40% of global CO_2 emissions reductions.
- An acceleration of current R&D programs will be needed to achieve GHG management goals; existing technologies are not suitably developed for either capturing CO_2 at large sources or for storing CO_2.
- A common need for all potential sequestration technologies is large-scale demonstration for periods long enough to prove their technical and economic feasibility and to ensure CO_2 remains permanently in storage.
- Deployment of GHG emissions reduction technologies will require federal policies that support R&D, cost-sharing by the federal government in the first-of-a-kind (FOAK) demonstration of new technology, and tax incentives to encourage technology deployment.

Among the study's recommendations:

- DOE should continue to promote public-private partnerships, both domestically and internationally, to identify opportunities, incentives and regulatory impediments affecting voluntary actions to reduce GHG emissions and to conduct research and technical assessments of carbon management technologies and opportunities.
- In recognition of the global nature of GHG issues, DOE should expand its cooperation with the Departments of State and Commerce in the areas of international RD&D for carbon management technologies, as it has begun to do with the FutureGen project.
- DOE should continue to work with the private sector to refine the technology "roadmap" for advanced coal-based power generation technology and carbon capture, transport and sequestration technology, with particular attention to defining the time and cost necessary to achieve the roadmap's technical and economic goals.
- DOE should conduct and support R&D to improve the efficiency of coal-based power generation for both new and existing (or repowered) units as the most cost-effective and commercially available near-term means for reducing GHG emissions.
- DOE should expedite research on a wide range of CO_2 capture options to improve energy efficiency and reduce the cost of capture.

- DOE should conduct a sufficient number of large-scale, long-term field tests of promising sequestration options to ensure that sinks of sufficient size and integrity are available to store large volumes of CO_2.

March 2006 - Coal: America's Energy Future (Volumes I & II)

Secretary of Energy Samuel Bodman requested that NCC prepare a study identifying the challenges and opportunities of more fully leveraging domestic U.S. coal resources to meet the nation's future energy needs and reduce dependence on imported energy. The request referenced President George W. Bush's State of the Union address calling for increased investment in zero-emission coal-fired plants.

The report detailed the prospective benefits associated with coal conversion technologies, including coal-to-liquids and coal-to-natural gas as a means to relieve cost and supply pressures for the nation's transportation and industrial/residential sectors dependent on oil and natural gas. It addressed the promise of managing carbon emissions through efficiency improvements at coal power plants and via CCS technology utilization and the employment of Enhance Oil Recovery (EOR).

Among the recommendations offered:

- NCC urged Congress to appropriate full funding for clean coal programs authorized, including FutureGen and the Clean Coal Power Initiative (CCPI).
- NCC advocated improving the ability of industry to attract private capital for new facilities through the use of various financial incentives, including 100% expensing in the year of outlay for coal-to-liquids and coal-to-gas plants.
- NCC also advocated assuring the EOR in new basins using CO_2 from coal plants would attract investment through increasing the Section 43 investment tax to 50%, creating an explicit exemption from the Alternative Minimum Tax (AMT) for new production from EOR, and providing federal and state royalty and severance tax relief for oil produced until capital payout.

June 2007 - Technologies to Reduce or Capture & Store Carbon Dioxide Emissions

Secretary of Energy Samuel Bodman requested that NCC conduct a study examining the status and challenges associated with various CCS technologies, existing R&D efforts and relevant federal programs. The Secretary requested recommendations regarding additional research opportunities and public policy objectives that might be pursued, as well as a recommended technology-based framework for mitigating GHG emissions from coal power plants.

In its overarching recommendations, NCC noted that it is imperative that the nation immediately accelerate deployment of technologically and economically favorable high-efficiency advanced coal combustion, coal liquefaction and gasification technologies. The report additionally called for the critical need to accelerate development, demonstration and deployment of CO_2 reduction and CCS technologies to control and sequester CO_2 emissions from coal.

More specifically, NCC recommended that:

- DOE work closely with other appropriate agencies within the federal government to streamline the long, costly and complicated permitting process for siting, building and operating power plants and associated CO_2 capture, transportation and storage facilities.
- DOE work cooperatively with the Environmental Protection Agency (EPA) to facilitate implementation of regulations in alignment with New Source Review (NSR) requirements to allow existing power plants to effectively comply with regulations while simultaneously making efficiency improvements in plant operations.
- DOE significantly ramp up RD&D funding across the full spectrum of CCS technologies (capture, compression, transportation, storage and monitoring) to ensure the U.S. can meet industry, state and national expectations for CCS.
- DOE continue to fund and support the various activities of the Regional Carbon Sequestration Partnerships, including those associated with engineering, legal liabilities, ownership issues, leakage and monitoring.
- DOE support RD&D projects that cover a wide variety of capture technologies, including those that capture less than 90% of CO_2 in recognition that capture rates would increase with technology maturation.
- DOE should pursue large-scale demonstration of advanced ultra-supercritical coal power generation, including the deployment of new alloys and components.
- DOE should promote significant additional R&D projects related to the transportation and safe storage of CO_2, coordinating its efforts with other federal agencies.
- DOE should undertake 3-5 projects (at both pulverized coal and IGCC plants) at a scale of about 1 million tons/year of CO_2 injection to understand the outstanding technical questions and to demonstrate to the public that long term storage of CO_2 can be achieved safely and effectively.

May 2008 - The Urgency of Sustainable Coal

Secretary of Energy Samuel Bodman requested that NCC conduct a study addressing the technology and regulatory framework necessary to increase America's use of clean coal for energy security, environmental improvement and economic prosperity.

The study findings advocated for advanced coal power plant technologies with integrated CCS as being critical to lowering U.S. electric power sector CO_2 emissions and crucial to substantially lowering world CO_2 emissions if the technology is supported in rapidly growing Asia. It noted that RD&D pathways had been identified to demonstrate a full portfolio of economically attractive, commercial-scale advanced coal power and integrated CCS technologies suited for use with the broad range of U.S. coal types by 2025.

Among the specific recommendations offered:

- NCC encouraged DOE to work with EPA and Congress to remove regulatory hurdles that impede the implementation of supply efficiency enhancements, including a more workable New Source Review (NSR) interpretation.
- The Secretary was urged to solicit funding from Congress for large-scale, CCS demonstrations on the order of 1 million tons of CO_2/year, to be conducted in different regions and with different coals and technologies.
- NCC advocated for the Secretary to work with various parties, most particularly the states and other federal agencies, to promote a legal framework for CCS that would encourage development.
- NCC urged support or R&D on coal-based electricity technologies, including CCS, to ensure adequate supplies of electricity to support the broad commercial implementation of Plug-in Hybrid Electric Vehicles (PHEVs) or other electric vehicles.
- NCC recognized that in-situ gasification has the potential to dramatically reduce the costs of Synthetic Natural Gas production and thereby CCS. It was recommended that a formal program be undertaken to investigate how Underground Coal Gasification (UGC) might enable or hinder CCS development and deployment and to identify potential synergies that would enhance economics and site performance.

December 2009 - Low Carbon Coal: Meeting U.S. Energy, Employment & Carbon Dioxide Emission Goals with 21st Century Technologies

Secretary of Energy Steven Chu requested the NCC conduct a study on the value and use of coal in a carbon constrained energy market. NCC was asked to focus on the issues surrounding the application of CCS for the existing fleet of coal-based electricity generation plants, examining varying amounts of CO_2 capture to explore whether there might be advantages to initially capturing lower amounts of CO_2, i.e., 50-60%. Value-added opportunities, such as Enhanced Oil Recovery (EOR) and other beneficial reuse applications were also to be considered.

In its recommendations to the Secretary, NCC:

- Supported implementation of the DOE plan to have 10 large-scale CCS demonstration projects on line by 2016, with the goal of initiating widespread deployment to coal-based generation with CCS at commercial scale in the next 8-10 years.
- Recommended that the DOE work with other relevant groups to implement the National Research Council's conclusion that the existing coal-based generation fleet could be fully replaced by a combination of retrofitted, repowered and new coal-based generation with CCS.
- Recommended that DOE work with other groups to enable the production of 2 million barrels of oil/day through CO_2 based EOR.
- Urged the Secretary to expand the CO_2 storage tests currently underway through the Regional Carbon Sequestration Partnership (RCSP) program to large, longer duration injection tests in a wider range of geologic and oil/gas/coal fields and fund characterizations of 5-10 potential commercial scale CO_2 storage sites.
- Urged establishment of a "Pioneer Plants" program to achieve about 7 GW of coal-based power generation integrated with CCS with the goal of achieving four years of operation and storage site monitoring by 2020.
- Advocated for continued and expanded research to improve the performance and reduce the cost of CCS for greenfield and retrofit applications, including expedited testing at pilot and large-scale of promising CO_2 capture technologies.
- Highlighted the need for an appropriate mix of medium to high levels of financial incentives to stimulate investments in CCS projects.
- Supported the expansion of the Clean Coal Power Initiative (CCPI) program with additional rounds of CCPI support to allow for opportunities to demonstrate technologies that have matured through R&D to the commercialization stage. Additional support was also urged for consortia-matching projects, such as FutureGen, that would support commercial-scale demonstration of promising CCS technologies.
- Urged increased support for R&D to develop improved high-temperature and pressure materials to validate the use of these materials for boilers, turbines and other critical components to enhance power plant efficiency.
- Advocated for DOE to streamline the application, selection and funding processes associated with the CCPI and demonstration programs.

March 2011 - Expediting CCS Development: Challenges and Opportunities

Secretary of Energy Steven Chu requested the NCC conduct a study focusing on the management of emissions of CO_2 from both the existing and new fleet of coal-based electricity generating plants. NCC was asked to address issues associated with 1) establishing viable strategies for industry to deploy CCS technologies, 2) defining technical areas that merit Federal support to expedite deployment, 3) establishing a feasible timeline for moving forward with low-carbon coal technologies and 4) identifying impacts that legal and regulatory policies pose on the deployment of CCS technologies.

In response, NCC recommended that the DOE:

- Expand its overall leadership role in developing CCS technologies and accelerate the near-term deployment (2015-2020) of integrated commercial-scale CCS demonstration projects.
- Support efforts to address non-technical pipeline development challenges to CCS deployment on a large scale, including regulatory, financing, siting, permitting and public outreach.
- Expand and accelerate near-term geological characterization and field testing programs, as well as enhance programs to support the development of monitoring, verification and accounting tools.
- Continue to evaluate and promote EOR related storage opportunities as well as broaden efforts to support the beneficial reuse of CO_2.
- Support policies to align and avoid an overlap of regulatory programs applicable to CCS, including exemption from CERCLA and RERA.
- Support policies to clarify the requirements for CO_2 injection and storage on federal lands.
- Support policies to clarify that an injection permit grants the right to inject and storage CO_2 in geologic strata that do not contain mineral resources in commercial quantity and do not have a current or reasonably foreseeable use.
- Support policies designed to ensure that after certain requirements are met during the post-closure phase of a CCS project, liability be transferred away from the private sector.

June 2012 - Harnessing Coal's Carbon Content to Advance the Economy, Environment & Energy Security (CCS-EOR)

Secretary of Energy Steven Chu requested the NCC conduct a study focused on the capture of CO_2 emissions and its use for Enhanced Oil Recovery (EOR) or the production of other beneficial products. The NCC study determined that advanced coal technology, coupled with capturing carbon emissions for use in EOR, could lead to annual revenues of $200 billion in industry sales and $60 billion in federal, state and local taxes, and to the creation of over one million jobs. Additionally, the study detailed how the U.S. could reduce its imports of petroleum by over six million barrels per day, thereby increasing our nation's energy independence and reducing carbon emissions equivalent to almost 100 GW of coal-based electric power.

The NCC noted the following findings/recommendations:

- Regulatory certainty is necessary for the development of a robust CCUS/EOR industry. NCC recommends that the appropriate federal, state and local regulatory agencies, with coordination and cooperation from industry, work with the Secretary of Energy to develop a stable and consistent regulatory framework to promote CCUS/EOR technology applications.
- DOE has proven its leadership capabilities on regional CO_2 storage projects. NCC recommends that the Energy Secretary meet and work with a wide range of stakeholders, including coal, electricity generation, petroleum production and chemical manufacturers, to find new and innovative ways to develop financial support to create demonstration/early mover projects.
- Lessons learned from developing Nth-of-a-kind (NOAK) plants will reduce CO_2 capture costs and promote growth in CCUS/EOR applications. NCC recommends accelerating the widespread deployment of CCUS/EOR technologies to allow these economic benefits to be realized more rapidly.
- Education and training programs are needed to develop the necessary work force with the appropriate skills for implementation of a robust CCUS/EOR industry. While it is incumbent upon industry and the appropriate educational entities to work together to develop and implement such programs, support and encouragement from the Secretary of Energy on this educational need is recommended.
- Regulations on the state level will be required to support the concurrent use of CO_2 for EOR and storage of CO_2. Such regulations must be based both on commercial viability and environmental protection. The Secretary should work with the Interstate Oil and Gas Compact Commission (IOGCC) and other state organizations to develop regulatory recommendations for concurrent CO_2 EOR and CO_2 storage.
- In order to develop a long distance pipeline network for transport of captured CO_2, regional large scale, coal based capture projects must be developed. Industry and the Energy Secretary should collaborate to develop pipeline network scenarios that will incentivize the development of these long distance pipelines.
- The DOE is uniquely situated to coordinate efforts to expedite the implementation of CCUS/EOR in candidate areas of the country, thereby speeding and enhancing economic development in these areas. A coordinated effort would include DOE, the Regional Carbon Sequestration Partnerships, industry, environmental groups and other stakeholders.

Appendix I. National Coal Council Reports
June 1986 – January 2015

June 1986	Coal Conversion
	Clean Coal Technologies
	Interstate Transmission of Electricity
	Report on Industrial Boiler New Source Performance Standards
June 1987	Reserve Data Base: Report of The National Coal Council
	Improving International Competitiveness of U.S. Coal and Coal Technologies
Nov. 1988	Innovative Clean Coal Technology Deployment
Dec. 1988	Use of Coal in Industrial Commercial, Residential & Transportation Sectors
June 1990	Industrial Use of Coal and Clean Coal Technology – Addendum Report
	The Long Range Role of Coal in the Future Energy Strategy of the United States
Jan. 1992	The Near Term Role for Coal in the Future Energy Strategy of the United States
	Improving Coal's Image: A National Energy Strategy Imperative
May 1992	Special Report on Externalities
Feb. 1993	Role of U.S. Coal in Energy, the Economy& the Environment
	A Synopsis of NCC Reports (1986 – 2003)
Nov. 1993	The Export of U.S. Coal and Coal Technology
Feb. 1994	Clean Coal Technology for Sustainable Development
May 1995	Critical Review of Efficient & Environmentally Sound Coal Utilization Technology
Nov. 1995	The Implications for Coal Markets of Utility Deregulation & Restructuring
Feb. 1997	Vision 2020: The Role of Coal in U.S. Energy Strategy
Oct. 1997	Clean Air Act Rules, Climate Change & Restructuring of the Electricity Industry
Nov. 1998	Coal's Role in Achieving Economic Growth and Environmental Stability
May 2000	Research & Development Needs for the Sequestration of Carbon Dioxide
May 2001	Increasing Coal-Fired Generation Through 2010: Challenges and Opportunities
May 2003	Coal-Related Greenhouse Gas Management Issues
Nov. 2004	Opportunities to Expedite the Construction of New Coal-Based Power Plants
March 2006	Coal: America's Energy Future (Volumes I & II)
June 2007	Technologies to Reduce or Capture and Store Carbon Dioxide Emissions
May 2008	The Urgency of Sustainable Coal
Dec. 2009	Low Carbon Coal: Meeting U.S. Energy, Employment & Carbon Dioxide Emission Goals with 21st Century Technologies
March 2011	Expediting CCS Development: Challenges and Opportunities
June 2012	Harnessing Coal's Carbon Content to Advance the Economy, Environment & Energy Security
May 2014	Reliable & Resilient: The Value of Our Existing Coal Fleet
January 2015	PENDING ~ Bridging the CCS Chasm:
	An Assessment of Opportunities to Advance CCS/CCUS Deployment

Reports can be found on the NCC web site at www.NationalCoalCouncil.org

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