# Executive Summary

## Analysis Of Options For Funding Large Pilot Scale Testing Of Advanced Fossil-Based Power Generation Technologies With Carbon Capture And Storage

**Pilot and Demonstration-Scale Projects -- Lessons Learned**
**Potential for Public and Private Sector Partnering and**
**Barriers and Opportunities for Multi-National Cooperative Projects**

**March 21,2016**

**Funding and support for this report:**

This study comprises four primary sections labeled as Tasks One – Four. Task One is an overview of the study and also provides several conclusions based upon the information provided in the other three Tasks. Task Two was prepared by Howard Herzog, Task Three was authored by L.D. Carter and Task Four by Thomas J. Russial. This study was prepared under contract with the New Energy and Industrial Technology Development Organization (NEDO). Overall supervision of the study was the responsibility of the Coal Utilization Research Council (CURC). The CURC gratefully acknowledges the support and contribution of the staff of NEDO and in particular the leadership of Mr. Hiroyuki Hatada, Chief Representative of NEDO's Washington D.C. office. The CURC also expresses gratitude for the many contributions made by Howard Herzog, Doug Carter and Tom Russial, the authors of the three reports that are the corpus of this study, for their willingness to share their expertise and overall guidance to the development and execution of this study.

# Overview and Conclusions of the Study

## Task 1

**Shannon Angielski, Executive Director**
**Coal Utilization Research Council (CURC)**

# 1 Overview of the Study

The Coal Utilization Research Council (CURC)[1] wishes to thank the New Energy and Industrial Technology Development Organization (NEDO)[2] for their financial support as well as the guidance and knowledge they provided during the conduct of this study. Our gratitude is given also to the U.S. Department of Energy for support given during the initial organizational planning for the study.

This study is segregated into four tasks which include:

Task One: *The Overview of the Study*

- briefly describing the purpose of the study and general findings and conclusions

Task Two: *Lessons Learned from CCS Demonstration and Large Pilot Projects*

- a review and analysis of significant projects undertaken, or abandoned, worldwide in order to generate a set of "lessons learned" which can be considered in the future to better insure successful technology initiatives

Task Three: *Factors Impacting Private Sector Investment in Large Pilot CCS Projects*

- in addition to the technology risks involved in the development of CCS at the pilot plant stage, the author reviews and analyzes the very significant economic risks associated with CCS technologies and the inadequacy of current economic and regulatory incentives that might encourage development at the pilot scale level

Task Four: *Options for Funding Large Pilot Scale Testing of Advanced Fossil-Based Power Generation Technologies with Carbon Capture and Storage*

- in order to develop a knowledge base that could be used to evaluate opportunities for multinational collaboration as a means to fund large pilot projects the author examines country-specific information about large pilot plant interest, legal and regulatory conditions, and financial incentives for technology development in Canada, Japan, the

[1] The Coal Utilization Research Council (CURC) is an organization of coal-using utilities, coal producers, equipment suppliers, universities, 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).

[2] About NEDO: Japan's New Energy and Industrial Development Organization (NEDO) actively undertakes the development of new energy and energy conservation technologies, verification of technical results, and introduction and dissemination of new technologies (e.g., support for introduction). Through these efforts, NEDO promotes greater utilization of new energy and improved energy conservation. With the aim of raising the level of industrial technology, NEDO pursues research and development of advanced new technology. It also supports research related to practical application.

Special thanks to Hiroyuki Hatada, Chief Representative, of NEDO's Office in Washington DC whose interest and support of this study has been key to participation by NEDO.

Republic of Korea, and the United States with the goal of compiling an initial "baseline" of understanding from which a subsequent assessment (that is, a follow-on study) can then be undertaken to consider mechanisms or models that might be used by multiple countries to support common projects. [3] [4]

## 1.1 Background and Rationale for the Study

Many national governments have found that development and wide-scale deployment of carbon capture and storage (CCS) technology for fossil-based power generation is necessary to meet world-wide climate objectives. It is also widely believed that the cost of fossil-based power integrated with CCS must be reduced and the technology proven cost-effective at scale to be deployable world-wide. Technology improvements will derive from a combined program of laboratory-scale research and development (R&D), "proof of concept" at a large pilot plant scale (e.g., 10 – 50 MWe), and commercial-scale (200 MWe and larger) demonstration projects. Large pilot-scale projects are a critical step in this technology progression. This is so because commercial-scale versions of these technologies entail prohibitive risk and cost in the absence of successful pilot scale projects.

Despite best intentions, nations collectively have not found a formula to advance beyond R&D activities and to bring the necessary number of large scale CCS pilot and demonstration projects to completion. Accordingly, only a small and insufficient number of large-scale power projects with CCS have advanced. Many projects have stalled or failed for lack of financial support or consistent government policies designed to encourage technology development and demonstration.

On November 18-19, 2014, the Coal Utilization Research Council, (CURC) with support from the United States Department of Energy (DOE) and energy sector companies, convened a workshop to consider industry viewpoints on what is needed to foster advanced coal technologies with CCS at large pilot scale in the U.S. A significant finding from the workshop was that the private sector may be willing to participate in the development of pilot scale projects but that the current uncertain market for CCS does not justify such participation without very significant public support.

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[3] Special thanks to New Energy and Industrial Technology Development Organization of Japan (NEDO), Natural Resources Canada (NRCan) and the Korea Institute of Energy Research (KIER) for their participation in the development of information provided in part 4 of this study.

[4] The authors of Tasks Two – Four are:

Task Two: Howard Herzog, Senior Research Engineer, Massachusetts Institute of Technology Energy Initiative

Task Three: L.D. Carter, Independent Contractor, formerly Director, Office of Planning and Environmental Analysis, Office of Fossil Energy, U.S. DOE.

Task Four: Tom Russial has been involved with fossil energy and CCS programs for 30 years as a staff attorney and later Chief Counsel at the U.S. Department of Energy's National Energy Technology Laboratory and more recently in the private sector.

Each of the tasks two – four was drafted by the named author and the information and any conclusions made in the document are solely to be attributed to the author and are not the opinions or conclusions of NEDO, the U.S. DOE or CURC.

Since completion of the November 2014 workshop, it can be argued there is even greater urgency in determining how to initiate the planning, construction, operation and global information sharing needed to undertake large-scale projects equipped with advanced clean coal or other fossil-based power generation technologies that incorporate $CO_2$ capture and sequestration. This urgency is driven by a number of factors including, but not limited to --

- In December 2015, 195 Nations met in Paris, France at the twenty first session of the Conference of the Parties (COP21) and agreed to non-binding greenhouse gas reductions globally. Notably, Article 2 of the agreement states that the Parties to the agreement will respond to the threat of climate change by: "*Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C....*"[5] It is widely accepted that broad deployment of CCS is required to meet this climate objective; otherwise the financial costs are exponentially greater to attain the goal and, realistically without CCS the temperature goals are likely not achievable.

- Coal demand continues to increase worldwide growing in production from 3 billion tonnes in 1971 to almost 8 billion tonnes in 2014[6]

## 1.2 **Primary Findings of the Study**

Readers are encouraged to review the content and conclusions of the three papers following this "overview". Briefly, the principal conclusions made in these papers are the following:

Task 2: A review of major $CO_2$-related capture projects worldwide reveals that almost all the successful projects had ties to the oil and gas industry, either as a source of the $CO_2$ or through the use of the $CO_2$ for Enhanced Oil Recovery (EOR). To date, there are only three projects operating or under construction at coal-fired power plants. As a result, there has been limited success in driving down the cost of coal with CCS (or other fossil fuel with CCS). Another finding is that diminished international financial support for the development of CCS-related technologies is occurring. This latter conclusion is evidenced most clearly by the abandoned coal-focused CCS initiatives by the European Union and the United Kingdom.

Task 3: Examination of the weak financial position of key U.S. private sector stakeholders (i.e. coal producers) and limited market expectations for U.S. coal use over the next several decades will substantially reduce the chance for promising technologies to advance to large pilot and demonstration testing and commercial deployment. Other issues confronting CCS technology development in the U.S. include:

[5] Adoption of the Paris Agreement, Annex, Article 2, Paragraph 1. (a), United Nations Framework Convention on Climate Change, FCCC/CP/2015/L.9/Rev.1, 12 December 2015, https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.
[6] Key World Energy Statistics – 2015, International Energy Agency, 2015.

- The cost and abundance of natural gas supplies largely derived from shale gas, causing power generators to rapidly transition to natural gas fueled electricity generation;
- Clean Air Act regulations, including regulations to control the emissions of $CO_2$, that have contributed to substantial uncertainty regarding future regulation or government policy related to coal-based emissions; and
- The lack of demand in the U.S. for new coal-fueled power plants and uncertainties associated with CCS have dampened enthusiasm among major technology providers and equipment suppliers for pursuing and developing CCS technology.

Task 4: Legal and regulatory barriers to international collaboration on CCS projects are formidable. Further, it does not appear that sufficient public support will be forthcoming from any one country to meet the need for aggressive and accelerated planning and construction of needed pilot projects. Given current circumstances the combined financial resources of multiple countries are required. Governments have collaborated in the past to support large scale pilots although the history of collaboration on large fossil projects is limited. Successful collaboration is not simple. Technology interests, timelines, and budgetary resources must align; legal, regulatory and contractual constraints must be analyzed and addressed; and complex government and private sector relationships must be reduced to agreement. Opportunities exist for collaborative large fossil pilots but additional analysis and knowledge sharing by public and private sector stakeholders is required to refine the concept and develop effective approaches.

## 1.3 **Conclusions and a Possible Pathway Forward**

Without the successful development and widespread use of CCS globally, and given the world's continued reliance upon coal for affordable energy, the chance for containing global temperature rise is doubtful.[7] Better fossil-based power technologies and CCS technologies at reduced costs will be a key factor in meeting climate change goals. This requires the construction and operation of large scale pilots and follow-on demonstration plants to prove the technologies at near commercial scale prior to widespread commercial deployment. Pursuit of the status quo will not get the world to the commercialization of these technologies in time to realize the goals of COP21.

[7] Even if it is possible to address temperature increases without CCS, as some have argued, the costs would be enormous. For example, the Fifth Assessment Report by the Intergovernmental Panel on Climate Change found that many of the models used in that assessment could not reach a 450ppm $CO_2$-eq goal without CCS, and for the four that could, mitigation costs increased by an average of 138% compared to model projections that included CCS technology as an emission reduction option. (Source: Working Group III Summary for Policy Makers – 5th Assessment Report, Table SPM.2, United Nations Intergovernmental Panel on Climate Change, 2014.

Much can be learned from efforts around the world during the last two decades to encourage CCS technology development. (See: the "lessons learned" section of H. Herzog's Task Two paper). In light of the limited success of previous attempts, and the current gravity and urgency of the situation, it seems abundantly clear that much more public sector support is needed. Consideration must be given to bolder, faster and more concerted approaches to ready the technologies for commercial deployment and international collaboration may be a way of accelerating technology development and subsequent deployment.

Any option that can facilitate and streamline multinational collaboration should be evaluated including, for example, the establishment of an independent, multi-country funded, multinational organization whose primary mission is to accelerate technology development through financial support of large scale pre-commercial plants.

# Lessons Learned from CCS Demonstration and Large Pilot Projects

## Task 2 Report

**Prepared by:**
**Howard Herzog**

***Disclaimer:*** This report contains significant information about dozens of CCS pilot and demonstration projects worldwide. Every effort was made to be as accurate as possible. However, many of these projects are in a state of flux and the references used are quite varied. Therefore, some of the project details may have changed or be in error. However, any such problems will not change the analyses or findings in this report.

# 2 Summary

This task is part of a project focused upon identifying and understanding the legal, regulatory and financial issues, opportunities and impediments across the globe related to the planning, construction and operation of projects with carbon capture and use/storage of $CO_2$ (CCS). The objective of this task is to identify and assess, primarily from a financing perspective, fossil fuel projects worldwide capable of capturing and using or storing carbon dioxide that have been or are being pursued. To accomplish this goal, programs set up by governments with the objective of promoting CCS demonstration projects were analyzed, as well as selected CCS demonstration and pilot projects. The outcome of this assessment is the following list of lessons learned:

1. There are strong links between the successful CCS demonstration projects and the oil & gas industry.

2. Access to markets has to move beyond EOR.

3. Regulatory drivers are critical to creating markets for CCS.

4. Business drivers play a major role.

5. Over reliance on government subsidies is a risky business.

6. Successful CCS power projects used multiple financing components.

7. Innovative CCS power projects (e.g., poly-generation) are interesting, but may be hard to replicate.

8. Gasification-based power projects have a poor record.

9. Setting arbitrary time limits on projects generally has led to failure.

10. CCS projects that have shorter timelines have greater chances of success.

11. Stronger political support is needed for CCS.

12. All major CCS demonstration projects require a public outreach program.

## 2.1 **Overview**

This task is part of a project focused upon identifying and understanding the legal, regulatory and financial issues, opportunities and impediments across the globe related to the planning, construction and operation of projects with carbon capture and use/storage of $CO_2$ (CCS). The objective of this task is to identify and assess fossil fuel projects worldwide capable of capturing and using or storing carbon dioxide that have been or are being pursued. The focus of this assessment is large scale demonstrations (>1 million tons $CO_2$/year). However, Section 2.4.3 examines large pilot projects (>10MWe or equivalent). The assessment includes not only projects that have been successful, but also projects that have been abandoned and why (i.e. lessons learned). Note that the task's objective is not to include every CCS project ever announced, but to include enough projects to generate a set of lessons learned concerning project financing, as well as legal and regulatory issues.

Section 2.2 of this task report presents background material on two key topics: (1) options for financing CCS projects and (2) the current status of CCS demonstration projects. Section 2.3 reviews major CCS demonstration programs worldwide. These are programs set up by governments with the objective of promoting CCS demonstration projects. Section 2.4 analyzes selected CCS projects primarily from a financing perspective. Projects are also presented where other issues (e.g., regulatory, public acceptance) were important. Finally, Section 2.5 synthesizes the information in Sections 2.2-2.4 in order to summarize the lessons learned and to draw conclusions.

# Task 3: Factors Impacting Private Sector Investment in Large Scale CCS Projects

**Prepared by:**
**L.D. Carter**
**Independent Contractor**

***Disclaimer**: This Task 3 Report has been prepared as part of a larger study of options for funding large pilot scale testing of advanced fossil-based power generation technologies with carbon capture and storage.*

*The author thanks those who contributed material and comments to improve the quality of this report. However the author is solely responsible for the content of this report. Special thanks are extended to NEDO for its financial contribution to this report.*

*While the author has endeavored to provide accurate and timely information in this report, no warranty is made as to the accuracy or usefulness of the material contained herein. References to specific companies, products or technologies are not to be construed as endorsements by the author or CURC. Information and statements contained in this report are not intended to be legal advice and should not be relied upon as such.*

# 3 Executive Summary

This paper discusses the factors that influence the degree to which the private sector is willing to invest in large pilot scale projects (approximately 10-50 MWe) that apply carbon capture and storage (CCS) technology to power plants. The discussion is based primarily on market conditions in the U.S., although there is a brief discussion reflecting stakeholders based in Canada, Japan, and South Korea.

The role of large pilot projects in technology development is to provide performance data enabling the design of commercial-scale demonstration units, or in some cases enabling the design of fully commercial units. The traditional private sector stakeholders in large pilot projects and commercial-scale demonstration projects have been companies that supply equipment to fossil-fueled power plants, coal companies, and electric utilities that own or may build fossil fueled power plants, especially coal-fueled power plants. In U.S. markets, two of these three sectors are seriously challenged by unfavorable economic conditions. About 25% of U.S. coal production is from companies that are currently in bankruptcy proceedings, and a coal sector financial index has had remarkably poor performance over the past decade. Equipment suppliers to power plants in the U.S. are faced with minimal incremental demand for additional electrical generating capacity over the next decade and U.S. government agencies project minimal demand for new coal-fueled power plants for a much longer period of time. Electric utilities in the U.S. generally have healthy balance sheets, but a sample of electric utility Integrated Resource Plans (IRPs) found none that expects to build a new power plant equipped with CCS within its planning outlook, typically 20 years.[24]

In most electric power markets, discretionary investments tend to flow toward projects that offer an optimal balance between risk and financial reward. An emerging technology like CCS presents a challenging decision process because of uncertainty regarding many of the basic issues to be considered in projecting risks and rewards. Investment attitudes of potential private sector participants in large pilot projects involving CCS technologies have been gleaned from:

- The stakeholders' economic strength and current profitability, as reflected in stock price trends, market sector indices, and other published financial information
- Published electric utility planning documents (IRPs)
- U.S. Government projections of future electricity supply by fuel and technology class

[24] Both government and private sector projections generally assume currently available technology, or gradually decreasing prices based on "learning curves" for emerging technologies like CCS. They do not reflect disruptive technologies that could dramatically impact electricity demand, or the economics of potentially transformational electricity supply technologies.

- A 2014 report documenting an industry-sponsored workshop on potential support for large pilot projects for CCS
- A limited survey of stakeholders, performed for this paper

In general, stakeholders consistently held that their willingness to invest in a large pilot project would depend on the existence of a "persuasive business case" for the investment. In other words, the amount that they would invest would need to be supported by a quantitative analysis that the investment would result in greater profits than other attractive uses of the company's available funds. Additionally, recognizing that a large pilot project could cost hundreds of millions of dollars, stakeholders said that the necessary resources would have to be available for the project. Within this general framework, the amount of "cost-share" that the private sector would support for a large pilot project was determined to be shaped by a range of factors, including:

- Minimal projected growth in electricity demand in the U.S. over the next decade, and projections for minimal deployment of new coal-fueled units through 2040 (Low demand for a new technology reduces the potential profits that flow from its development.)
- Financial weakness of coal producers in the U.S., and perhaps to a lesser degree, major equipment suppliers to coal-fueled power plants
- Risk of technology failure
- Risk that the commercial technology may be more costly than expected
- The time lag between when an investment in a pilot technology is made and the time when commercial deployment of the mature technology will take place
- The potential for competitors to deploy the developed technology without having to invest in its development (free rider concept)
- The risk of changing regulatory requirements, including $CO_2$ emission limits and long-term liability for stored $CO_2$
- The risk of improving economics for competing technologies, exacerbated by the time needed to commercialize power/CCS technologies
- The value of a technology that expands choices for the electric power sector, enhancing technology competition and fostering lower prices
- Whether a large pilot of a technology is sufficient to support commercialization of the technology without also building a commercial scale demonstration unit (this is thought to vary by technology)

# Options for Funding Large Pilot Scale Testing of Advanced Fossil-Based Power Generation Technologies with Carbon Capture and Storage

## Task 4 Report
## Multinational Government Collaboration


## Prepared by: Thomas J. Russial
## Consultant to the Coal Utilization Research Council





The author extends his thanks to the representatives of the New Energy and Industrial Technology Development Organization, Korea Institute of Energy Research, and Natural Resources Canada for their valuable contributions to the Task 4 effort. The author also extends thanks to L.D. Carter and Ben Yamagata for their very constructive comments during the review of this report.

# 4 Executive Summary

The purpose of the large pilot plant study is to evaluate options for governments and industry to fund projects that will test advanced fossil-based power generation technologies with carbon capture and storage (CCS). Task 4 of the study is focused on multinational collaboration as a means to mitigate the cost and financial risk associated with large pilot projects. The study defines "multinational collaboration" to mean two or more governments providing financial support to an individual large pilot project or group of projects. "Large pilot project" means a project that tests advanced fossil fueled electric power generation technology, carbon capture technology, or storage technology that has not been tested beyond small scale and is capable of significantly reducing the cost of fossil-based power integrated with CCS. The starting assumption of the study is that large pilot projects are generally within the range of 10-50MWe. As discussed in the Report, participants have been asked if they agree with the assumption.

*Task 4 Key Findings*

1. Multinational collaboration offers the opportunity for governments to leverage resources to mitigate the cost and financial risks associated with large pilot projects and thereby increase the number of successful projects.

2. Government funded fossil energy research programs have similar objectives and development timelines. Further analysis of overlapping interests may lead to a suite of power and CCS technologies that are well suited for multinational collaboration at the large pilot scale.

3. Various issues have the potential to hinder multinational collaboration.

The study premise - widely accepted by many in the climate community - is that broad deployment of CCS is required to meet global climate objectives but that the cost of fossil-based power with CCS must be reduced for the technology to be affordably deployable world-wide. Cost reduction will come from technology innovation. Before a new power plant technology can be deployed, it typically must be proven at large pilot scale and subsequently demonstrated at commercial scale.

History reveals that the high cost and financial risk associated with first-of-a-kind pre-commercial projects has caused many technically sound projects to fail for lack of adequate resources despite some amount of financial assistance from a government source. Budgetary constraints limit the amount of funds that governments are able to contribute to large scale projects. Consequently, the public contribution to individual projects can be more a function of the available funds rather than the funds that are required to effectively initiate and then take a project through definition, planning and design, construction and operation. Furthermore, optimistic projections on the need, timing and utilization of the new technologies may lead to an unrealistic belief that the private sector can bear a significant portion of project cost and be able

to recover the investment on commercially acceptable terms. Difficulties encountered by pre-commercial projects and cost and financial risk are discussed in the Task 2 and Task 3 Reports.

Government to government collaboration on research and development (R&D) activities has proven effective in various forms.[83] Since insufficient funding often proves fatal to large pre-commercial projects, Task 4 concentrates on financial support rather than on other types of collaboration. Large pilot projects may cost in the 10s to 100s of millions of dollars depending upon the technology and level of CCS integration.[84] By leveraging the common interests and resources of like-minded governments, the odds of project success may significantly improve when compared to the case where individual governments go it alone.

The Task 4 study countries - Japan, the Republic of Korea, Canada and the United States (US) - have a long history of cooperation on fossil energy and/or CCS R&D through various mechanisms including multinational member organizations such as the Carbon Sequestration Leadership Forum (CSLF), the International Energy Agency (IEA), and the Asia Pacific Economic Cooperation (APEC) as well as country to country agreements and understandings. The four provide an excellent opportunity to explore the potential for multinational financial cooperation on large pilot projects.

Study country information was compiled on large pilot project interest; relevant law, regulation and policy; existing or planned government programs that may provide financial support for large pilot projects; and, potential issues. A comparative review was conducted and the data suggests that opportunities exist for collaboration that can contribute to the success of large pilot projects. Additional knowledge, analysis and discussion are needed to further refine the concept. Key points and identified issues are highlighted below and discussed in the report.

Multinational collaboration requires a shared interest in the advancement of fossil power and CCS technologies which clearly is the case for the study countries who have been leaders in fossil energy R&D. However, shared does not necessarily mean identical and for successful collaboration there must be an alignment of technology interests, development timelines, project size, and budgetary priorities and resources. Opportunity areas for large pilot projects may include advanced capture technologies, second generation and transformational power technologies and others. The limitations of Task 4 do not allow for an assessment of specific technologies that are ready for multinational collaboration. Further analysis of intersecting needs and interests by a broad group of government and other stakeholders can lead to a suite of technologies that is well suited for collaboration.

Based on the study country sample, and historical examples, countries have authority to support large scale multinational projects in one fashion or another. Nevertheless, national laws or

[83] Examples include knowledge sharing, researcher exchanges, and collaborative projects.
[84] See Task 3 Report.

policies may restrict a country's ability to financially support extraterritorial projects and/or may limit funding to domestic companies. Individual country laws and policies must be examined in the context of the various collaborative models to determine effective approaches to deal with legal or policy restrictions.

Terms and conditions contained in government funding agreements may conflict with provisions used by other governments or simply may not be familiar to companies that have not previously done business with the government. Intellectual property (IP) rights have been identified as a trouble spot for multinational projects although the potential for conflict and misunderstanding is not isolated to IP. Significant delay may occur while provisions are analyzed and negotiated. A detailed understanding of where issues and conflicts may arise and development of solution pathways can streamline resolution and contribute to successful collaboration.

Collaboration models should be evaluated to determine which would be most effective for large pilot projects taking into consideration stakeholder interests and concerns. The examination may include the advantages and disadvantages of formal and informal government to government relationships, how issues that may impact project success can best be addressed under the various models, timing in light of technology deployment needs, host site location and knowledge sharing obligations.