

**Analysis of Options to Overcome Barriers to Unilateral and
Multilateral Large-Pilot Projects for Fossil Fuel Based Power Plants
Equipped with CCS**

FINAL REPORT

July 2017

Funding and Support for this Report:

This report was written for the United States Energy Association, supported by the Department of Energy under Award Number DE-FE0024159, and by the Washington Office of the New Energy and Industrial Technology Development Organization (NEDO) of Japan. Overall supervision of the study was the responsibility of the Carbon Utilization Research Council (CURC).

CURC gratefully acknowledges the support and contributions of the staff of the United States Department of Energy (DOE), including Jarad Daniels, Acting Deputy Assistant Secretary for Clean Coal and Carbon Management, and Scott Smouse, Senior Advisor for the Office of Clean Coal and Carbon Management, both with DOE's Office of Fossil Energy, and the staff of the Washington D.C. office of NEDO.

CURC also wishes to acknowledge the participants listed in the appendices to this report that contributed to this study by sharing their knowledge and experience involving advanced carbon dioxide capture and storage technologies, which greatly helped to shape and inform this study.

CURC also expresses gratitude for the many contributions made to this study by Doug Carter and Tom Russial, who served as the Task 2 and Task 3 coordinators (respectively) and the principal authors of the Task 2 and Task 3 chapters that are the corpus of this study, and for their willingness to share their expertise and overall guidance in the development and execution of this study.

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The Task 2 and 3 Reports are the coordinator's summation of information gathered during the course of the Study. Participation in the Task 2 or 3 Working Group does not signify endorsement of this report by any Working Group member.

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Abbreviations

ACALET	Australian Coal Association Low Emissions Technology
ACT	Accelerating CCS Technologies
ANLEC R&D	Australian National Low Emission Coal Research and Development
CPP	Clean Power Plan (United States)
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Storage and Utilization
CERC	United States -China Clean Energy Research Center
CO ₂	Carbon Dioxide
CO ₂ eq	Carbon Dioxide Equivalent
CSLF	Carbon Sequestration Leadership Forum
CURC	Carbon Utilization Research Council
DOE	Department of Energy (United States)
EC	European Commission
ECCSEL	European Carbon Capture and Storage Laboratory Infrastructure
EEA	European Economic Area
EIA	Energy Information Agency
ERA-NET	European Research Area Network
ERIC	European Research Infrastructure Consortium
FOA	Funding Opportunity Announcement (United States)
GHG	Greenhouse Gas
IEA	International Energy Agency
IEA-GHG	International Energy Agency Greenhouse Gas R&D Programme
(I)NDC	(Intended) Nationally Determined Contributions (Paris Agreement)
IPR	Intellectual Property Rights
IPCC	Intergovernmental Panel on Climate Change
MI	Mission Innovation
MOU	Memorandum of Understanding
NEDO	New Energy and Industrial Technology Development Organization
NRCan	Natural Resources Canada
MWe	Megawatt electric
MWth	Megawatt thermal
ppm	Parts per million
PTRC	Petroleum Technology Research Centre
ROAD	Rotterdam Capture and Storage Demonstration Project
R&D	Research and Development
RD&D	Research, Development, and Demonstration
TCM	Technology Centre Mongstad
TRL	Technology Readiness Level

1. Phase 2 Report Key Findings

The purpose of the two-phase large-pilot plant study is to evaluate innovative options for governments and industry to fund projects that test fossil-based power generation and carbon capture, utilization, and storage technologies (hereinafter CCS or CCUS) at the large-pilot scale. The Study considers large-pilots to be generally in the range of 10-50 MWe involving technology that has not been tested beyond small scale that is capable of significantly reducing the cost of fossil-based power integrated with CCS.

1.1. Phase 2, Task 2 Key Findings

Phase 2, Task 2 addresses factors impacting private sector investment in large-pilot scale CCS projects for projects funded by a single country, reviews barriers to such projects, and identifies potential approaches to overcome those barriers. The report also identifies and considers options for overcoming factors adversely impacting investment in large-pilot scale CCS projects.

TASK 2 - KEY FINDINGS

1. Large-pilot scale fossil fueled electric power technology projects with CCS are an essential part of the CCS technology development chain. Such projects are typically 10-50 MW_e in capacity and cost \$100-500 million (U.S. \$).
2. These large-pilot projects face significant barriers, including a perception of a limited near-term market for the commercialized technology, their relatively high cost, difficulties securing financing, and inadequate or counter-productive government policies.
3. A portfolio of policies and incentives will be necessary to advance large-pilot scale CCS projects.
4. Measures to address market barriers would endorse the need for a diversified generating portfolio that included fossil fuel-based generation with CCS to meet social goals related to climate change.

(continued)

TASK 2 - KEY FINDINGS (cont.)

5. Financial barriers could be overcome by a mix of financial incentives that recognize the range of differences in pilot projects. For example, "tear-down" projects and projects that only demonstrate capture ("catch and release") would benefit primarily from capital cost-related incentives, whereas projects continuing operation after completion of pilot testing and permanently storing CO₂ are also amenable to incentives based on operation such as CO₂ storage credits. The incentive mix could include tax credits, grants, and loan assistance. Sources for funds could vary by country and include general tax revenues, climate programs, and fees levied on electricity users and fossil producers. Incentives should be viable across the full range of electric generation business structures. Policymakers should seek financial participation from non-traditional supporters of new technologies such as environmentally purposed foundations, export credit agencies, and purpose-based public finance institutions.
6. Measures to reduce the cost of CCS technologies would reduce financial barriers to pilot projects. These measures could include increased bench-scale R&D, pursuit of modular technologies, and reusable large-pilot scale test platforms.
7. Needed policy initiatives center on a genuine commitment by governments to the development of CCS-based technologies. Specific measures that might demonstrate such a commitment include providing financial incentives for large-pilot scale projects, enacting regulatory incentives such as "bonus allowances" or using allowance sales by "cap&trade" jurisdictions to fund large pilot projects, levying fees to support dedicated funds for large-pilot projects, and exercising regulatory flexibility for environmentally beneficial pilot projects and commercial demonstration projects. A government program to store CO₂ captured at initial pilot and demonstration projects would overcome barriers to CO₂ storage for those units.

1.2. Phase 2, Task 3 Key Findings

Phase 2, Task 3 draws on government and private sector expertise to explore significant barriers that may hinder successful multinational collaboration, and evaluates collaborative models that may be most effective for large pilots. The report identifies lessons learned, best practices and provides recommendations that can facilitate collaboration.

TASK 3 KEY FINDINGS

1. Governmental collaboration on fossil-based power and CCS technology development is widespread, ranging from laboratory research to demonstration scale across the power generation and CCS value chain.
2. Large-pilot projects present unique financing risks and challenges that could be mitigated by multilateral financial collaboration.

(continued)

TASK 3 KEY FINDINGS (cont.)

3. National interests must be considered in framework development. The need for substantial domestic involvement in return for a country's contribution to large pilot projects may be compelling, can complicate framework development, and will impact project structure.
4. Countries and regions have different viewpoints on fossil-based power and CCS technology development and deployment. A singular collaborative approach may not work. Targeted collaboration and framework development by countries with like-minded viewpoints may be preferred.
5. Development of a collaborative framework is a complex undertaking, requiring time, human resources, and cross-disciplinary skills. Completion may take several or more years. Compromises between the perfect and the achievable must be considered
6. For collaboration to be successful, sustained and consistent political support is necessary.
7. Concurrent award of government support and flexibility in managing use of government funds for project expenditures will facilitate project development and implementation.
8. Intellectual property rights are perceived as a potential barrier to collaboration. Early resolution of intergovernmental issues along with early agreement among project team members on intellectual property rights would facilitate collaborative projects.

2. Structure of the Study Effort and Phase 2 Report

Figure 2.1 below shows the role this report serves as a continuation of two efforts previously undertaken by CURC. The first effort was a workshop convened by CURC in November 2014 and attended by utility company representatives, technology developers, financial experts, and government personnel for the purpose of gaining perspective on what is needed to foster advanced fossil-based power technologies and CCS technologies that are ready for pilot plant-scale demonstration.¹ In general, workshop participants concluded that such projects were a necessary and useful element in moving new technology concepts from bench scale to commercialization. Participants also cited a number of barriers to large-pilot scale CCS projects, including the challenge of financing such projects.² The major conclusions drawn from the workshop include:

1. Large-pilot projects are in fact a necessary step in technology development since transition from bench scale to commercial demonstration involves unacceptable technical and economic risk.
2. Pilots in the range of 10-50 MWe are appropriate; however, certain advanced technology components may be tested at a smaller size.
3. A number of advanced fossil-based power and CCS technologies have been proven at small scale and are ready for larger scale testing.³ Transformational technologies were of particular interest.
4. Large-scale pilots present a financing challenge. They may cost \$100 – \$500 million,⁴ which is beyond balance sheet financing for most technology developers. And, they are unlikely to generate sufficient revenue to support typical project-based financing given that they are usually sub-commercial in scale.
5. Due to risk and business case concerns, the private sector may be able to share 10-20 percent of large-pilot project costs. Substantial financial support must come from governments.
6. Innovative financing mechanisms should be explored including international collaboration.

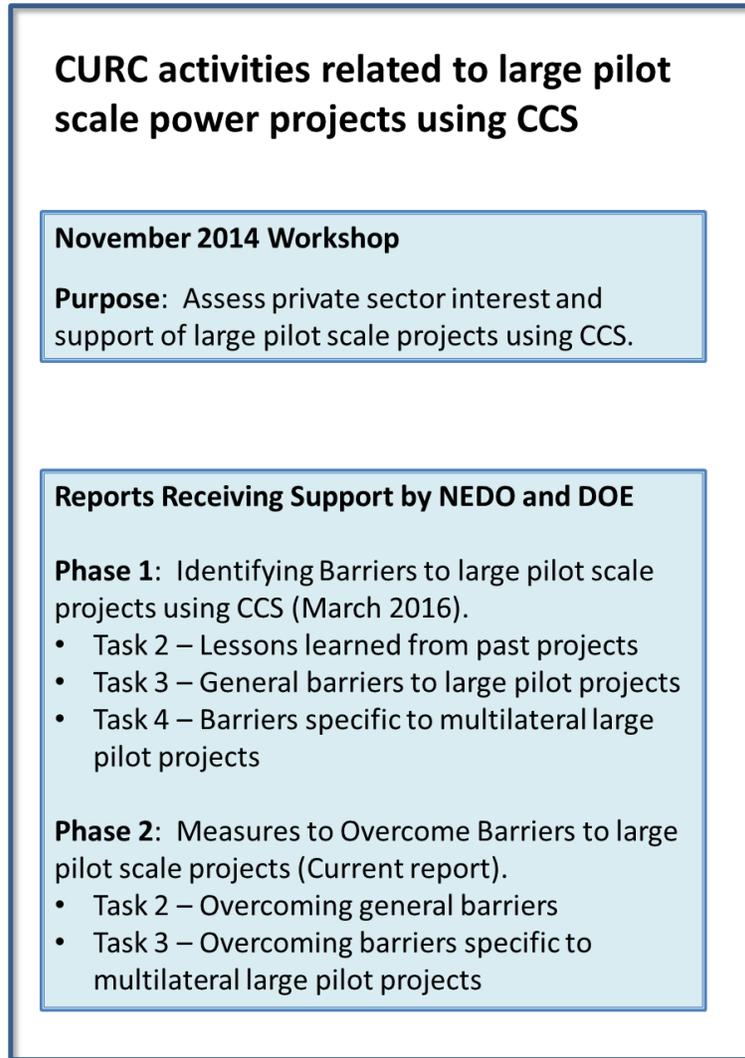
¹ S See L.D. Carter, *Technical Workshop Report: An Industry View: Advancing the Next Generation of Coal Conversion Technologies* (convened by the Coal Utilization Research Council, with support from its members and the USDOE) (Dec. 2014), <https://www.coal.org/2014-technical-workshop-report>.

² *Id.*

³ Workshop participants and participants in Phase 1 of this Study identified candidate technologies for large-pilot testing including: supercritical CO₂ power cycles, advanced ultra-supercritical systems, chemical looping combustion, pressurized oxy-combustion, oxygen transport membranes and ion transport membranes, fuel cell systems, post-combustion capture systems, CO₂ utilization, and advanced gasification technologies.

⁴ All references in the report to \$s means United States Dollars unless noted otherwise.

Figure 2-1 Continuum of CURC work related to large pilot projects



The other prior CURC project was Phase 1 of the current study, which was completed in 2016.⁵ The Phase 1 study supports the hypothesis that innovative approaches are needed to fund large scale pilots. The Study also identified multinational collaboration as a potentially important component of large-pilot financing. The premise is that governments with overlapping R&D missions can find value in leveraging financial resources to support the various promising technologies in the pipeline. Resources can be pooled, redundancies eliminated, and ultimately more large-scale projects may reach successful completion.

⁵ See *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*, CURC (Mar. 21, 2016), <https://www.coal.org/global-ccs-white-paper> (the Phase 1 Study and the current Phase 2 Study were partially supported by Japan’s New Energy and Industrial Technology Development Organization (NEDO) and the USDOE)).

The Phase 2 Study is a follow-on effort to investigate options to overcome barriers to financing large-pilot projects (10-50 MWe) for fossil fuel-based power plants with CCS as well as barriers to multinational collaboration as a funding approach for such projects.

3. Introduction and Background to Phase 2 Study

This Phase 2 report investigates options to overcome barriers to financing large-pilot projects (10-50 MWe) for fossil fuel-based power plants with CCS as well as barriers to multinational collaboration as a funding approach for such projects. However, a brief discussion of three background issues will aid understanding of the more substantive issues that constitute the balance of the report:

1. The need for CCS technology
2. The purpose of large-pilot scale projects in the larger scheme of technology development
3. The definition of large-pilot scale projects

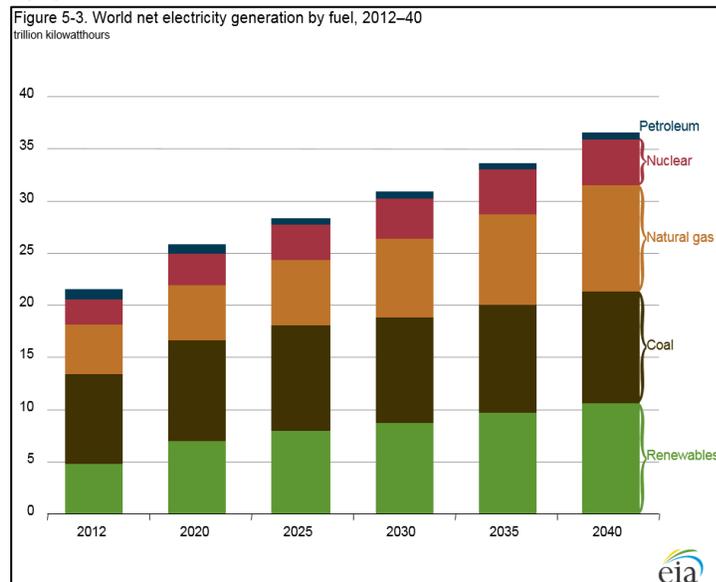
3.1. The Need for CCS Technology

The core thesis of this Study is that advanced technology development can achieve significantly more cost-effective and efficient fossil fuel-based electric power systems with CCS and as a consequence enable and accelerate global decarbonization of the fossil power sector. The thesis is based on the assumption that fossil fuel-based electricity will continue to be a part of the energy mix in many countries for the foreseeable future.

Sources and distribution of electric power are expected to evolve as nations and regions continue to address electricity needs, energy security, environmental issues, and Paris pledges.⁶

Nevertheless, fossil fuels are predicted to remain a major source of electricity supply globally

Figure 3-1 World Net Electricity Generation by fuel through 2040



Source: U.S. Energy Information Administration, *International Energy Outlook 2016* (May 2016)

through 2040 and beyond. In the Reference case for its 2016 International Energy Outlook (IEO2016), the United States Department of Energy's Energy Information Agency (DOE/EIA) forecasts that coal will continue to be the largest single fuel used for electricity generation globally until 2040 with renewable generation (including hydroelectric power) beginning to surpass coal-fired generation in 2040. Taken together, coal and natural gas-based power production constitutes about 60% of global generation throughout the projection period. Coal-fired

⁶ *Adoption of the Paris Agreement*, United Nations: Framework Convention on Climate Change, Dec. 12, 2015 http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf. (The Paris Agreement entered into force on 4 November 2016.)

generation declines to 29% of the global total in 2040; however, total global coal-fired generation increases from 8.6 trillion kWh in 2012 to 10.6 trillion kWh in 2040. Natural gas fueled electricity generation increases from 22% of total world generation in 2012 to 28% in 2040.⁷ The IEO2016 Reference case takes into consideration national and regional initiatives to reduce greenhouse gas (GHG) emissions and Nationally Determined Contributions (NDCs) under the Paris Agreement.⁸ If EIA's projections hold true, there will remain thousands of fossil fueled power plants in operation through mid-century that require some measure of CO₂ abatement to meet the goals set forth in the Paris Agreement.

The Intergovernmental Panel on Climate Change (IPCC) projects that if atmospheric concentrations of CO₂eq are kept to 450 ppm by 2100, it is likely that global temperature rise will stay below 2°C over the 21st century relative to preindustrial levels.⁹ International Energy Agency (IEA) analysis foresees a significant role for CCS in achieving the 2°C target taking into consideration current NDCs. See Figure 3.2. In describing model results related to meeting caps on global temperature increases, stated in its Fifth Assessment Report (AR-5): *"Many models could not limit likely warming to below 2° C over the 21st century relative to pre-industrial levels, if additional mitigation is considerably delayed, or if availability of key technologies, such as bioenergy, CCS and their combination (BECCS) are limited."*¹⁰ *"Note that many models cannot reach concentrations of about 450ppm CO₂-eq by 2100 in the absence of CCS...."*¹¹ Moreover, for the four models that could limit temperature increases to 2 °C without CCS, the IPCC concluded that mitigation costs would be 138% more expensive without CCS technology.¹² *"In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO₂-eq) ... fossil fuel power generation without CCS is phased out almost entirely by 2100."*¹³ The International Energy Agency states that under its modeling, *"CCS contributes one-sixth of total CO₂ emission reductions required in 2050."*¹⁴

⁷Paul Holtberg et al., *International Energy Outlook 2016*, U.S. Energy Information Administration, p. 81-99 (May 2016), [https://www.eia.gov/outlooks/ieo/pdf/0484\(2016\).pdf](https://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf)

⁸ The U.S. Clean Power Plan (CPP) is not included in the Reference case.

⁹ O. Edenhofer et al., *Climate Change 2014 Synthesis Report Summary for Policymakers*, Intergovernmental Panel on Climate Change, (2014), https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf. (Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA).

¹⁰ *Id.*

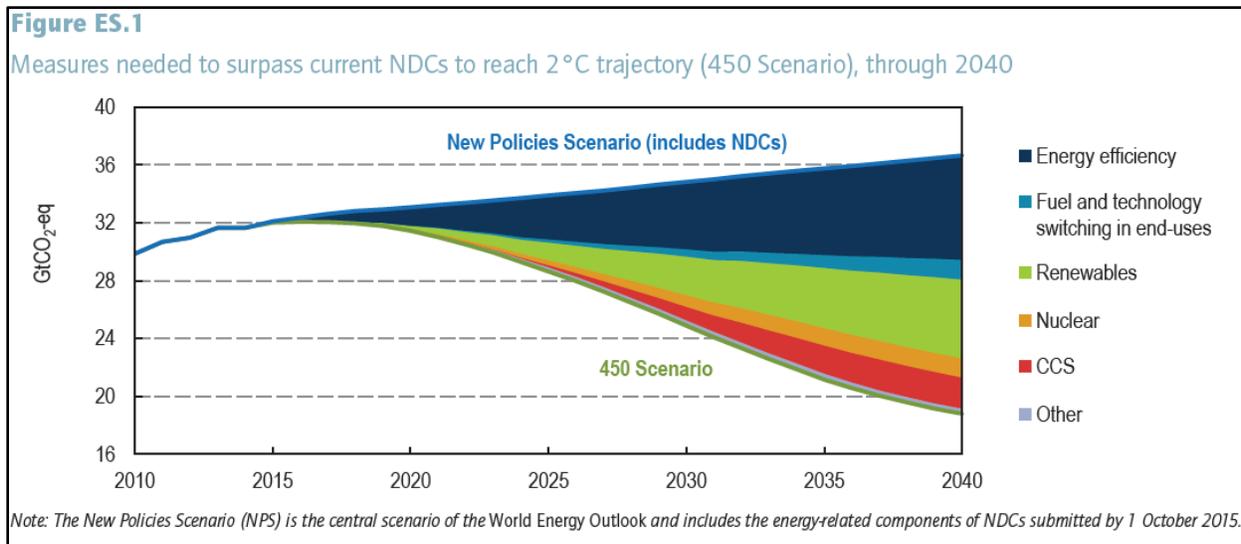
¹¹ *Id.*

¹² *Id.*

¹³ *Id.*

¹⁴ Carbon capture and storage website, International Energy Agency, retrieved May 13, 2017, <https://www.iea.org/topics/ccs/>.

Figure 3-2 Measures needed to surpass current NDCs to reach 2°C Trajectory (450 Scenario), through 2040



Source: © OECD/IEA 2016 Energy, Climate Change and Environment Insights 2016, IEA Publishing, Licence: www.iea.org/t&c; sourced from © OECD/IEA 2015 Medium-Term Renewable Energy Market Report 2015 and World Energy Outlook, IEA Publishing. Licence: www.iea.org/t&c

In its World Energy Outlook 2016, IEA notes that “a step-change in the pace of decarbonisation and efficiency improvement is required in the 450 Scenario.”¹⁵ In addition to accelerated deployment of renewables, nuclear power (where acceptable), and end-use efficiency, IEA supports accelerated deployment of CCS as well as clean energy research and development efforts by governments and companies.¹⁶

Deeper emission reductions will be required to achieve the Paris Agreement target of holding the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C. Greater deployment of CCS, technological improvements to reduce carbon intensity in coal and gas power generation along with biofuel cofiring and CCS, bio-generation with CCS, and increased use of CCS in industry, are cited by IEA as potential measures to help achieve the reductions.¹⁷

The need for technology advancements at the large-pilot scale is not limited to just CCS or the role that CCS plays in addressing the global climate challenge. Historically, we have seen large-pilot scale technologies support the advancement of new environmental control equipment and coal generation technologies for combustion and gasification. New, highly efficient technologies use less fossil fuel resources for more electric output with reduced emissions of both CO₂ and other criteria pollutants, and will be necessary to support the global increase in the use of coal and fossil fuels. Improved technology for the utilization of fossil fuels, including CCS, will deliver significant benefits to society— including safeguards for energy security, improvements in

¹⁵ International Energy Agency, World Energy Outlook 2016, Executive Summary at 3 (2016), <https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf>

¹⁶ *Id.*

¹⁷ International Energy Agency, Energy, Climate Change & Environment 2016 Insights (2016), <https://www.iea.org/publications/freepublications/publication/ECCE2016.pdf>

air quality, and a robust economy resulting from lower capital and technology cost savings in new and existing plants, fuel cost savings, low electricity prices, and jobs creation. The Carbon Utilization Research Council (CURC) and the Electric Power Research Institute (EPRI) have published several Advanced Coal Technology Roadmaps that document these benefits from improved technology.¹⁸ The 2015 Roadmap identifies key research, development, and demonstration (RD&D) priorities for developing cost-effective, efficient, and environmentally acceptable technologies that convert coal to electricity and other useful forms of energy, including CCS technologies. Implementation of the 2015 Roadmap recommendations are projected to result in technologies that deliver significantly higher value in terms of cost, efficiency, flexibility and environmental performance compared to today's state of the art technologies. The 2015 Roadmap also recommends implementing a large-scale pilot program that anticipates United States federal support for evaluating new technologies under real operating conditions at a scale beyond laboratory and bench- scale and before testing technologies in a commercial-scale demonstration, which is also the subject of this study.

3.2. The Purpose of Large-Pilot Scale Projects in the Larger Scheme of Technology Development

Almost all major engineering innovations are developed through a progression of stages that increase in scale. This approach to technology development is based partly on the process of scientific discovery, and partly on desire to manage technology risk. As noted below, these progressive steps are sometimes identified using the TRL system. Objectives for large-pilot scale projects usually include:¹⁹

- Confirm that the technology will function as expected on real power plant fuel gas or flue gas, rather than on a simulated gas used for small scale laboratory tests.

Figure 3-3 View of 30-MWe Callide Oxyfuel Boiler equipment



Source: Figure 3.3, "Callide Oxyfuel Project - Lessons Learned – May 2014." Courtesy Oxyfuel Technologies Pty Ltd (A: boiler house, B: fabric filter, C: flue gas exit duct, and D: recirculated flue gas duct)

¹⁸ The CURC-EPRI Advanced Coal Technology Roadmap - July 2015 Update, Coal Utilization Research Council and the Electric Power Research Institute, July 2015, www.coal.org/roadmap. https://media.wix.com/ugd/80262f_ada0552d0f0c47aa873df273154a4993.pdf.

¹⁹ L.D. Carter, *Technical Workshop Report, An Industry View: Advancing the Next Generation of Coal Conversion Technologies*, Coal Utilization Research Council, (Nov. 18-19, 2014), https://media.wix.com/ugd/80262f_0e0ffae694454287ad5a14998327d3f2.pdf.

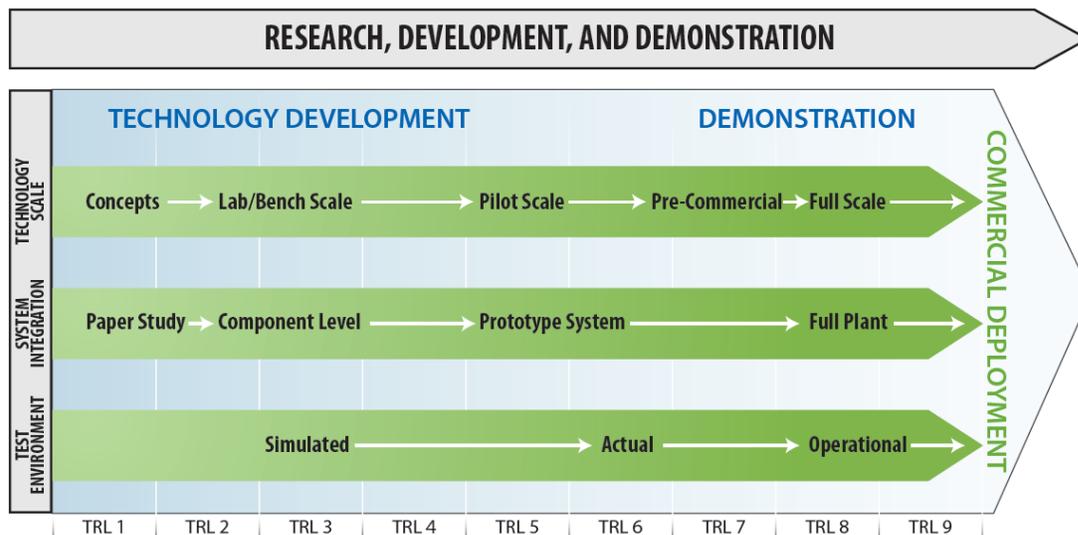
- Develop data needed to improve estimates of the capital cost of a larger scale demonstration unit, or ultimate commercial scale units.
- Develop data to enable the design of the next step in technology development, normally a commercial scale demonstration unit that can operate under varying conditions typical of a fully commercial unit.

Successful large-pilot scale projects enable technology developers to discover and resolve problems with an emerging technology at a relatively small scale, and at relatively small cost. They also tolerate a greater level of risk acceptance than commercial scale projects, so inclusion of the large-pilot scale "step" can accelerate the development of large improvements in a technology.

3.3. Defining Large Pilot Scale Projects

The National Aeronautics and Space Administration (NASA) adopted a concept called "Technology Readiness Level" (TRL) to help standardize discussions of evolving space technologies. TRL's are typically a numerical value between 1 and 9, with the higher values reflecting greater degrees of technology maturity (see Figure 3.4).²⁰ In the United States, government support for CCS research has been predicated on a degree of private sector investment in a particular project. The percentage of required private sector contribution increases with technology maturity (TRL value).

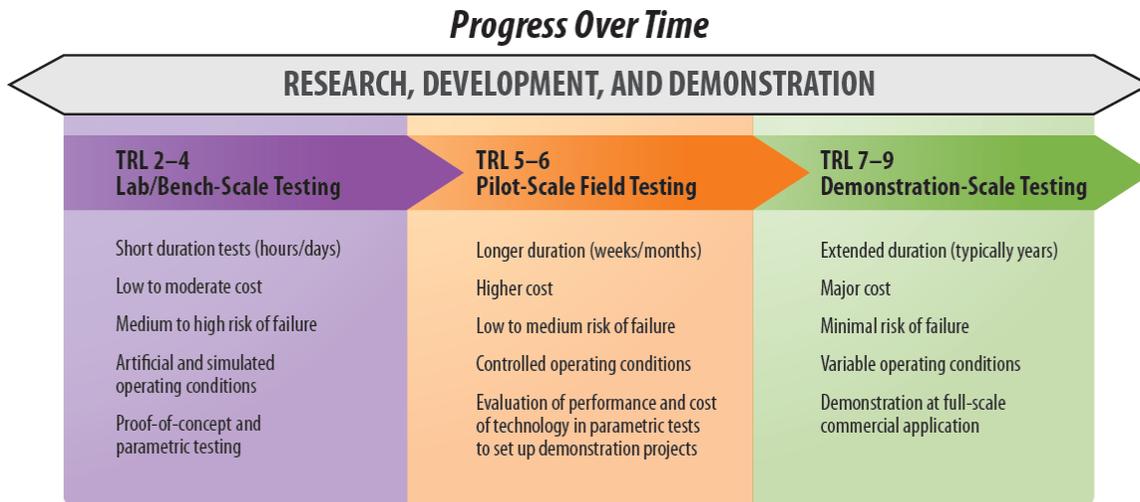
Figure 3-4 TRLs



²⁰ *Carbon Capture Technology Program Plan*, U.S. Dep't of Energy (Jan. 2013). <https://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/Program-Plan-Carbon-Capture-2013.pdf>.

Characteristics of the various TRLs can be viewed in Figure 3.5, below.²¹

Figure 3-5 TRL Characteristics



For purposes of this report, "large" pilot-scale projects for power generation technologies will be defined as TRL 6, ranging in capacity from approximately 10 MW_e to 50 MW_e. However, the Study does not presume a particular configuration for large-pilots and assumes that technologies and components may be piloted as part of integrated or partially integrated systems or in stand-alone configurations, depending upon what makes the most technical and economic sense. Such projects include:

- Fully integrated "stand alone" projects incorporating power generation, CO₂ capture, and CO₂ storage
- Capture and storage projects using CO₂ taken from "slipstreams"²² at existing commercial energy facilities
- Designs intended to operate for a brief testing period of a year or two before being dismantled, or designs intended to be operated in a near-commercial mode after pilot testing is completed
- Projects that capture CO₂, but then release (vent) it to the atmosphere

This report assumes that large-pilot scale power projects with CCS will have a capital cost in the \$100 - 500 million range, although slipstream designs and designs that do not store captured CO₂ could be less. Note that all references in the report to \$s means United States Dollars unless noted otherwise.

²¹ *Id.*

²² A "slipstream" is typically a small portion of the flue gas diverted to the capture facility instead of exiting the power plant's emission stack. For example, a slipstream might be equivalent to 2-5% of the total flue gas produced by the power plant. For pre-combustion capture systems, an analogous design concept would be to divert a portion of the fuel gas to the capture system.

4. Task 2 - Identification of Key Barriers and Discussion of Options for Overcoming Barriers to Planning, Construction, and Operation of Large Scale CCS-Related Pilots

4.1. Task 2 Executive Summary

As discussed in Chapter 3, carbon capture and storage (CCS) technology is considered an essential element of a global climate change mitigation program, and large-pilot scale projects using CCS are an essential step needed for the development of improved CCS technologies. Large-pilot scale electric power generating projects are defined as projects with a generating capacity ranging from 10-50 MWe. Such projects can carry capital costs of \$100-500 million and require several years for design, construction and pilot operation. The nature of specific pilot projects varies considerably based on the type of technology being evaluated and the goals of the technology developer. For example, some projects are dismantled after completion of their testing program, while others shift into a commercial-like mode of operation. Some projects use fuel gas or flue gas from an existing power plant, while others include a new power generation unit within their scope.

Large-pilot scale projects using CCS face a range of challenges or barriers. These include 1) market barriers such as the perception of a limited near-term market for CCS technologies; 2) financial barriers which are based in part on the relatively high cost of the projects, risks associated with the specific technology, and challenges to demonstrating a persuasive business case for investment in a pilot project; and 3) policy barriers, which include an insufficient commitment to development and deployment of CCS by many governments.

It is unlikely that the private sector stakeholders that have traditionally supported technology development in the electric power sector, acting alone, can marshal the resources necessary to take CCS technologies through demonstration at the large-pilot scale. Support will be necessary from other sectors including government and possibly recent entrants in technology development such as purpose-oriented foundations and lending institutions. Moreover, a portfolio of policy and financial measures will likely be needed. For example, future markets for CCS technology could be expanded by government policies that broaden renewable portfolio standards to extend credits to CCS. Effective financial incentives appear to be well known to policy makers, but their effectiveness is limited by the amount of funding governments are willing to spend and these incentives need to be designed to accommodate the unique nature of large-pilot scale projects. Traditional sources of government funding include general tax revenues, low cost financing, bonds or federal grants. Other sources that have been proposed specifically to generate a revenue stream for CCS projects or for CO₂-mitigation programs include targeted assessments or fees on electricity consumers, or revenues generated by emission mitigation regulatory programs. Possible sources of non-government funding include environmentally oriented foundations and lending organizations, and consortiums of energy intensive

corporations. However, many if not most of the potential approaches needed to facilitate large-pilot scale CCS technologies ultimately depend on the existence of a genuine commitment by governments to commercialize this technology.

4.2. Task 2 Methodology

Phase 2, Task 2 employed the following general approach:

- An organizational meeting for the overall Phase 2 effort was held in Washington, DC, on December 12, 2016. Meeting participants included private sector stakeholders representing technology developers and suppliers, electric power generating companies (technology users), fossil fuel suppliers, and academia. At that meeting, the major findings of the Phase 1 report regarding barriers to large-pilot scale CCS projects were reviewed. A conceptual approach for conducting the Phase 2, Task 2 effort was presented and meeting participants were invited to offer suggestions for improving the conceptual approach. Meeting participants were also invited to join a working group being formed to discuss options to overcome barriers to large-pilot scale CCS projects associated with power generation. Doug Carter was designated as the Coordinator and principal author for the Task 2 section of this report.
- The Working Group was formalized and designated "Working Group 2" (WG2) to distinguish it from a similar working group formed to assist in Task 3. Appendix 6-1 includes a list of WG2 members.²³
- The Task 2 Coordinator prepared an informal white paper highlighting the findings of the barriers set forth in the Phase 1 report and listing a range of possible options to overcome barriers to large-pilot scale power projects with CCS. The paper was distributed to WG2 members and those participants were asked to provide comments and additional reference material relevant to Task 2.
- On February 7, 2017, a conference call was conducted among members of WG2 to discuss the white paper and discuss options to overcome barriers to large-pilot scale power projects with CCS.
- Using the input from the WG2 conference call and additional material from published literature, the Task 2 Coordinator prepared a Draft Final Report for Task 2.
- The Draft Final Report was distributed to WG2 members and CURC, and was the subject of a second conference call for the working group on April 18, 2017.
- Using the input from the WG2 conference call and subsequent written comments, the Task 2 Coordinator prepared a Final Report for Task 2 which is set forth herein.

Figure 4.1 presents the schedule for Task 2.

²³ Participation in WG2 does not signify endorsement of this report by any working group member.

Figure 4-1 Task 2 schedule

Dec	Jan	Feb	Mar	Apr	May
Organizational meeting	White Paper	Webinar / Conf. Call		Draft Final Report & WG Conf. Call	Final Report
Initial input from WG					

4.3. Potential Barriers to Large Pilot Scale Fossil Fuel-Based Power Projects With CCS

Barriers to unilateral projects involving fossil-based electric power systems with CCS were addressed in Section 3 of the March 21, 2016, CURC report.²⁴ Section 3 focused on the business and regulatory environment in the United States, but included a limited discussion of international markets. This paper reflects and expands on the discussion of project barriers in the 2016 paper. In the discussion below, barriers to large-scale pilot projects with CCS are organized into three groups: market barriers, financial barriers, and policy barriers.

4.3.1. Market barriers

Perhaps the most vital prerequisite for increasing interest in large-pilot scale power projects with CCS is a conclusion by potential project participants (e.g., equipment suppliers, technology developers, customers and fuel producers) that there is, or will be, a market and need for commercial power systems with CCS. Currently, that perception does not exist. Hence, overcoming barriers to large-pilot scale projects requires measures designed to specifically address market barriers to commercial deployment of these technologies.

Projected growth of coal and natural gas-fired generation is presented in Figures 4.2, 4.3 and 4.4 as totals for the world, the European Union -28, and the United States, respectively.

²⁴ Op. Cit., CURC, 2016.

Figure 4-2 Global power generation

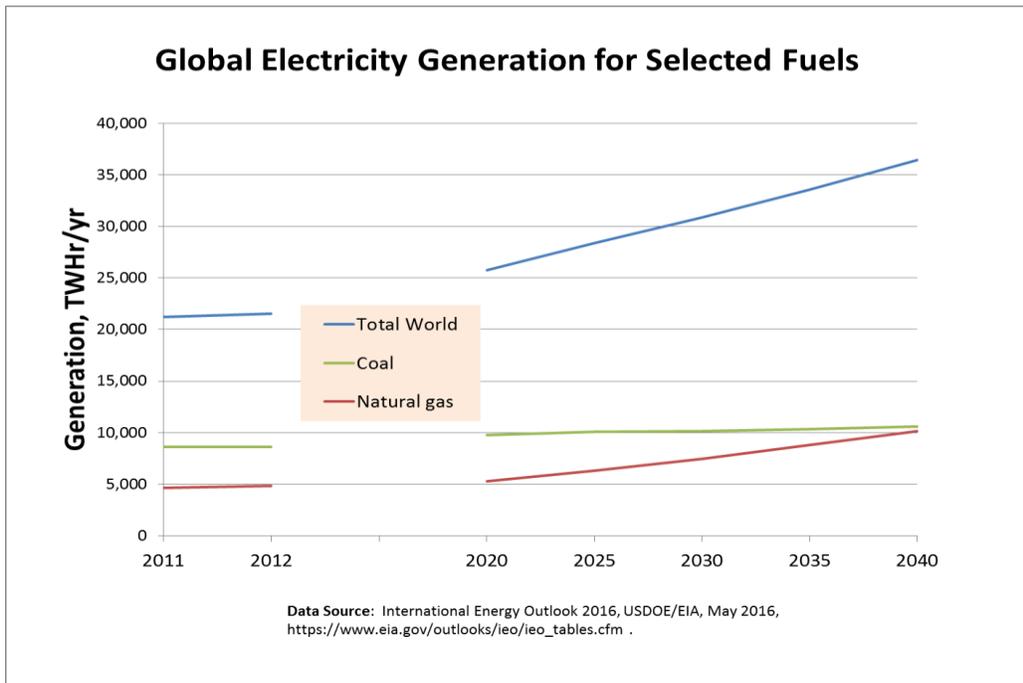


Figure 4-3 Projected power generation in the EU

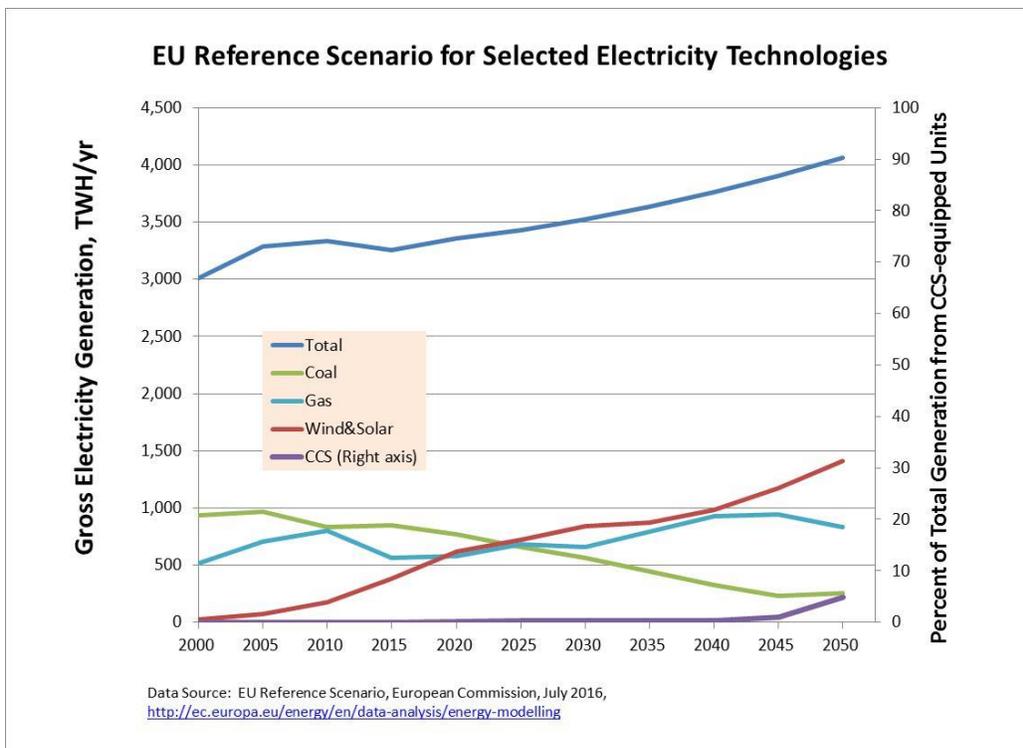
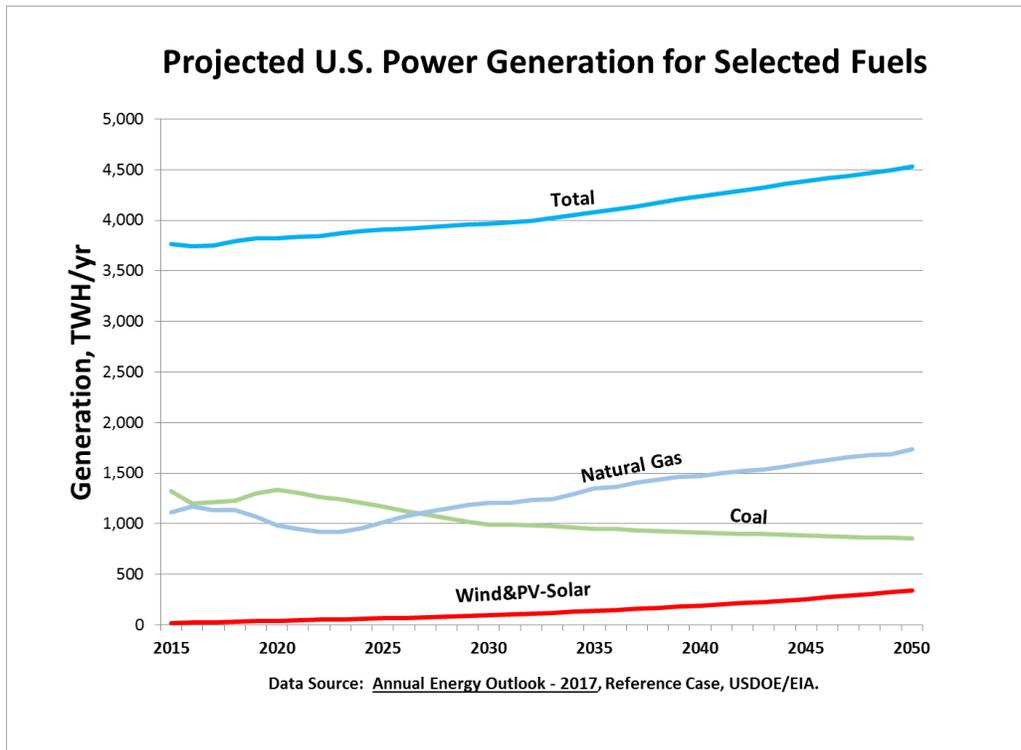


Figure 4-4 Projected power generation in the U.S.



These projections are by different modeling groups, using different assumptions and methodologies, but taken together they indicate:

- Total electricity generation, and generation from natural gas are both expected to increase globally, in the European Union, and in the United States.
- Coal use is projected to be relatively constant globally, but decrease substantially in both the European Union and United States.
- Projected use of CCS is expected to occur on about 5% of total generating capacity in the European Union. Although not shown in Figure 4.3, projected market penetration of CCS in the United States is even less.

These scenarios for limited market penetration for CCS technologies are supported by the fact that, currently, no new coal fueled power plant is projected in the United States through 2050.²⁵ A separate analysis of United States generation was made assuming repeal of recently promulgated regulations limiting CO₂ emissions from existing United States coal-fired power plants. Under that scenario, United States coal-fired generation was projected to increase a modest 4% by 2050, and, again, no new coal fired plant was projected over the forecast period.²⁶ The situation for coal may be even less optimistic in the United Kingdom, which is considering a policy to close all its existing coal-fired power plants by 2025 — unless they install CCS

²⁵ Annual Energy Outlook - 2017, U.S. Dep't of Energy (Jan. 5, 2017), [https://www.eia.gov/outlooks/aeo/pdf/0383\(2017\).pdf](https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf).

²⁶ *Id.*, ("no Clean Power Plan" scenario).

technology, which is not expected given the age of the power plants and the cost of currently available CCS technologies.^{27, 28} Only minimal coal-based construction activity is reported for Europe. Eurelectric, an association representing the broad interests of the electricity industry across Europe, announced on April 5, 2017, that (with the exceptions of Greece and Poland) its membership "does not intend to invest in new-built coal-fired power plants after 2020."²⁹ Conversely, while coal use is projected to diminish markedly in the North America and Europe, a substantial amount (350 GW) of new coal power plant construction is reported underway globally, primarily in non-OECD Asia (China, India, Vietnam, Indonesia) and in Turkey,³⁰ but these nations have not demonstrated strong interest in deploying CCS on power plants in the near term.

The previous graphs portray significant growth for natural gas-fired power generation. Global power production from natural gas approximately doubles between 2020 and 2040. Projections for growth in natural gas-fired power generation in the European Union and United States are robust, with a 48% and 56% increase in projected generation in 2050, compared to 2015.^{31, 32}

4.3.2. Financial Barriers

United States private sector stakeholders that have traditionally supported development of advanced coal-based technologies may have reduced resources or reduced willingness to invest in future fossil-based CCS technology development unless a "persuasive business case"³³ can be made for the technology project. For example, a significant fraction of United States coal production is from mining companies that are now in or have recently emerged from bankruptcy protection. A review of several United States electric utility Integrated Resource Plans³⁴ (IRPs) found none of these utilities projected the construction of a new coal-fueled power plant within the IRP's planning horizon (typically 20 years).³⁵ In addition, several of the larger electric power

²⁷ *Coal Generation in Great Britain - The pathway to a low-carbon future: consultation document*, UK Dep't for Business, Energy & Industrial Strategy (Nov. 2016), https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577080/With_SIG_Unabated_coal_closure_consultation_FINAL_v6.1_.pdf.

²⁸ *UK aims to close coal-fired power plants by 2025*, Reuters (Nov. 18, 2015), <http://www.reuters.com/article/britain-energy-policy-idUSL8N13D0UK20151118>

²⁹ *European Electricity Sector gears up for the Energy Transition - A Statement by EURELECTRIC*, Eurelectric (Apr. 5, 2017), http://www.eurelectric.org/media/318380/eurelectric_statement_on_the_energy_transition_2-2017-030-0250-01-e.pdf.

³⁰ Christine Shearer et al., *A Shrinking Coal Plant Pipeline: Mid-2016 Results from the Global Coal Tracker*, End Coal, <http://endcoal.org/resources/shrinkingcoal/>.

³¹ *EU Reference Scenario - 2016*, European Commission, (July 15, 2016) <http://ec.europa.eu/energy/en/data-analysis/energy-modelling>.

³² Op. Cit., Annual Energy Outlook - 2017.

³³ A "persuasive business case" is an assessment that an investment in a CCS project can generate a return commensurate with the risks associated with the project and commercialization of the technology, and with the time needed to realize that return, compared to other investment opportunities being considered by the organization.

³⁴ Integrated Resource Plans are formal documents prepared by rate-regulated electric utilities that demonstrate that utility's assumptions regarding future electricity demand, and how the utility will meet that demand, with consideration of expected power plant retirements, new plant construction, power purchase plans, and demand-side management measures.

³⁵ Op. Cit., CURC, 2016, Section 3.8.

plant equipment suppliers in the United States have undergone recent reorganizations, a trend that continues with the recent acquisition of Alstom Power by General Electric.³⁶ The challenge for establishing a "persuasive business case" for new technology development is exacerbated by the time lag between "proof of concept" of a new technology at a 1 MW_e scale, and commercial deployment at a 250 - 500 MW_e scale. This time lag is perceived by many private sector companies as too long for a return on the investment, particularly when combined with the perceived lack of a market for CCS.³⁷

Large-pilot scale projects involving fossil fuel-based power production systems equipped with CCS face unique challenges, compared to smaller R&D projects or larger commercial demonstration projects. Systems in the size range of 10 MW_e to 50 MW_e are likely to have capital costs in the range of \$100 million to \$500 million — sums that are beyond the means of most technology developers. Pilot projects may also be operated on a parametric basis, meaning that their primary purpose is to test a variety of operational conditions to generate data that is necessary to estimate performance under various conditions in order to design larger, commercial-scale systems. Hence, unlike a commercial demonstration unit, these pilot plants may not be designed to operate on a continuous basis, at least not until after completion of pilot testing. As a result, some revenue streams available to a commercial-scale project are likely not available to a large-pilot scale project. Sale of CO₂ for enhanced oil recovery (EOR), a cost mitigating element of all existing demonstration-scale electric power/CCS systems to date, may be encumbered or impractical for a project designed to operate intermittently or for only a few years. Also, the amount of CO₂ provided by some large-scale pilots may be insufficient to be of interest to EOR operators. For example, the Petra Nova CCS project was initially planned at a scale to capture 375,000 tonnes per year CO₂, but was expanded to 1.4 million TPY (240 MW_e) to better match the needs of nearby commercial EOR opportunities.³⁸ A reliable revenue stream, such as that provided by sale of electricity and/or CO₂ is usually essential for projects requiring debt financing. *"As a general (if not universal) rule, lenders will not forgo recourse to a project's Sponsor unless there is a revenue stream from the project that can be secured for purposes of ensuring repayment of the loans."*³⁹ In other words, "project financing" - financing secured by the assets of the project rather than the full assets of the parent company involved in the project - is generally not available unless the project's sponsor can identify revenues streams from the project sufficient to repay the requested debt. Moreover, commercial financing may be encumbered by the fact that these pilot projects, which are intended to address the immaturity of

³⁶ Press Release, General Electric, *GE Completes Acquisition of Alstom Power and Grid Businesses*, (Nov. 2, 2015), <https://www.genewsroom.com/press-releases/ge-completes-acquisition-alstom-power-and-grid-businesses-282159>.

³⁷ For example, design, construction, and limited operation of a large-pilot project, followed by a commercial scale demonstration project can require 10-20 years. If the economic justification for the pilot plant investment is based on subsequent commercial sales of a technology, such a delay in realizing revenues may be economically impractical. Moreover, during that period, markets, government policies, and competing technologies can change significantly.

³⁸ *Petra Nova W.A. Parish Fact Sheet: Carbon Dioxide Capture and Storage Project*, CCS Technologies at Massachusetts Institute of Technology (Sept. 2010), https://sequestration.mit.edu/tools/projects/wa_parish.html.

³⁹ Wilson Sonsini Goodrich & P.C. Rosati, *Project Finance for Renewable Energy and Clean Technology Projects*, WSGR PC, 4 (Sept. 2014), <https://www.wsg.com/publications/PDFSearch/renewable-energy-primer-0914.pdf>.

a technology or integrated system, have an inherently higher level of risk than commercial demonstration units and commercial units. These factors prevent traditional commercial financing from being considered a viable option.

Lastly, electric utilities that are rate-regulated may be denied cost recovery from their customers for pilot-scale projects that are perceived as "research" rather than "generation" assets. A recent International Energy Agency (IEA) report compared the challenge for pilot projects (second generation technologies) compared to current first generation demonstration projects: "*While CCS technology will experience significant technological advancement, cost reduction and broader application as the CCS industry grows over time, first-generation technology is proven. Bankable Engineering, Procurement, and Construction contracts can be secured for this technology from equipment producers. The same is not true for second-generation technologies which have yet to be commercially proven.*"⁴⁰

These constraints on the availability of conventional private sector financing of pilot projects would appear to place greater dependence on other sources of revenue, a role traditionally played by governments seeking to assist in the development of technologies needed to achieve government policies and goals. For example, government support has played a significant role in funding the three existing power plant commercial demonstration projects involving CCS.⁴¹

4.3.3. Policy barriers

The primary objective of a pilot project is to facilitate commercialization of the technology under consideration. Policies that discourage commercial scale CCS projects indirectly deter large-pilot scale projects by undermining the overall business case for developing the technology. Hence, both policies that directly impact a large-pilot scale project, and policies that directly impact commercial scale projects are relevant to an investment decision related to the large-pilot scale project.

Public views on climate change vary significantly by region of the world and by those within the same region but having differing social philosophies. For example, a Pew Center survey published in 2016 found that Latin Americans and Europeans believed climate concerns were immediate, whereas those in the Middle East and in the United States believed that problems were less immediate.⁴² The survey found that, in the United States, 20% of responders identifying themselves as Republicans thought climate change "is a very serious problem", while 68% of those identifying themselves as Democrats thought that climate change is a very serious problem. Moreover, public opinions on climate change vary over time. Gallup reported in 2016 on United States opinions on climate change since 1990 and showed concerns peaked in 1990,

⁴⁰ Coal Industry Advisory Board, An International Commitment to CCS: *Policies and Incentives to Enable a Low-Carbon Energy Future* at 24 (Nov. 21, 2016), https://www.iea.org/ciab/papers/CIAB_Report_CCSReport.pdf.

⁴¹ These are the Kemper County 582 MW IGCC project in Mississippi, the 110 MW Boundary Dam repowering project in Saskatchewan, Canada, and the Petra Nova 240 MW "slip stream" project near Houston, Texas.

⁴² Richard Wike, *What the world thinks about climate change in 7 charts*, Pew Research Center, (Apr. 18, 2016) <http://www.pewresearch.org/fact-tank/2016/04/18/what-the-world-thinks-about-climate-change-in-7-charts/>.

2000, 2008, and 2016, but hit lows in 1998, 2004, and 2010-11.⁴³ According to the survey, 41% of Americans believe that climate change "will eventually pose a serious threat to them or their way of life"; while 57% do not. Gallup reported in 2015 that 32% of Americans surveyed worry about climate change "a great deal" -- the lowest concern expressed for the six environmental issues cited by the survey.⁴⁴ These mixed and changing views on the seriousness and immediacy of climate change impacts are likely reflected in policies supported by elected officials.

Many OECD governments have expressed support for the development and deployment of CCS technologies on fossil-fueled power plants. Nevertheless, some government policies serve to impede such development and deployment. A recent report prepared for the International Energy Agency concluded, "*An international commitment to CCS requires that governments have the political will to put in place well-designed CCS policies that: (1) stimulate CCS market uptake, (2) support CCS project development, (3) enable CCS project funding and (4) advance next-generation CCS technologies.*"⁴⁵ Government measures impacting CCS include:

- Uncertain or overly burdensome rules on CO₂ storage — These include procedural requirements for reporting for projects using CO₂ for enhanced oil recovery in the United States, re-permitting of CO₂ injection well plans if the EOR injection pattern is changed,⁴⁶ protracted review periods for permit applications related to CO₂ injection wells, and liability exposure for injection well operators extending 50 years or longer after CO₂ injection ceases.^{47,48}
- Lack of commitment — Some government CCS incentive programs have been initiated, only to stall later. For example, the European Union launched a program to demonstrate 12 commercial scale CCS projects by 2020.⁴⁹ However, the one project awarded funding in 2014⁵⁰ was refused development consent by the United Kingdom Secretary of State in

⁴³ Lydia Saad and Jeffrey M. Jones, *U.S. Concern About Global Warming at Eight-Year High*, Gallup (Mar. 16, 2016), http://www.gallup.com/poll/190010/concern-global-warming-eight-year-high.aspx?g_source=CATEGORY_CLIMATE_CHANGE&g_medium=topic&g_campaign=tiles.

⁴⁴ Jeffrey M. Jones, *In U.S., Concern About Environmental Threats Eases*, Gallup (Mar. 25, 2015), <http://www.gallup.com/poll/182105/concern-environmental-threats-eases.aspx>.

⁴⁵ Coal Industry Advisory Board, *An International Commitment to CCS: Policies and Incentives to Enable a Low-Carbon Energy Future* (Nov. 21, 2016), https://www.iea.org/ciab/papers/CIAB_Report_CCSReport.pdf.

⁴⁶ Subpart RR Flaws Preclude EPA's Reliance on CO₂-EOR in the Proposed NSPS Rule, Denbury, (undated), quoted by Rep. Weber at hearing of House Environment Subcommittee, Committee on Science, Space, and Technology, March 12, 2014.

⁴⁷ *German CCS Legislation*, Global CCS Institute, <https://hub.globalccsinstitute.com/publications/dedicated-ccs-legislation-current-and-proposed/german-ccs-legislation> (last visited May 18, 2017),.

⁴⁸ Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells, 75 Fed. Reg. 77,230 (Dec. 10, 2010) (codified at 40 C.F.R. §§ 124, 144, 145, 146, and 147).

⁴⁹ *European financial strategies to incentivize CCS*, Global CCS Institute, <https://hub.globalccsinstitute.com/publications/financing-ccs/european-financial-strategies-incentivise-ccs> (last visited May 18, 2017).

⁵⁰ *CCS Community hails NER300 funding injection for White Rose Project*, Global CCS Institute (July 8, 2014), <https://www.globalccsinstitute.com/news/institute-updates/ccs-community-hails-ner300-funding-injection-white-rose-project>.

2016.⁵¹ In the United States, government support for certain commercial scale projects selected for funding was withdrawn when stipulated deadlines for progress were not met. Overall, fewer than a dozen large-pilot scale power projects with CCS have received government support globally.⁵² In the United States, relatively little funding has been provided for large-pilot scale or commercial scale demonstration projects since 2008.

- Absence of policy parity — In both the United States and in the European Union, substantial operating subsidies have been provided to renewable energy technologies, generally long after the renewable energy technology has established itself in the marketplace. Comparable support has not been provided to fossil fueled technologies equipped with CCS, even though the CCS technology is less mature.

4.4. Overcoming Barriers

A listing of possible mechanisms to overcome barriers to large-pilot projects for fossil power generation with CCS is presented below. The mechanisms are organized by the type of barrier (market, financing, government policy), recognizing that these categories overlap to some degree. The order of presentation is not an indication of preference by the Task 2 working group or the author, and the inclusion of concept should not be considered an endorsement.

4.4.1. Overcoming market barriers

Approaches that expand the ultimate commercial market for an emerging technology provide "market pull" for conducting projects at the large-pilot scale and commercial demonstration scale. The expectation of a significant commercial market is considered necessary to establish a persuasive business case for investing in large-pilot projects.

Possible paths to overcoming market weakness for fossil fueled power plants equipped with CCS include:

- Repowering or replacing the aging fleets of existing coal-fired power plants with power cycles including CCS. These CCS-equipped power cycles could be coal or gas-fueled, and reflect conventional steam or gas turbine-generators, or emerging power cycles such as those employing supercritical CO₂ as a working fluid. However, for this approach to be effective, either the cost of these repowering and replacement systems with CCS must be dramatically reduced, or government intervention in markets (employing either carrots or sticks) will be necessary.
- Implementation of government policies to incorporate CCS technology on all fossil fuel fired power systems. Note that such policies will result in deployment of CCS

⁵¹ *National Infrastructure Planning: White Rose Carbon Capture and Storage Project*, Capture Power Limited (Apr. 13, 2016), <https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/white-rose-carbon-capture-and-storage-project/>.

⁵² Author's interpretation of data presented in Massachusetts Institute of Technology, Carbon Capture & Sequestration Technologies website, (Pilot CCS Projects), https://sequestration.mit.edu/tools/projects/index_pilots.html.

technology only if the cost of power from CCS-equipped units is competitive with alternative sources of power generation.

- Fostering technology advances resulting in significantly lower costs for new power systems with CCS. These might take the form of technical improvements in the power system's thermodynamics (efficiency), physics, or chemistry; or development of lower cost manufacturing of power systems via modularity and mass production of standard designs; or development of high value uses for captured CO₂.

4.4.2. Overcoming financial barriers

Commercial-scale and large-pilot scale low-carbon fossil energy-based systems tend to be much larger, and therefore much more costly per installation, than alternative renewable energy-based low carbon technologies. For example, wind and solar projects can typically be evaluated at a 1 MW_e scale⁵³ instead of the 10-50 MW_e scale assumed here for fossil power systems with CCS. Hence, the relatively high cost for large-pilot scale projects using CCS is a major barrier that is central to most financial barriers to CCS. There is a broad range of possible approaches to reduce financial barriers to pilot projects for fossil-fueled generation technologies equipped with CCS via provision of monetary incentives. Most of these incentives have been used by governments in the past for promoting environmental goals, either directly, or indirectly through regulatory programs authorized by governments. These include:

- Tax incentives — Investment tax incentives⁵⁴ and production tax incentives⁵⁵ have been provided on a limited basis for projects involving CCS in the United States. Accelerated depreciation is another approach for lowering the effective capital cost of a project. Note that a production tax incentive could be of limited value for a pilot project if operation of the project were structured around periodic parametric tests.
- Private activity bonds — This financing mechanism, which is common in the United States, excludes from federal taxation the interest from bonds to certain categories of private sector projects such as airport construction and mass transit. Such an exclusion effectively lowers the interest rate on the bond. Legislation has been proposed in the United States Senate to extend the applicability of such tax-exempt financing to carbon capture projects.⁵⁶

⁵³ Coal Industry Advisory Board, An International Commitment to CCS: Policies and Incentives to Enable a Low-Carbon Energy Future (Nov. 21, 2016), https://www.iea.org/ciab/papers/CIAB_Report_CCSReport.pdf.

⁵⁴ *E.g.*, 26 U.S.C. § 48A (2012) (Investment tax credit for qualifying advanced coal projects), <https://www.law.cornell.edu/uscode/text/26/48A>.

⁵⁵ *E.g.*, 26 U.S.C. § 45Q (2012 & Supp. III 2015) (Credit for carbon dioxide sequestration), <https://www.law.cornell.edu/uscode/text/26/45Q>.

⁵⁶ Carbon Capture Improvement Act of 2015, S. 2305 114th Cong. (1st Sess. 2015) (introduced on November 19, 2015), <https://www.congress.gov/bill/114th-congress/senate-bill/2305/text>. Carbon Capture Improvement Act of 2017, S. 843, 115th Cong. (introduced on April 5, 2017), <https://www.congress.gov/bill/115th-congress/senate-bill/843?r=19>.

- Loans and loan guarantees —
 - Government assured financing would directly address the challenge of obtaining commercial financing for technology development projects with inherently high risk. Moreover, such assured financing tends to support a greater portion of a project's cost to be financed with debt. Increasing the debt/equity ratio for projects would reduce the project cost, because debt requires a lower rate of return than equity.⁵⁷ Title 17 of the Energy Policy Act of 2005 created a loan guarantee program within the United States Department of Energy for assisting certain advanced technologies, including CCS; but to date no power system with CCS has received a loan guarantee. The appeal of United States loan guarantees would be enhanced if the currently required "Credit Subsidy Cost" fee charged in the loan guarantee program were waived for pilot-scale projects.⁵⁸ Note that for loan guarantees to be practical for pilot-scale projects, the project developer would be required to identify revenue streams sufficient to repay the loan.
 - Financing for large scale energy projects has historically been provided by:⁵⁹
 - Commercial loans secured by the project. Generally, project financing requires a low risk technology and secure revenue streams to support loan repayment. "Project finance lenders almost never want to be the first to finance an untested technology."⁶⁰
 - Loans by Export Credit Agencies, tending to support sales from companies in the Agency's country
 - Public Finance Institutions and Multilateral Institutions that have political or social objectives beyond commercial economics
 - "Green Banks" focusing specifically on environmental goals⁶¹

However, these organizations generally expect the project to be an established technology, the borrower to have a history demonstrating the ability to manage the proposed project, and projected revenue streams from which the loan can be repaid. Such characteristics are often absent from a large-pilot scale project.

⁵⁷ 2CO Energy Limited, Making the business case for CCS (Nov. 2012), <http://hub.globalccsinstitute.com/sites/default/files/publications/85746/making-business-case-ccs.pdf>.

⁵⁸ J. Price, Effectiveness of Financial Incentives for Carbon Capture and Storage, (Dec. 19, 2014), http://ieaghg.org/docs/General_Docs/Publications/Effectiveness%20of%20CCS%20Incentives.pdf.

⁵⁹ Societe Generale, Financing Large Scale Integrated CCS Demonstration Projects (May 2014), <http://hub.globalccsinstitute.com/sites/default/files/publications/157868/targeted-report-financing-large-scale-integrated-ccs-demonstration-projects.pdf>.

⁶⁰ Wilson Sonsini Goodrich & Rosati, PC, Project Finance for Renewable Energy and Clean Technology Projects at 5 (Sept. 2014), <https://www.wsgr.com/publications/PDFSearch/renewable-energy-primer-0914.pdf>.

⁶¹ The UN Green Climate Fund provides funding for low emission and climate-resilient projects in developing countries. <http://www.greenclimate.fund/about-gcf/global-context#mission>. A similar pooled fund could be designed for large-pilot scale projects using CCS technology.

- An innovative concept used by the World Bank⁶² to promote emissions reduction was a "reverse auction" for projects that mitigate methane emissions from landfills, animal waste sites, and wastewater sites. Auction winners were assured a floor price for future carbon credits after certifying the emission reductions. The approach would work with regulated projects that are economically viable at the emission mitigation floor price.
- Grants — The United States DOE Clean Coal Technology program, initiated in 1985, and successor programs also managed by United States DOE have funded large scale advanced coal-based technology projects in the United States.⁶³
- Prizes — The United States Government has employed prizes to spur technology development in non-power sectors.⁶⁴ In addition, XPRIZE, a non-profit, is currently executing the NRG COSIA Carbon XPRIZE competition to develop conversion and reuse applications for captured CO₂.^{65,66}
- Funds — Approaches that generate funds to finance advanced energy projects having above-market prices have been used for non-CCS technologies. These generally involve charging a fee to a broad industry sector to generate a fund, and then using that fund to support a limited number of projects for a specific technology. For example, a "Contract for Difference" (CFD) approach has been employed by the United Kingdom to support deployment of low carbon technologies such as wind turbines and solar electric systems.⁶⁷ This subsidy has been competitively awarded using funds provided by a statutory levy on all United Kingdom -based licensed electricity suppliers. Existing CFD programs have been used to provide a subsidy for commercially demonstrated technologies that remain above market prices. Nevertheless, such a pooled funding approach could be combined with a reverse auction⁶⁸ approach to fund pilot-scale projects.⁶⁹

⁶² Pilot Auction Facility website, <http://www.pilotauctionfacility.org/content/about-paf>.

⁶³ See, e.g., U.S. Dep't of Energy, Clean Coal Technology Programs: Program Update 2007, DOE/FE-0514, as of September 2007 (Jan. 2008),

https://www.netl.doe.gov/File%20Library/Research/Coal/Reference%20Shelf/2007_program_update.pdf.

⁶⁴ J. Gustetic & T. Kalil, Accelerating the Use of Prizes to Address Tough Challenges (July 20, 2015)(describing a range of Federal programs employing prizes), <https://www.digitalgov.gov/2015/07/20/accelerating-the-use-of-prizes-to-address-tough-challenges/> .

⁶⁵ M. Gruver, Cooking oil, graphene among CO2 capture prize entry ideas, AP News (July 27, 2016), <https://apnews.com/928a4ed44eb64ec3998cc3dfd0bdc575/cooking-oil-graphene-among-co2-capture-prize-entry-ideas>

⁶⁶ Reimagine CO₂, <http://carbon.xprize.org/> .

⁶⁷ UK Department for Business, Energy & Industrial Strategy, Electricity Market Reform: Contracts for Difference (Feb. 8, 2017), <https://www.gov.uk/government/collections/electricity-market-reform-contracts-for-difference>.

⁶⁸ A "reverse auction" is one where the lowest bid by a seller is selected, in contrast to a normal auction, where the highest bid buyer is selected.

⁶⁹ For example, a \$/MWh fee applied to power generators or purchasers could be used to establish a CCS pilot plant fund. Fund administrators could implement a "reverse auction" that awarded CCS projects that met basic eligibility criteria and projected the lowest cost of capture and storage of CO₂.

- Feed-in tariffs — This approach allows an electricity supplier to recover revenues that are above market prices. These tariffs have been used to foster early deployment of electricity conservation measures and renewable energy technologies such as wind and solar in the United States, Canada, Europe, Japan, China, India and other nations.⁷⁰ Feed-in tariffs have not been applied to large-pilot scale projects, and are impractical for a system conducting parametric testing or for slipstream projects. However, it is possible that a large-pilot scale unit that has completed its parametric testing could shift to a commercial operating mode partially supported by an above-market tariff.
- Offsetting revenue streams — Sale of electricity and CO₂ from a project is a potential source of revenue to offset the cost of the project and to improve the economic prospects of the project. However, pilot projects are generally operated to generate design data for commercial-scale demonstration units (or sometimes for fully commercial units), rather than for maximizing sales. In addition, the quantity of CO₂ generated in pilot-scale projects may be too small to justify EOR or other uses. For example, a developer of one proposed 50 MW_{th} (~25 MW_e) project concluded that a CO₂ offtake contract was impractical.⁷¹ Similarly, a 20 MW_e slipstream project piloting pre-combustion CO₂ capture near Buggenum, Netherlands, vented captured CO₂.⁷² Operation of a pilot unit as a commercial generator (with revenue streams for electricity and CO₂ sales) after completion of parametric testing may be one way to enhance the economic appeal of these projects and their access to debt financing.
- Stabilizing revenues from sale of CO₂ for EOR — In North America, EOR revenues have been a key component of revenues to offset CO₂ capture costs for the three commercial demonstrations of CCS technology on power plants. However, the price paid for CO₂ for use with EOR is contractually pegged to the price of crude oil, which is highly variable over time. This price uncertainty can negatively impact financing for a CCS project. An innovative approach to ensure stable EOR revenues via a government hedge mechanism was included in a legislative proposal in 2015.⁷³ The gist of this approach is that if oil prices (and CO₂ prices) are above expected values, the CO₂ seller pays money to the government, and if oil prices are below expected values, the government pays money to the CO₂ seller.

⁷⁰ Feed-in tariff, Wikipedia, https://en.wikipedia.org/wiki/Feed-in_tariff (last visited May 18, 2017).

⁷¹ Development of the SCO₂ Allam Cycle - 50 MW_{th} Demonstration Plant Update, J Fedvet, 8 Rivers Capital, Supercritical CO₂ Power Cycles Symposium, March 28, 2016, <http://www.swri.org/4org/d18/sco2/papers2016/Keynote/JeremyFedvet.pdf>.

⁷² Carbon Capture & Sequestration Technologies, Buggenum Fact Sheet: Carbon Dioxide Capture and Storage Project, MIT CCS Project Database, <http://sequestration.mit.edu/tools/projects/buggenum.html> (last visited May 18, 2017).

⁷³ See Advanced Clean Coal Technology Investment in Our Nation Act of 2015, S. 601 § 203 (introduced by U.S. Senator Heitkamp on February 26, 2015).

- A 2015 report prepared for the Brookings Institution⁷⁴ suggested a combination of policies to create a market for CCS technology and a portfolio of monetary incentives to support early commercialization. In general, these approaches appear oriented toward commercial scale demonstrations or post-demonstration deployment, rather than large-pilot scale projects.
- Unconventional sources —
 - Bill Gates, working with more than twenty other billionaires, established the Breakthrough Energy Coalition to fund radical approaches to clean energy. The coalition pledged to invest at least \$2 billion in new technologies.⁷⁵ The coalition is working with a parallel government structure, Mission Innovation, involving the European Union and 22 countries committed to doubling government research in clean energy over a five year period.⁷⁶ Note that the XPRIZE effort cited above is funded entirely by the private sector, so it could also be considered "unconventional".
 - An MIT report concluded that venture capital is an unlikely source of funds for advanced energy systems. "VCs look to invest in start-ups that can quickly achieve scale to address a high-growth market and provide large payoffs (ten to one hundred times the invested capital) within a short time frame."⁷⁷

A significant issue raised by stakeholders at the previously cited 2014 CURC workshop on large-pilot scale CCS projects was whether these large-pilots would be temporary in nature ("tear-downs"), or whether they would continue operation after the pilot test period concluded. Views among stakeholders varied, but many believed that the capital cost of units in the upper half of the capacity range of large-pilot scale units, perhaps those of 25 MW_e and larger, would be so great that these pilot projects would be designed to operate in a commercial mode after completion of pilot testing protocols.⁷⁸ This is a key issue because a unit that continued to operate, with revenue streams from the sale of electricity and possibly the sale of CO₂, could identify income needed to repay the initial project construction loan. It is also possible that such a unit could provide a continuing test facility for CCS technology innovations. An example of such a hybrid "commercial/research" facility can be found in Sweden. The Chalmers University of Technology constructed an innovative 75MW fluidized bed combustion system as a prototype

⁷⁴ John P. Banks & Tim Boersma, Fostering Low Carbon Energy - Next Generation Policy to Commercialize CCS in the US, Brookings Institution (Oct. 2015), <https://www.brookings.edu/research/fostering-low-carbon-energy-next-generation-policy-to-commercialize-ccs-in-the-united-states/>.

⁷⁵ J. Condliffe, MIT Technology Review, Bill Gates's \$1 Billion Fund Will Back Radical Clean Energy Ideas (Dec. 12, 2016), <https://www.technologyreview.com/s/603111/bill-gatess-1-billion-fund-will-back-radical-clean-energy-ideas/>.

⁷⁶ See generally Mission Innovation, <http://mission-innovation.net/> (last visited May 18, 2017).

⁷⁷ B. Gaddy, *et al.*, Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation, An MIT Energy Initiative Working Paper, at 4 (July 2016).

⁷⁸ Op. Cit., Technical Workshop Report, 2014.

for combined heat and power systems that could use a variety of biomass materials as fuel.⁷⁹ Most of the capital cost of the facility was provided by the Swedish government, and it continues to operate using wood chips for fuel. Operating, maintenance, and fuel costs are paid with revenues from the sale of steam for district heating. Private sector entities that wish to test combustion of alternative forms of biomass pay to do so. Following completion of testing the alternative biomass fuel, the unit reverts to commercial operation on wood chips.⁸⁰ Although this facility does not use CCS technology, it demonstrates how a unit can operate in both a research mode and a commercial mode.

Project-specific innovative financing, although difficult to generalize, could provide a path forward for some larger scale CCS projects. For example, in 1975, Wheelabrator Frye built its first United States waste-to-energy plant in Saugus, Massachusetts, with project financing based on tipping fees (payments for taking ownership of municipal wastes) and sale of steam. Following several years of pilot operation, the facility was refinanced and added a steam turbine generator, allowing more lucrative sales of electricity to the regional Independent (electricity transmission) System Operator.⁸¹

4.4.3. Overcoming policy barriers

Several types of policy initiatives could foster financing of large-pilot projects employing CCS technology.⁸² These include:

- Funding commitment — "*An international commitment to CCS requires that governments have the political will to put in place well-designed CCS policies that: (1) stimulate CCS market uptake, (2) support CCS project development, (3) enable CCS project funding and (4) advance next-generation CCS technologies*"⁸³ "*Business-as-usual implementation of government permitting, grants, guarantees, and other approvals will not suffice.*"⁸⁴ Funding commitments can take the form of both providing the private sector with resources needed to accomplish policy objectives, and allowing flexibility in how the private sector conducts projects selected by the government for support.

Moreover, some United States government incentive programs have imposed strict timetables on the design, permitting, and construction of CCS projects awarded federal funding. The consequence of failure to meet a deadline has been withdrawal of federal funding. Although included as a laudable effort to accelerate the projects, such deadlines were exceeded for some projects (most notably FutureGen 2), resulting in withdrawal of

⁷⁹ L. Walsh, Researchers improve waste and biomass combustion, *Ends Waste & Bioenergy* (Oct. 9, 2015), <http://www.endswasteandbioenergy.com/article/1367831/researchers-improve-waste-biomass-combustion>.

⁸⁰ Presentation by Klas Andersson, Chalmers University, to the CURC Technical Subcommittee (March 15, 2017).

⁸¹ Personal communication from James Wood, Director, U.S.-China Clean Energy Research Center, Advanced Coal Technology Consortium, to author (Feb. 15, 2017) (on file with author).

⁸² Inclusion of a measure in this section does not imply advocacy for or support of that approach by the author or CURC. The order in which measures are presented is not indicative of priority.

⁸³ *Op. Cit.*, Policies and Incentives to Enable a Low-Carbon Energy Future.

⁸⁴ *Id.* at 11.

government financial support and project cancellation. A more tolerant policy regarding the schedules of large, first-of-a-kind projects may be more productive.

A policy commitment to use government resources to fund large-pilots and to allow flexibility in executing projects selected for funding is an obvious approach to foster future pilot projects.

- Regulatory incentives — It is tempting to suggest that aggressive regulatory policies would prompt development and deployment of power generation technologies with CCS. However, it is clear that governments would not adopt major new policy initiatives merely to promote a new technology. Decisions to adopt climate change mitigation policies will properly rest on a balancing of the impacts of the social, economic, and environmental impacts of such policies. The following thoughts are offered for consideration:
 - Regulations requiring CCS on new fossil-fueled power plants can provide a market for this technology, but only if the cost of CCS-based power, with incentives, is competitive with alternative sources of power, with incentives. In the absence of economically competitive CCS technologies, a mandate for CCS use could actually be counterproductive to advancing CCS technology.
 - Carbon taxes or fees could provide a similar incentive, but, again, only if the CCS system were price-competitive with other sources of electricity.^{85,86} "While there is a recognized role for a price on carbon in some markets, a price on carbon is an insufficient policy on its own, and in many cases works against bringing CCS forward to global markets."⁸⁷ Note that most carbon tax programs are designed to impose a tax sufficient to change behavior (e.g., \$15 - \$168 per tonne CO₂). An alternative tax approach would be to use a much smaller tax (e.g., \$1 - \$2 per tonne CO₂) to create a fund to support improved GHG control technologies, including pilot-scale CCS projects.
 - Clean energy standards, similar to renewable energy portfolio requirements enacted by many state governments in the United States, could provide a pooled financing approach for a limited number of commercial CCS projects. The state of Michigan provides such a mechanism.⁸⁸ A federal Clean Energy Standard (CES), including CCS, was proposed by Senator Bingaman in 2012.⁸⁹ Commercial deployment of CCS under a CES might follow the example provided

⁸⁵ Coal Industry Advisory Board, An International Commitment to CCS: Policies and Incentives to Enable a Low-Carbon Energy Future (Nov. 21, 2016), https://www.iea.org/ciab/papers/CIAB_Report_CCSReport.pdf.

⁸⁶ J. Price, Effectiveness of Financial Incentives for Carbon Capture and Storage (Dec. 19, 2014), http://ieaghg.org/docs/General_Docs/Publications/Effectiveness%20of%20CCS%20Incentives.pdf.

⁸⁷ Op. Cit., Policies and Incentives to Enable a Low-Carbon Energy Future.

⁸⁸ J. Heeter & L. Bird, National Renewable Energy Laboratory, Including Alternative Resources in State Renewable Portfolio Standards: Current Design and Implementation Experience (Nov. 2012), <http://www.nrel.gov/docs/fy13osti/55979.pdf>.

⁸⁹ Clean Energy Standard Act of 2012, S. 2146, 112th Cong. (Introduced by Sen. Bingaman 3/1/2012), <https://www.congress.gov/112/bills/s/2146/BILLS-112s2146is.pdf>.

by many current state renewable portfolio standards: implementation through a competitive bidding process managed by a utility.⁹⁰

- Allowance-based incentives — For state or national programs that mandate a "cap&trade" approach to limiting CO₂ emissions over time, a portion of the compliance allowances distributed by the government could be set aside for projects using CCS.
 - This type of program was set forth in the United States acid rain mitigation program in 1990 for control technologies reducing SO₂ emissions.⁹¹
 - Similarly, "bonus allowances" for CO₂ reductions from use of CCS were included in proposed United States climate change mitigation legislation in 2008 and 2009.⁹²
 - Bellona has proposed use of emission unit allowances in the European Union's innovation fund to offset a portion of the cost of CCS projects, and to make support available to "partial chain" projects (projects involving either capture, transport, or storage of CO₂, but not necessarily all three).⁹³
 - Shell is reported to have negotiated a "2-for-1" carbon credit with Alberta, Canada, for CO₂ captured at the Quest oil-sand upgrading project.⁹⁴
 - California transfers a portion of revenues from its cap&trade program to the state's "Greenhouse Gas Reduction Fund." During fiscal year 2016-17, the fund provided over \$1.1 billion to various environment-related projects.⁹⁵

⁹⁰ See, e.g., PacificCorp, 2016 Renewable Resource Request for Proposal,

http://network.bellona.org/content/uploads/sites/3/2015/09/Bellona-Feedback-to-EC-ETS-revision-proposal_Sept-2015.pdf.

⁹¹ Clean Air Act Amendments of 1990 § 404(d)(6), Pub. L. No. 101-549, 104 Stat. 2399, 2596. Power plants using qualifying SO₂ control technologies were also eligible for a delayed compliance date for the required emission reductions.

⁹² E.g., the American Clean Energy and Security Act of 2009, H.R. 2454 § 115 (passed by the U.S. House of Representatives on June 26, 2009), provided up to 72 GW of coal capacity with bonus allowances for use of CCS. The bill failed to pass in the Senate and did not become law. <https://www.congress.gov/bill/111th-congress/house-bill/2454/text?q=%7B%22search%22%3A%5B%22hr2454%22%5D%7D&r=5>

⁹³ *Bellona Europa feedback to the European Commission's proposal for revision of the EU Emissions Trading System*, Bellona Europa (Sept. 2015), http://network.bellona.org/content/uploads/sites/3/2015/09/Bellona-Feedback-to-EC-ETS-revision-proposal_Sept-2015.pdf.

⁹⁴ M. Mazzetti, Opportunities for CCS implementation in the Nordic Countries at 6, Technical Report D1.4.1201, (Sept. 2012), https://www.sintef.no/globalassets/sintef-energi/nordiccs/d1.4.1201-opportunities-for-ccs-implementation-in-the-nordic-countries_web.pdf. Under a "2-for-1" arrangement, the company is provided twice the normal credit awarded for not emitting CO₂. For example, if the current carbon fee is \$30/tonne CO₂, this feature would be worth \$60/t of CO₂ permanently stored by the CCS project.

⁹⁵ California Air Resources Board, 2017 Annual Report, Cap-and-Trade Auction Proceeds at 6 (Mar. 2017).

- Regulatory flexibility —
 - The 1990 Amendments to the United States Clean Air Act included provisions that exempted the installation of certain clean coal technologies from otherwise applicable new source review procedures.⁹⁶ Such provisions thereby eliminated requirements that were time consuming and created exposure to possible litigation during permitting. Although the 1990 incentives were specific to SO₂ control technologies, a similar concept could be applied to CCS (both for large-pilot projects and commercial demonstration projects).
 - Regulatory flexibility might also be appropriate for the more onerous elements of regulations applicable to CO₂ storage. Designed for commercial scale projects, these rules may be excessive for projects in the 10 MW_e - 50 MW_e size range.
 - *"Major CCS projects will likely take two to five years to permit absent streamlined processes. FOAK [First of a Kind] CCS projects will often face challenges in the permitting process unless there is operational flexibility provided in the permits for the early years of operation when plant performance is being optimized."*⁹⁷

4.4.4. Thinking outside the box

Concepts that might reduce barriers to large-pilot scale CCS projects but do not fit well within the structured framework presented above are discussed below.

- Large-pilot scale test platforms — The concept for a reusable test platform for small pilot- scale CCS projects is well established. DOE created the National Carbon Capture Center (NCCC) in 2009, which is operated by Southern Company. The NCCC works with both pre-combustion and post-combustion CCS technology developers to evaluate emerging technologies.⁹⁸ The attributes that make a test platform attractive include the ability to reuse the basic power generation (or syngas generation) portion of the facility, the availability of testing equipment, access to facility operators with expertise and experience in solving problems related to testing a new CCS technology, and established protocols for ensuring safety and environmental protection. These features allow faster and less costly technology evaluation if a technology is amenable to the design limitations of the test platform. Moreover, working with an established operation implicitly reduces project risk. It is difficult to imagine a universally adaptable facility at the large-pilot scale that could be used as a basis for such varying technologies as advanced sorbents, membrane separation, supercritical CO₂ working fluids, pressurized

⁹⁶ Clean Air Act Amendments of 1990 § 415, Pub. L. No. 101-549, 104 Stat. at 2596 (Clean coal technology regulatory incentives).

⁹⁷ Op. Cit., Policies and Incentives to Enable a Low-Carbon Energy Future.

⁹⁸ National Carbon Capture Center, <https://www.nationalcarboncapturecenter.com/what-we-do> (last visited May 18, 2017).

oxy-combustion processes, and chemical looping processes. Nevertheless, just as the NCCC is bifurcated into pre-combustion and post-combustion operations, it might be feasible for a larger scale platform to address a subset of the full range of CCS technologies. This "platform" strategy may be part of the design of a six year project begun in 2016 to evaluate power plants using CO₂ as a working fluid (instead of steam).⁹⁹

- Segregated CO₂ storage. In general, power plant operators lack expertise in storing CO₂ in saline geologic reservoirs, enhanced oil recovery, or CO₂ pipeline transport. Moreover, potential revenues from CO₂ sales for EOR are linked to the price of crude oil decades into the future, and potential liability for stored CO₂ may extend for fifty years after a proposed power plant ceases to operate. Hence, it is not surprising that some pilot-scale CCS projects are "catch and release" and do not actually store CO₂ separated from flue gas or fuel gas. One approach to address the problem of unfamiliarity with CO₂ storage mechanisms would be to promote the creation of either private sector or public sector entities that would manage the back half of the CCS activity: CO₂ storage. With a larger infrastructure than would be possible for a single-unit operation, such an entity could pursue options like moving CO₂ to natural reservoirs currently being used to supply CO₂ for EOR. This mode of operation might offer a practical endpoint for CO₂ from intermittent pilot facility operation, or continuous operation of a pilot facility of insufficient size to support completely an EOR operation. In the United Kingdom, the Crown Estate has reviewed these issues and others and concluded, "*early targeted government investment in CO₂ storage appraisal combined with mechanisms to provide income support [for CO₂ transport and storage infrastructure] in the face of an uncertain emerging market are critical prerequisites for generating future option value and delivery of choices for private sector investment in industrial decarbonisation, low carbon fuels, and power generation.*"¹⁰⁰ The Norwegian state, through its state owned enterprise Gassnova, has outlined an approach for demonstrating CCS at energy intensive industrial applications, in which the Government takes the overall initiative for a first CCS chain. This is done by supporting up to three industrial projects for capturing CO₂ from their production process, and to support a storage provider willing to receive and store the CO₂ captured. The storage site is an offshore saline formation already identified. The support will be given in line with the state aid regulation as set out by the European Union, and, importantly, the state is prepared to share the overall risk with the companies entitled for support. The purpose of the project is to demonstrate a full CCS chain, to develop and disseminate learning from the project to internationally, and to contribute to development of market players along the entire CCS chain. The ambition is

⁹⁹ The project team includes the Gas Technology Institute, Southwest Research Institute, and GE Global Research. The 10 MWe pilot project is funded in part by the U.S. Department of Energy. Press Release, Southwest Research Institute, SwRI Teaming With GTI to Demonstrate Supercritical CO₂ Power Plant (Oct. 17, 2016), <http://www.swri.org/node/8959>.

¹⁰⁰ The Crown Estate provides leases for transportation and storage of CO₂ in areas of the 12-mile nautical seabed and continental shelf that is managed by the Crown Estate. The Crown Estate, Balancing the Carbon Cycle at 7, <https://www.thecrownestate.co.uk/media/501895/ei-balancing-the-carbon-cycle.pdf>.

to have a full chain in operation by 2022. Feed-studies are soon to start up according to plan, and final investment decisions are expected in 2019.^{101, 102}

- Private sector technology fund — Energy intensive industries have a number of reasons that extend beyond altruism to support development of CCS technology. For example, industries like cement manufacture, refining, and steel production may be subject to CO₂ emissions mitigation requirements. Fossil fuel producers are already finding diminished markets due to concerns regarding greenhouse gas emissions. In addition, fossil energy using and energy producing corporations are encountering increasing pressure from some stockholders to take measures that those stockholders consider socially responsible or protective of stockholder interests.^{103,104} Although some corporations might choose to conduct their own internally financed research on CCS, other firms might decide to form a voluntary consortium to act collaboratively or contribute to a fund that would finance CCS projects. The Oil and Gas Climate Initiative (OGCI) is an example of such a multi-firm collaborative. The OGCI is made up of ten oil and gas companies committed to advancing technologies to reduce greenhouse gas emissions associated with the oil and gas industry.¹⁰⁵ The organization has announced its intent to invest \$1 billion over the next ten years to develop such technologies, with an initial focus on CCUS and reductions of methane emissions from the global oil and gas industry.¹⁰⁶

4.5. Discussion and recommendations

Successful programs for commercializing CCS technology will involve a combination of measures to expand markets for fossil fueled electric power technologies with CSS, including measures to facilitate financing of large-pilot projects and commercial demonstration projects and public policies that provide a nurturing environment for the emerging CCS technologies. Moreover, the varying situations in different countries, different business structures for power generation, and different characteristics of CCS technologies mean that the optimal "package" of measures could vary greatly between countries, and for different types of CCS technology projects.

¹⁰¹ Press Release, Norwegian Ministry of Petroleum and Energy, An important step towards full scale carbon capture and storage (Apr. 19, 2017), <https://www.regjeringen.no/en/aktuelt/an-important-step-towards-full-scale-carbon-capture-and-storage/id2549719/>.

¹⁰² Large Scale CCS in Norway, Presentation by Stale Aakenes, Chief Economist, Gassnova.

¹⁰³ T. Patel, *Shareholder Pressure Increasing Over Climate Change Risks*, Bloomberg News, May 21, 2015, <http://www.bloomberg.com/news/articles/2015-05-21/shareholders-pressure-increasing-over-climate-change-risks>.

¹⁰⁴ O. Davis, *Exxon, Chevron Face Unprecedented Investor Pressure Over Climate Change Disclosure*, International Business Times, May 24, 2016, <http://www.ibtimes.com/exxon-chevron-face-unprecedented-investor-pressure-over-climate-change-disclosure-2373145>.

¹⁰⁵ Oil and Gas Climate Initiative website, <http://www.oilandgasclimateinitiative.com/>.

¹⁰⁶ Press Release, OGCI announces \$1 billion investment in low emissions technologies, (Nov. 4, 2016), <http://www.oilandgasclimateinitiative.com/news/announcing-ogci-climate-investments>.

4.5.1. Expanding markets for CCS

The private sector will not likely exhibit enthusiasm for investments in large-pilot scale power projects with CCS unless it believes that a significant market opportunity exists for the commercial versions of the pilot project technology. Hence, expanding commercial markets for CCS will help overcome business-related barriers to large-pilot scale projects. Specific measures to expand markets might include:

- Most fossil energy-based power systems with CCS are envisioned as relatively large units (e.g., 500 MW_e or more), whereas electricity market needs in advanced economies may trend towards smaller units. Technology developers should consider prioritizing development of systems that are modular in nature and amenable to smaller incremental increases in electricity demand. Such units also offer potential savings via factory manufacture and mass production.
- Expanded focus of commercial CCS application to include retrofit and repowering of existing fossil fueled power plants.
- As in the European Union Emissions Trading System and in local cap&trade jurisdictions such as California's, include all fossil fueled power generation in the emissions reduction programs.
- Limit deployment incentives to technologies that have minimal market penetration. Providing government subsidies to mature technologies creates a market barrier to competing technologies like CCS that are not established in the marketplace.

4.5.2. Overcoming financial barriers

4.5.2.1. Categorical considerations

Developers of large-pilot projects involving CCS exhibit a broad range of business designs, and different measures are appropriate for different types of projects within this range. The most obvious mode of differentiation is the division between "tear-down" pilot projects that are dismantled after completion of pilot tests, and projects that could shift to a commercial-like operation for decades following completion of pilot testing. Units with a commercial operation period are amenable to several types of incentives, including production tax credits, CO₂ storage credits, "bonus" allowances such as the 2-for-1 credits provided to the Quest project. Additionally, their revenue streams from sale of electric power and (potentially) CO₂ enable a range of debt-based financing options. In contrast, "tear-down" projects must rely on incentives that are related to capital cost buy-downs, such as investment tax credits and grants, and have little potential for debt-based project financing. "Tear-down" CCS projects face a strong financial challenge because they are both expensive (e.g., over \$100 million in capital cost), and have no direct revenue stream from which to repay debt financing. Their most likely business case justification is based on expectations of revenues from commercial deployment of a technology that generally must

have several years of large-pilot scale construction and operation, and several additional years of commercial-scale project design, permitting, construction and operation.

Within the category of projects that would experience commercial-like operation, a second segregating characteristic is whether the project would raise revenues from beneficial use of captured CO₂. CCS projects in North America tend to be associated with EOR operations, whereas projects in Europe are oriented toward CO₂ storage in saline formations. For oil prices projected in the timeframe of likely pilot project operation (e.g., 2025-2050), EOR-CO₂ revenue could cover a significant fraction of the cost of a large-pilot project. Thus, measures that encourage the use of captured CO₂ for EOR would have a favorable impact on such pilot projects.

A third factor differentiating large-pilot scale projects with CCS is whether they are capable of integrating with an existing power plant. For example, the capital cost of the Petra Nova project was significantly reduced by its operation using a flue gas slipstream from an existing coal-fired power plant. Many post-combustion capture technologies are amenable to slipstream configurations. Similarly, some pre-combustion technologies can operate with fuel gas (syngas) streams associated with existing IGCC power plants, or perhaps coal-to-chemical or coal-to-methane facilities. However, technologies that reflect a fully integrated design of the power system and the capture system, such as chemical looping, are less likely to be applied to an existing facility. "Full integration" technologies will generally require more substantive incentives and a longer lead time for design, permitting, and construction.

4.5.2.2. Financial incentives

A broad range of possible financial incentives for CCS projects is presented in Section 4.4.2 and will not be repeated in this section. However, certain types of incentives appear to merit further attention. First, it should be noted that resources for a large-pilot scale CCS project must come from one or more of the following sources:

- Traditional private sector technology developers such as equipment suppliers, equipment users (electric utilities), or fuel suppliers — if a persuasive business case can be made for the project itself or the commercialized version of the technology, and the project is consistent with the organization's resources and investment priorities.
- Government — if support for the technology is consistent with government policies, budgets, and priorities, such as environmental improvement or promoting the business interests of that country. Government funds could originate from traditional tax revenues, a carbon tax, a fee levied on electricity consumers or fuel producers, or redirection of climate allowances.
- Non-traditional private sector entities, such as charitable foundations, policy-oriented lending institutions, or other non-government organizations — if the project is

consistent with their organization's goals, resources, and priorities, such as environmental improvement.

Given the time required for the commercialization of technologies currently at the large-pilot scale stage of development, the uncertainty of future markets, and the relatively high cost of large-pilot scale CCS projects, it seems unlikely that the resources necessary for rapid implementation of a global program involving large-pilot scale CCS projects will proceed with support only from traditional private sector stakeholders. In past programs for development of technologies essential to providing a public good, governments have invested not only in research and development, but also in pilot-scale and commercial-scale demonstration programs. For example, governments have provided substantial incentives for R&D, demonstration and early commercial deployment for some renewable energy technologies, such as wind and solar-based electric power technologies. Proven government funding mechanisms include tax incentives, grants, and loan assistance (e.g., loans, loan guarantees, and reduced interest mechanisms like tax-free bonds). The sources of these government resources has varied in the past, and included general tax revenues; user fees applied, for example, to electricity sales; carbon tax revenues or revenues from the sale of emission allowances in a cap&trade program.

Financial support may also be provided by non-traditional private sector entities such as foundations, export credit agencies, or purpose-base public finance institutions. Historically, such entities have shown greater interest in supporting deployment of renewable energy technologies, but these attitudes may change due to reports by the UNFCCC that have demonstrated the extreme difficulty of meeting policy goals for climate change mitigation without affordable CCS technology. Foundations, organizations like the Breakthrough Energy Coalition, and "green" banks could be approached by policy makers and encouraged to support CCS projects. Additionally, energy intensive industries that see CCS technology development as a way to support their long term business interests, wish to respond positively to shareholder pressure to reduce financial risk to climate change regulations, or perceive environmental stewardship as part of their corporate mission, could form coalitions to fund CCS technology projects. Corporations should consider the example provided by the Oil and Gas Climate Initiative¹⁰⁷ and consider forming similar collaboratives within their respective industry sectors. It should be noted that individual companies have also engaged in such activities in announced in-house research programs and programs offering financial "prizes" for successful CCS-related technologies.

Another approach to reduce the financial barriers to large-pilot scale CCS projects is to reduce the cost of the technologies. Mechanisms to achieve this include:

¹⁰⁷ Op. Cit., OGCI.

- More intensive research at the bench scale and small pilot-scale.
- Pursuit of modular technologies that may allow both, (1) a greater amount of plant construction at the CCS technology manufacturer's site and less at the power plant site, and (2) for some modular technologies, replacing the commercial demonstration project with extended operation of the large-pilot project - reducing costs and accelerating deployment.
- Replicating the approach used by the National Carbon Capture Center to establish a test platform to be reused by multiple technology developers over time. Such a test platform has not been proposed for large-pilot scale projects, and would be impractical for some technologies, but for others it might offer more rapid commercialization and cost savings for the pilot project.

Broader cost sharing is another mechanism to facilitate pilot project financing. Readers are directed to Section 3 of this report for an in-depth discussion of multilateral approaches to support large-pilot scale power projects employing CCS.

4.5.3. Policy initiatives

As cited earlier in this paper, a commonly stated recommendation for advancing CCS technologies is a genuine commitment to that technology by governments. Government measures that extend beyond rhetoric include the financial incentives reviewed in Sections 4.4.3 and 4.5.2.1, policy parity with other climate change-based electric power technologies, and expedited permits for environmentally beneficial large-pilot scale and commercial-scale CCS projects.

Policy initiatives that provide an alternative to funding such incentives from general tax revenues include line charges paid by electricity providers, revenues from cap&trade programs (similar to the California program cited earlier), "bonus" allowances provided under cap&trade programs, and small (e.g., \$1-2/tonne CO₂) carbon taxes placed on energy consumers or producers.

Most of the barriers associated with non-EOR CO₂ storage could be overcome by a government infrastructure program that would store captured CO₂ in geologic (saline) formations until CCS technology is established in the marketplace, e.g., from projects initiating storage over the next few years. The cost of such a storage program could either be paid by a user fee, a general fee placed on electricity transmission, or could be part of the government's financial support of this evolving technology.

Government regulatory policies also could assist in providing a market for CCS technology, and for assisting in cost recovery for CCS projects in rate-regulated sectors of the power generation sector. As observed in Section 4.4.3, however, command and control regulations will only promote technology deployment if it is otherwise economically competitive.

The most important policy-related recommendation of Task 2 is that a successful program to foster large-pilot scale power projects using CCS will require a portfolio of policies, financial incentives, and regulatory incentives. The best mix of policies and incentives will almost certainly vary by type of technology and by country.

5. Task 3 - Potential Mechanisms or Models through Which Multilateral Projects Might be Undertaken

5.1. Task 3 Executive Summary

By multilateral collaboration, the Study means two or more governments providing financial support to an individual large-pilot project or group of projects. Phase 2, Task 3 used a multi-nation working group structure to further explore significant barriers that may hinder multilateral collaboration and evaluate possible models that may be effective for collaboration.¹⁰⁸

Large-scale pilots are a necessary step in technology progression, but they present unique challenges. They may cost in the range \$100-500 million, which is beyond balance sheet financing for most technology developers. And, given that they are not usually commercial operations, they are unlikely to generate sufficient revenue to support typical project-based financing.¹⁰⁹ The Phase 1 Study and earlier work identified a number of candidate technologies for large-pilot scale testing including potentially transformational technologies. Assuming, for example, that 20 large-pilot projects are warranted, the total portfolio value could be \$2-10 billion. These levels can stress or break the research budgets of individual countries. Hence, Task 3 focuses on multilateral collaboration as a component of large-pilot project financing in order to leverage the common interests and financial resources of governments.

Multilateral cooperation on fossil energy research and development activities is widely practiced. However, owing to the size and nature of large-scale pilots, potential barrier issues - summarized below and discussed more fully in the Report - may substantially hinder collaboration if they cannot be mitigated when countries develop their collaborative framework(s).

Domestic source policies and practices. It is not uncommon for countries to link their financial support for research and development activities to the involvement of domestic entities. With large-pilots costing \$100 million or more, countries may require substantial domestic involvement in return for their contributions. Domestic source requirements will likely complicate development of a collaborative framework and the process for selecting projects. Furthermore, projects must be designed to satisfy individual country requirements which may not result in the optimal project structure.

Different national or regional CCS goals and strategies. National and regional viewpoints differ concerning the type of technology development that may best contribute to global decarbonization efforts. Also, various governments view their role in supporting technology

¹⁰⁸ Other innovative financing mechanisms explored in Phase 2, Task 2 are addressed in Section 2 of this Report.

¹⁰⁹ Balance sheet financing is typically debt financing that appears on a company's cash flow statement and balance sheet, and which impacts debt-equity ratios and perceived corporate strength. An alternative to balance sheet financing for projects generating revenues might be "Project Financing" which can be accounted "off balance sheet."

development differently and from vastly different financial situations. This suggests that attempts to develop a common, global collaborative structure may not be productive. Targeted collaboration among like-minded countries could be an effective alternative.

Differences in planning, selection and funding processes. Development of a multilateral collaborative framework for large pilot project financing is a complex undertaking that will require reconciliation of individual country processes. The progression of advanced fossil-based power and CCS technologies from large-pilot scale to commercial deployment can take a number of years but climate targets dictate urgency in the development and deployment of CCS technologies. Accordingly, for multilateral collaboration to be most meaningful to national and global objectives, issues must be resolved and frameworks developed expeditiously. This will be a challenge for countries and require compromise and flexibility.

Changing national priorities. Changing national priorities have the potential to adversely impact long-term projects and multi-national funding may magnify project risk from changing priorities. Sustained and consistent support is necessary.

Management of intellectual property rights (IPR). Management and allocation of intellectual property rights among countries and among project participants has been cited as a problem area that may hinder or delay large scale project. The Study identifies similarities in the way that countries approach ownership and exploitation of IPR. Nevertheless, multilateral IPR protocols and agreements take time. Early resolutions of issues can facilitate collaboration.

Task 3 also examined past and current collaborative fossil-based power and CCS technology projects and initiatives for lessons learned that can inform collaboration going forward. Five potentially effective collaborative models were reviewed, each having advantages and disadvantages that must be considered in structuring a framework.

A possible next step for governments considering formal collaboration on large-pilot projects may be to test the thesis of this Study by engaging each other, technology developers and technology users to assess whether:

1. There is sufficient common interest among country groups in fossil-based power and CCS technologies to warrant collaborative initiatives at the large-pilot scale;
2. There is a pathway to resolve potential framework barrier issues in a reasonable timeframe that will allow such projects to contribute to desired deployment timeframes; and,
3. Technology developers and users have an interest in participating in collaboratively funded projects.

5.2. Task 3 Background and Methodology

5.2.1. Task 3 Background

Phase 2, Task 3 is a follow-on to Phase 1 expanding the scope beyond the original Study countries and drawing on government and private sector expertise to explore significant barriers that may hinder successful multinational collaboration and evaluate collaborative models that may be most effective for large-pilots.¹¹⁰

Assuming multinational collaboration is worthwhile, the question becomes how to make collaboration most effective for large-pilots. Governments must work within their own legal, regulatory, and policy regimes and must consider their own national interests. Industry perspectives must also be considered since large-pilots will be based primarily on pre-existing privately owned technology. Consequently, the potential for conflicts and disagreement is great. Conflict resolution causes delay, which is detrimental to large projects, as it drives up costs (e.g. inflationary costs, project team expenses during delay, interest on financing, etc.), can negatively affect sponsor and host site participation, and can compromise technology deployment timelines.

During the course of Task 3 discussions, some participants questioned the pursuit of advanced technology R&D to achieve more cost-effective power generation and CCS technology versus supporting commercial demonstrations using current technology to prove the viability of CCS, learn by doing, and build a business case for deployment. The discussion revealed regional and national differences that suggest a singular approach to multilateral collaboration may not work. These differences are discussed in this document. It is noted that pilot testing and commercial demonstration are both viewed as essential steps in the technology development and deployment progression and this Study's focus on large-pilots is not intended to diminish the value of commercial demonstrations.¹¹¹ In fact, much of the Task 3 discussion is also applicable to multilateral collaboration on demonstrations. Commercial demonstrations have suffered from similar business case issues facing large-pilots: (1) Insufficient project revenue streams; (2) Non-existent or inadequate carbon pricing; (3) Absence of a clear regulatory framework supportive of CCS development and deployment; and, (4) risk and liability.¹¹²

Motivations for supporting advanced fossil-based power technology and CCS technology development vary by country and region. Various reasons are identified in Table 5-1.

¹¹⁰ The Phase 1 Study countries were Japan, Canada, the Republic of Korea, and the US.

¹¹¹ In the Technology Readiness Level (TRL) hierarchy used by governments and research organizations, large pilots precede commercial demonstrations, which precede commercial readiness – the final TRL level.

¹¹²The Study's Phase 1, Task 2 Report, prepared by Howard Herzog, contains a comprehensive discussion of lessons learned from CCS demonstration and large-pilot projects.

Table 5-1 Reasons for Supporting Fossil Power Technology and CCS Technology Development

A belief that global climate objectives may not be achievable without CCS but timely and more cost-effective fossil-based systems (and bio-based systems) with CCS are needed to achieve wide-scale decarbonization and CCS deployment - particularly in the developing countries.
National and regional decarbonization efforts may be less costly through technology development programs tailored for the specific needs of the country or region.
Technology advancement may help a country or region preserve fossil fuels as reliable and environmentally acceptable energy resources that contribute to energy diversity and security.
Technology advancement may preserve export markets for countries or regions with substantial fossil fuel reserves.
Advanced technology may create markets for domestic power and CCS technology developers and markets for services including storage of CO ₂ .
More efficient and cost-effective technology can lower GHG emissions per unit of energy, and improve other environmental attributes.
CCS may increase opportunities for enhanced oil recovery in oil producing countries thereby contributing to a nation's energy and economic security.

The reasons are not mutually exclusive, but it is unrealistic to presume country and regional viewpoints on fossil power and CCS technology development and deployment are identical. Therefore, a framework for multilateral collaboration must respect the differences and accommodate areas where technology interests, development timelines, project size, and budgetary priorities align.

5.2.2. Task 3 Methodology

Task 3 involved a multi-national, cross-disciplinary working group with participants from governments, technology developers, projects, utilities, academia, and non-profit research organizations. Task 3 did not seek consensus but rather sought to obtain and report the individual and collective wisdom of the participants.

Over the course of Task 3, participants with knowledge of collaborative initiatives shared information about the programs. The Task 3 coordinator also held discussions with individuals familiar with large-scale collaborative projects.¹¹³ A cross section of small and large scale projects and initiatives (listed in Table 5-2) were examined to gain insight into such matters as the structure of collaborative projects, potential barrier issues, and approaches and lessons

¹¹³Thanks are extended to the Task 3 Participants and to Chris Spero (Project Director, Callide Oxyfuel Project), Norm Sacuda (Communications Manager, Petroleum Technology Research Centre), Andy Read (ROAD Project Capture Manager), and Joseph Giove (US Department of Energy) for their assistance in this Study.

learned that may inform development of a multilateral collaborative framework for large-pilot projects.¹¹⁴

Table 5-2 Projects, Test Facilities and Initiatives Reviewed

Pilot and Demonstration Projects	Description	Location
Callide Oxy Fuel Project	Australian and Japanese collaboration demonstrating oxyfuel technology with carbon capture at a 30-MWe pilot plant and 75-t/day CO ₂ capture plant.	Australia
FutureGen	Public private partnership to build and operate a near-zero emission commercial scale coal-fueled power plant with CCS.	US
Gas Technology Institute Oxy-PFBC Pilot	United States and Canadian collaborative R&D project to validate the oxy-pressurized fluidized bed combustion process and mature the technology in a new 1 MWth test facility.	US, Canada
IEA-GHG Weyburn-Midale CO ₂ Monitoring and Storage Project	Fifteen year, multi-country, public private collaboration to investigate the long-term fate and security of injected CO ₂ at the Weyburn and Midale oil fields in Canada. CO ₂ sourced from Great Plains Gasification Plant in North Dakota.	Canada
Rotterdam Capture and Storage Demonstration Project (ROAD)	Full chain CCS project with financial support from the Government of the Netherlands and the European Commission. Once constructed and operating, ROAD expects to capture 1.1 million tonnes of CO ₂ per year from a fossil-fueled power plant with storage under the North Sea.	Netherlands
Test Facilities	Description	Location
National Carbon Capture Center (NCCC)	US Department of Energy sponsored facility for testing post-combustion capture technologies and pre-combustion technologies at bench and small pilot scale. Capability to test on coal-derived flue-gas and syngas.	US
Technology Center Mongstad (TCM)	Large-scale post-combustion capture test facility owned by a joint venture of Gassnova (on behalf of the Norwegian state), Statoil, Shell and Sasol. Flexible facility with two units (approximately 12 MWe each in size) designed to test different solvent based technologies and capable of capturing a total of 100,000 tonnes CO ₂ /year.	Norway

¹¹⁴Many other projects, facilities and initiatives exist throughout the world that involve multi-nation support and/or may help inform the development of a collaborative framework for large-pilot projects. The number is too great for all to have been considered within the scope of Task 3. Omission here is not a judgment of their value.

Initiatives	Description	Location
Australian National Low Emission Coal Research and Development (ANLECR&D)	Not-for-profit organization funded by Australian Government and Australia's COAL21 Fund with the mission to develop the knowledge and skills needed to reduce the investment risk of low emission coal technology. Project portfolio exceeds AU \$100 million covering over 25 institutions throughout Australia.	Australia
CLIMIT	Norway's national program for research, development and demonstration of CCS technology. Collaboration between Gassnova and the Research Council of Norway.	Norway
US-China Clean Energy Research Center – Advanced Coal Technology Consortium (CERC-ACTC)	United States and China collaboration to facilitate a portfolio of joint R&D projects on fossil-based technologies including clean power generation, clean fuels, and CCUS.	US, China
ERA-NET ACT (European Joint CCS Program)	Multi-country co-funding scheme under the European Union Horizon 2020 and ERA-NET frameworks to support transnational CCS projects.	Europe
European Carbon Capture and Storage Laboratory Infrastructure (ECCSEL)	Multi-country collaboration to implement and operate a European distributed, integrated research infrastructure for CO ₂ capture, storage and transport research.	Europe
Horizons 2020	European Union Framework Programme for Research and Innovation (2014-2020).	Europe
Mission Innovation	Global initiative of 22 countries and the European Union to accelerate global clean energy innovation. The objective of Mission Innovation's Carbon Capture Innovation Challenge is to enable near-zero CO ₂ emissions from power plants and carbon intensive industries.	Multinational
Norway Grants	Grant mechanism through which Norway contributes funding to reduce economic and social disparities in the European Economic Area (EEA). Grants are available to 13 European Member Countries. Support areas include CCS. ¹¹⁵	Norway and EU Member Countries

Participants discussed issues via conference calls and one-on-one conversations with the Task 3 coordinator. The coordinator compiled Task 3 information and produced a draft Task 3 report that was submitted to the participant group for comment.

The Task 3 Report is the coordinator's summation of information learned during the course of the Study. Participation in the Task 3 Working Group does not signify endorsement of this report by any Working Group member.

¹¹⁵Norway along with Iceland and Liechtenstein also provide funding to reduce economic and social disparities in the EEA under the EEA Grants programme.

5.3. Potential Barriers to Multilateral Collaboration and Lessons Learned

Table 5-3 lists potentially significant barriers to multilateral collaboration on large-pilot projects identified and evaluated during Task 3.

Table 5-3 Potential Barriers to Collaboration

BARRIERS
1. Domestic source policies and practices
2. Different national or regional CCS goals and strategies
3. Differences in planning, selection and funding processes
4. Impact of changing national policies and priorities on long term projects
5. Management of intellectual property rights

Each barrier is explained below. Lessons learned from collaborative projects and initiatives are discussed along with potential mechanisms to mitigate the effects of the barrier.

5.3.1. Domestic source policies and practices.

The domestic source barrier relates to individual country policies and practices that link their financial support for RD&D initiatives to involvement of domestic entities in project performance. This is a common theme seen across collaborative RD&D projects. The nature and degree of involvement depends on country specific policies and the programs or projects. In some cases, payment of funds is restricted to domestic entities and/or to activities conducted within-country. In others, the use of fund is more flexible provided there is a domestic entity involved in the project. The theme is not absolute. There are instances of collaborative activities where the consideration for a country's contribution does not include a linkage to domestic involvement in project performance. Examples include:

- The IEA-GHG Weyburn-Midale CO₂ Monitoring and Storage Project (Weyburn Project), where contributions from the governments of Canada, Japan, and the United States were pooled in the project. The participants obtained access to project knowledge.
- FutureGen, where contributions from collaborating countries were provided to the United States to be pooled with USDOE funds for use on the project in return for membership on a government steering committee and access to project knowledge.¹¹⁶
- Norway Grants, where a stated purpose is to strengthen bilateral relations between the donor and beneficiary countries. During 2009-2014, grants were made available to 13

¹¹⁶ DOE Media Release, U.S. and India Sign Historic Agreement on FutureGen Project (Mar. 2, 2006), <https://energy.gov/articles/us-and-india-reach-historic-agreement-futuregen-project>; DOE Media Release, U.S. and South Korea Sign Agreement on FutureGen Project" (June 26, 2006) <https://energy.gov/articles/us-and-south-korea-sign-agreement-futuregen-project>. The FutureGen Project evolved over time and ultimately was cancelled.

European Union beneficiary countries that became members in 2004, 2007 and 2013. Supported technology areas included carbon capture and storage.¹¹⁷

With large-pilots potentially costing hundreds of millions of dollars, the need for substantial domestic involvement in consideration for a country's contribution may be compelling. As a consequence, domestic source policies and practices may be one of the more challenging barriers facing multilateral collaboration. Reconciliation of different country policies can substantially complicate framework development. Furthermore, individual country restrictions can dictate a teaming and organizational structure that may be relatively easy to accommodate on small R&D projects, but can be complex and difficult at the 10-50 MWe scale. Project work must be divided among team members to satisfy funding country requirements resulting in an allocation of country funds not necessarily best suited to project need. Task 3 participants made the following observations and recommendations related to domestic source policies and project structure:¹¹⁸

1. Collaboration without domestic content is difficult to justify - requiring strong reasons.
2. Flexibility helps project development.
3. Sometimes the benefits warrant changes in the law to accommodate the project.
4. The program value must be large enough to be meaningful. Sufficient government resources can mitigate the challenges of dealing with funding country requirements.
5. Integration of multiple technologies into a single project may make it easier to divide the project among team members in order to satisfy funding country requirements.
6. The decision on how to allocate work to satisfy funding country requirements must be done by the project team members.
7. Proposal preparation when there are funding country preferences can be complex and involve considerable effort among project team members to allocate work.

Lessons from past and ongoing projects and programs are discussed below.

Callide Oxyfuel Project

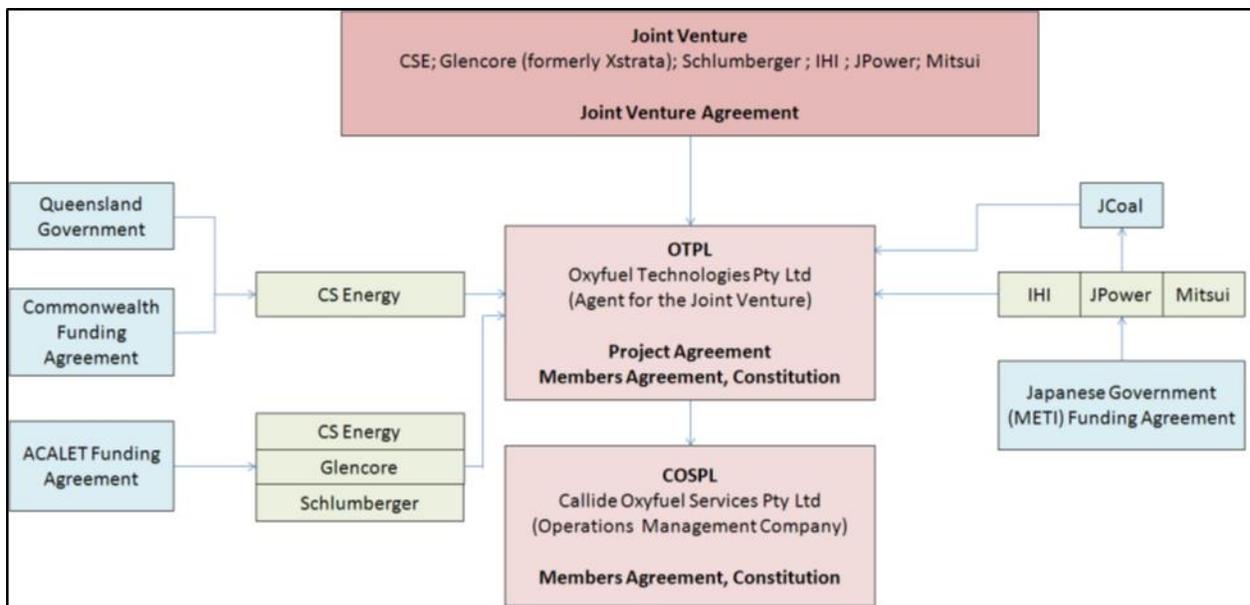
The Callide Oxyfuel Project at the Callide A Power Station in Queensland, Australia involved the repowering of the 30-MWe Unit No. 4 with oxyfuel technology, installation of two air separation units, and installation of a 75-t/day CO₂ capture plant treating a side stream from the oxyfuel boiler. The project was conducted through an unincorporated joint venture (JV)

¹¹⁷ See Norway Grants, Who We Are, <http://eeagrants.org/Who-we-are/Norway-Grants>. For information about the 2014-2021 programme, see EEA and Norway Grants 2014-2021, <http://eeagrants.org/What-we-do/EEA-and-Norway-Grants-2014-2021>.

¹¹⁸ Related comments have been combined into a consolidated observation. Participants also noted that multi-lateral support can trigger other issues such as cross border issues with CO₂ transport.

managed by a steering committee of the project participants. Figure 5-1 depicts the project structure.

Figure 5-1 Callide Oxyfuel Project Structure



Source: Figure 1, "Callide Oxyfuel Project - Lessons Learned – May 2014." Courtesy Oxyfuel Technologies Pty Ltd

A 2004 Memorandum of Understanding (MOU) between the Commonwealth of Australia and Japan set out the overall joint venture structure and basic principles of cost sharing. Details of the JV relationship including cost sharing, shareholding, revenue, and intellectual property rights were negotiated by the participants taking into consideration the terms of the government funding agreements. Negotiation of project funding and JV agreements took nearly 2 years. The total project budget was AU \$240 million and included substantial funding from the Commonwealth Government, Japan, and the Australian Coal Association (ACALET).¹¹⁹ Schlumberger, Glencore and the Queensland Government also provided support. Project revenue from electricity generation went back to the project. Funding from the Japanese Government flowed through the Japanese companies into the JV. Australian government and ACALET funds flowed into the JV through the Australian Participants. Funds were pooled in the JV for use on the project.

A feasibility study was completed in 2006. The front-end engineering design was completed and the financial investment decision made in 2008. Operations began in 2012. Over a 3-year period, the project demonstrated capture rates from the Oxyfuel flue gas stream to the CO₂ capture plant in excess of 85%; the ability to produce a high-quality CO₂ product for geological storage; increased boiler combustion efficiency; greater than 50% reduction in stack nitrogen

¹¹⁹ ACALET's \$82.8 million in support came via the COAL21 Fund established to help secure the future value of Australia's black coal resources. The Fund is "based on a voluntary levy on coal production." About COAL 21, http://www.minerals.org.au/resources/coal21/about_coal21.

oxides (NO_x) mass emission rates; and, almost complete removal of all toxic gaseous emissions from the flue gas stream in the CO₂ capture plant.

By any standard, the Project was successful. Lessons learned from the Project include:

1. Multi-nation financial collaboration can be an effective mechanism to support large-scale fossil-based pilot projects with CCS.
2. The combined substantial contributions from the Australian Commonwealth, Japanese, and Queensland Governments along with the ACALET contribution made an otherwise non-commercial project financially viable.
3. Although government funds flowed into the Project through the Australian and Japanese companies, the funds were pooled in the JV, thereby, providing the JV flexibility in managing the Project expenditures. The JV participants were also provided flexibility to organize the Project.¹²⁰

Pilot-scale Test Centers

Pilot-scale test centers (or platforms) have proven to be an effective approach to technology development while largely avoiding the complexities of domestic source policies. Examples include Technology Centre Mongstad (TCM) in Norway, the National Carbon Capture Center (NCCC) in the United States, and Canmet ENERGY's pilot-scale facilities in Canada. Only TCM at 12 MWe has the capability to test technologies at the scale contemplated by this Study. Nevertheless, there are similarities in how the facilities were conceived and are operated.

Facility construction was funded largely by the governments of the host countries along with industry contributions in some cases. The centers entertain and encourage collaborative projects including projects from outside of the host countries. Examples of multinational projects include:

- TCM, where ION Engineering from the

Figure 5-2 Technology Centre Mongstad



Source: Helge Hansen/TCM

¹²⁰ Although unrelated to domestic source policies, it was also noted that the Callide Project benefited from its small size and retrofit application which made permitting easier; from the fact that it was a discrete package with a planned start and finish; and from the fact that team members were mostly known from the outset and that the project was able to use a smaller implementation team than teams used on larger demonstration projects.

United States is testing its solvent capture system with financial support from the USDOE.¹²¹

- NRCan/CanmetENERGY, where The Gas Technology Institute (GTI), with support from the United States, is working with CanmetENERGY to validate the oxy-pressurized fluidized bed combustion process and mature the technology in a new 1 MWth test facility located at CanmetENERGY's facility in Canada.¹²²
- NCCC, where through March 2017, forty-five tests were either completed or are underway involving technology developers from the United States and six other countries.¹²³

Country funds are not pooled. TCM covers its own cost of test programs for items such as electricity and labor; technology developers cover their cost for equipment, solvents, and labor. In GTI's case, funds from Natural Resources Canada are used for the test facility and to fund R&D and test operations; USDOE funds are used by GTI for work within the scope of their DOE-funded project.¹²⁴ At the NCCC, technology developers do not pay for existing facilities or for normal NCCC operations, but do pay for their test unit costs and operating costs beyond normal operations. At all of the test centers, technology developers generally retain rights to background intellectual property rights (IPR) and the right to exploit newly developed project IPR.¹²⁵ Nonproprietary project information is disseminated through published reports, the International CCS Test Centre Network, and other means.

Pilot-scale test platforms work because countries have been willing to invest substantial funds in research infrastructure and then make it available at reasonable cost to the technology developers. It is uncertain how far the model can be extended to new and larger pilot-scale test platforms.

The current test center model has managed to avoid domestic source concerns that may challenge large collaborative pilots. Flexibility has helped. To illustrate, the USDOE includes a policy provision in its financial assistance agreements requiring a percentage of the direct labor element of project cost to be performed in the United States unless the recipient can demonstrate in their

¹²¹ See, Press Release, TCM, US Technology Developer Headed for TCM Mongstad (June 30, 2016), <http://www.tcnda.com/en/Press-center/News/2016/US-technology-developer-headed-for-Technology-Centre-Mongstad/>.

¹²² See, Press Release, GTI, U.S. and Canada Unveil Process to Generate Electricity and Heat with Zero Emissions (Oct. 18, 2016) <http://www.gastechnology.org/news/Pages/Process-to-Generate-Electricity-and-Heat-with-Zero-Emissions.aspx>.

¹²³ "NCCC Project Status Presentation" North American Energy Ministers Trilateral Meeting/Workshop #4, March 28-30, 2017.

¹²⁴ CanmetENERGY is a subrecipient to GTI under the DOE agreement. DOE has authorized GTI to expend up to 25% of project cost on foreign labor for performance of GTI's scope.

¹²⁵ The USDOE retains certain rights in project IPR as required by statute and regulations, but technology developers nonetheless receive, or are able to receive, exclusive rights to exploit project IPR. See Phase 1, Task 4 Report for a discussion of USDOE reserved rights. At TCM, the owners (Norway, Statoil, and Shell) receive full exposure to test data (but not company IPR) for use in their core business. Firewalls are put in place and disclosure terms negotiated as appropriate.

proposal to the satisfaction of the USDOE that the economic interest of the United States will be better served through a greater percentage of the work being performed outside the United States. Waiver or reduction of the percentage is at the discretion of the USDOE contracting officer. Traditionally, the USDOE Fossil Energy R&D Program set the United States labor percentage at 75%.¹²⁶ The provision has been cited as problematic for pilot projects located outside of the United States since project operations may involve a large amount of labor. Although waivers are available, the approval process can be time consuming. In a recent Funding Opportunity Announcement (FOA) seeking proposals for pilot testing of CO₂ capture technologies, and allowing for use of existing test facilities outside of the United States, the USDOE reduced the percentage to 50%.¹²⁷ Task 3 Participants noted that the reduction facilitated a capture project at TCM. It was also noted that the USDOE was able to recognize financial support provided by the host country to in-country project participants as eligible cost sharing under the USDOE agreement with the technology developer.¹²⁸

Lessons learned from the pilot-scale test centers include:

1. Extraterritorial test facilities can be a winning proposition for governments and technology developers if countries are willing to invest in projects conducted outside of their borders. They avoid the time and expense of building duplicate facilities and building up staff and operational expertise. And, they leverage country contributions thereby improving project financial viability.
2. The current test center financial model can mitigate issues caused by the national interest barrier.
3. Flexibility in domestic funding requirements can help achieve government program objectives. Assessment and adjustment of domestic source requirements in advance, when consistent with policy and program objectives, can facilitate project development.

ERA-NET ACT

ERA-NET ACT (Accelerating CCS Technology) is a “Cofund” scheme under the European Union’s ERA-NET framework which is designed to support public-public partnerships and joint programming initiatives between European Union Member States and other participants in the European Economic Area (EEA).¹²⁹

¹²⁶ See e.g. FOA #: DE-FOA-0001459, Pre-Project Planning for Advanced Combustion Pilot Plants (issued Jan 21, 2016).

¹²⁷ FOA #: DE-FOA-0001190, Small and Large Scale Pilots for Reducing the Cost of CO₂ Capture and Compression (issued Feb. 11, 2015).

¹²⁸ The USDOE typically requires at least 20% cost-sharing on R&D projects. Other US government financial support provided to project participants generally cannot be considered cost-sharing unless authorized by law. Other country funds provided to the project participants can be considered cost-sharing.

¹²⁹ ERA Coordination of Research Programmes, ERA-Net scheme, http://ec.europa.eu/research/era/era-net_en.html (last visited May 17, 2017).

The ACT Cofund involves nine countries and the European Commission (EC) contributing funds for a joint call for proposals related to CCS. Total funding commitments are €42 million. The ACT Call, issued in June 2016, sought proposals for large transnational projects and smaller transnational research and innovation projects. Project proposals could only be submitted by a project consortium consisting of at least three eligible applicants from at least two participating countries eligible for co-funding from the EC. National contributions are paid by the national funding body to that nation’s project team members. The multi-nation involvement and national funding limitation necessitated a tailored evaluation, selection and contract award process.

ACT is discussed in detail in Section 5.3.3, but it is noted here because it has formulated an approach to support collaborative CCS research in a competitive environment with the overlay of domestic source policies and practices.

5.3.2. Different national or regional CCS goals and strategies

Here, the challenge is in finding common ground among countries and regions with different technology development viewpoints and then incorporating that common ground into a collaborative mutually beneficial framework.

The Phase 1 Study identified overlap in research objectives among the four Study countries in both coal power generation and capture technologies. However, country objectives were not identical. The Report notes that successful collaboration requires an alignment of technology interests, development timelines, project size, and budgetary priorities and resources. During Phase 2 it became further apparent that material differences exist in national and regional fossil power generation and CCS technology development goals and strategies. See Table 5-1 for possible reasons why countries may choose to support fossil-based power and/or CCS technology development.

Technology development approaches are informed by goals and strategies. At the risk of over simplification, viewpoints and approaches can be summarized as shown in Table 5-4.

Table 5-4 Different Technology Development Perspectives

Viewpoint	Technology Development Approach
CCS is deployment ready	<ul style="list-style-type: none"> • Commercial demonstrations with state of the art technology to establish business case • Cost reduction through learning by doing and development of common transportation and storage infrastructure • Targeted R&D on capture and storage technologies
CCS cost-effectiveness must be improved	<ul style="list-style-type: none"> • Small and pilot-scale R&D on advanced and transformational power generation technologies and capture technologies that can substantially improve the combined cost-effectiveness of fossil-based power generation with CCS • Subsequent demonstration at commercial scale

Viewpoint	Technology Development Approach
Coal is falling out of favor	<ul style="list-style-type: none"> • RD&D on capture and storage technologies for the coal fleet • RD&D on gas power technologies and capture from gas power generation • Little or no interest in R&D or new coal power technologies
Coal and gas will comprise a substantial part of energy mix through mid-century and beyond	<ul style="list-style-type: none"> • RD&D on coal power technologies for new and existing plants • RD&D on new gas power technologies and capture from gas power generation

To illustrate the differences, coal-power interest is waning in Europe largely because of climate implications, and Europe is currently more interested in near-term demonstration of deployable decarbonization solutions for the power and industrial sectors.¹³⁰ Accordingly, the European Union’s Integrated Strategic Energy Technology (SET) Plan is focused on renewable and nuclear technologies in the power sector but not development of new coal power technologies.¹³¹ The SET Plan includes CCUS - targeting commercial-scale whole chain projects in the power and industrial sector; CO₂ transport infrastructure development; and, pilots on new capture technologies, storage, and production of fuels, chemicals, and other products from captured CO₂. By contrast, the United States, Japan, and Canada, and other countries still remain interested in developing advanced, more cost-effective coal-based power technologies as well as capture and storage technologies.¹³²

Technology development viewpoints are not likely to be changed through discussion and it is most likely unproductive to try. Instead, the preferred approach may be to acknowledge the fact that countries can reasonably differ and look for alignment of priorities and common technology areas for collaboration. Technology funding countries have roadmaps, program plans and other guidance documents that set the direction for RD&D activities and which can serve as the starting point in the search for common ground. And, countries have been sharing plans and objectives through international forums, such as the IEA and the Carbon Sequestration Leadership Forum for many years. More recently, 22 countries and the European Union established the Mission Innovation (MI) Initiative with the goal to dramatically accelerate global

¹³⁰ Full chain CCS projects in Europe include the Rotterdam Capture and Storage Demonstration Project (ROAD) in the Netherlands which will capture CO₂ from a new fossil fueled power plant with CO₂ storage under the North Sea, <http://road2020.nl/en/> (last visited May 18, 2017); and, Norway’s planned full scale CCS project which will capture CO₂ from industrial sites and transfer the CO₂ by ship to a storage facility on the Norwegian continental shelf. See Press Release, Ministry of Petroleum and Energy, Good potential for succeeding with CCS in Norway, <https://www.regjeringen.no/en/aktuelt/good-potential-for-succeeding-with-ccs-in-norway/id2506973/> (Apr. 7, 2016).

¹³¹ The EU plans on a regional basis through the development of a SET Plan. Information about the SET Plan and CCS targets can be found at <https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan>, and https://setis.ec.europa.eu/system/files/integrated_set-plan/setplan_doi_ccus-final.pdf (last visited May 17, 2017).

¹³² Assessment of US, Japanese, and Canadian interests are based on questionnaire results from the Phase 1 Study. See Table 4.1 Part A – Interest in Large-Scale Pilot Projects.

clean energy innovation including innovation in CCS. MI's scope includes information sharing on data, priorities, and plans - to facilitate stakeholder engagement and reveal collaboration opportunities among other objectives.¹³³

Reaching agreement on technology areas for collaboration does not appear to be an overwhelming task. Rather, the challenge is in developing an effective framework that can be used to implement the collaborative projects. A key objective of Task 3 is to look for opportunities to stream-line collaboration. Approaching each collaborative project as a new activity is resource intensive, time consuming for the governments and project participants, and not necessarily conducive to technology development and deployment goals. The European Union tiers technology specific program initiatives off of an overarching collaborative framework. Such an approach could be a model for a broader global collaboration on fossil power and CCS technologies if it could be developed and adopted in a reasonable time frame. Countries could elect to participate in specific interest areas in parallel with framework development. Interest areas could be divided as the countries deem appropriate such as by program (e.g., combustion) or specific technology (e.g., oxy-combustion). An alternative approach would have countries elect interest areas first, form interest specific country groups, and then develop collaborative frameworks tailored for each area.

Figure 5-3 Sequential Interest Group and Framework Development

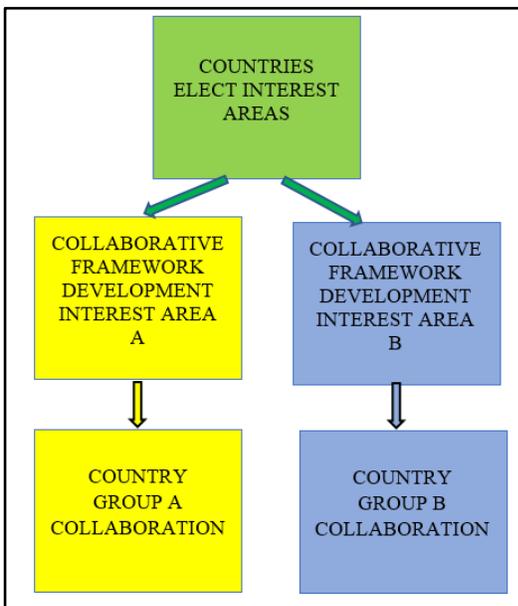
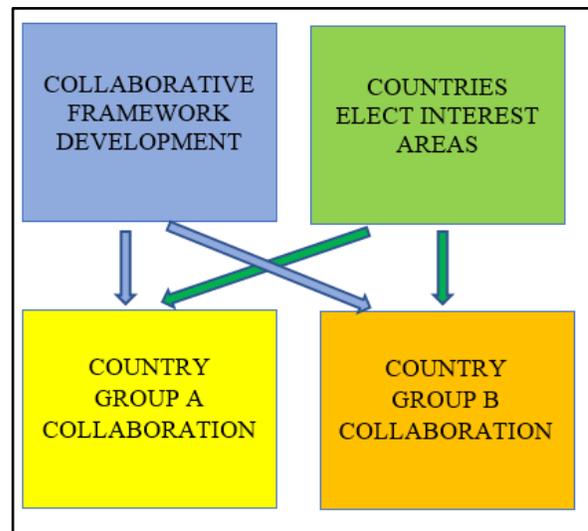


Figure 5-4 Parallel Framework and Interest Group Development



In theory, a 2-stage parallel development process could result in a faster product than the 3-stage sequential process. On the other hand, parallel framework development presumably involves a larger number of countries not all with the same interests, viewpoints and motivations. That may

¹³³ Mission Innovation, Accelerating the Clean Energy Revolution, <http://mission-innovation.net/> (last visited May 18, 2017).

slow framework development particularly if certain framework aspects are more applicable to one interest area versus another. Task 3 Participants observed that collaboration is easier when countries have similar problems, economics and cultures and is successful when national and commercial interests are aligned on a sustainable basis - suggesting that a 3-stage process may be more productive.

5.3.3. Differences in planning, selection and funding processes.

Regardless of the approach used to structure collaboration, frameworks must address fundamental issues. For collaboration to be minimally beneficial, joint planning is necessary along with agreement on scope, technology areas, coordinated timing of funding opportunities, and eligible project locations. This leaves matters such as selection processes, funding commitments, funding restrictions, applicant eligibility, IPR treatment, and project oversight to the discretion of the individual countries. The approach may be easiest for countries to implement since it treads the most lightly on existing country processes. However, the approach may not work well for large-pilot projects requiring multiple country funding for financial viability since the projects must be successful in two or more venues and then reconcile conflicts between the requirements of each venue. It also makes proposal selection risky for countries since projects relying on multiple country funds will have uncertainty in their financing plans. By contrast, the more countries cede decision making and process to a common authority, the more complex the collaboration and the more likely departures from existing processes will have to be evaluated and accepted. Yet, the one-stop-shop approach may prove best for large-pilot projects since projects will have financial certainty at the time of source selection and many intergovernmental conflicts can be resolved in advance during multilateral negotiations. Various collaborative models are outlined and discussed in more detail in Section 5.4. Past and current collaborations are examined here for lessons learned.¹³⁴

*ERA-NET ACT*¹³⁵

Discussed earlier in Section 5.3.1, ACT combines the financial and human resources of nine countries (the ACT Consortium) and the European Union to solicit, select, and award CCS projects of common interest.¹³⁶ It is worth addressing here in more detail both for its ingenuity in reconciling the CCS interests of many countries in a single action and for its complexity.

ACT was created specifically for transnational projects addressing any of five CCS thematic areas: Chain Integration, Capture, Transport, Storage, or Utilization. The ACT Consortium, with representation from each participating country, defined the scope, rules, and evaluation processes

¹³⁴ Noncompetitively awarded support is not a focus of this report since countries generally prefer competitive procedures. It is worth noting that when an international agreement specifies a particular project, it may serve as justification for awarding assistance on a non-competitive basis. For example, USDOE Financial Assistance Regulations permit the agency to provide financial assistance on a noncompetitive basis if “*The award implements an agreement between the United States Government and a foreign government to fund a foreign applicant.*” 2 C.F.R. § 910.126(c)(5) (2016).

¹³⁵ ACT information is derived from the ACT Call <http://www.act-ccs.eu/calls/>, and input from Task 3 Participants.

¹³⁶ The Research Council of Norway serves as the ACT Coordinator.

for the joint ACT Call. Participating countries determined the amount of their financial contributions which are set out in the Call. Each project proposal was required to be submitted by a project consortium consisting of at least three eligible applicants from at least two participating countries eligible for co-funding from the European Commission. The “Main Applicant” is responsible for running and managing the project and serving as the contact point with ACT on behalf of the project consortium. “Co-Applicants” are responsible for leading the project activities at their own organization. “Co-operation Partners” from countries not participating in the call, or partners that are not eligible for funding from participating agencies, may be included in the project consortium if (a) they finance their activity from other sources than ACT, and (b) the consortium in general fulfils the ACT requirement on the number of applicants from participating countries.

Applicants must comply with the rules of the ACT Call and each country participant in the project consortium must also comply with their specific funding agency rules such as eligibility criteria, co-funding requirements, national evaluation rules, and maximum funding per partner or per project. National funding agency rules are outlined in the ACT Call with cross links to the detailed requirements.

The Call uses a two-stage process where pre-proposals are first submitted, evaluated, and selected followed by full proposals from the selected consortia. Full proposals are evaluated by an independent international expert panel that ranks proposals according to the Call’s criteria. Based on the ranking by the panel, each country revisits the priorities to ensure that there is enough funding and to have a last say about project eligibility (i.e. “the national decision”). Thereafter, a joint policy board - where participants from all countries are represented - decide the grant. The ranking list cannot be broken. If the next in line project includes participants from a country that has already exhausted its budget on prior selections, that project could not be funded and the selection process stops unless the country agrees to provide additional budget or EC top up funding is used. Projects recommended for funding must have a signed consortium agreement between all partners prior to the start of the project, at least addressing the following topics:

- Internal organization and management of the consortium
- Intellectual property arrangements
- Settlement of internal disputes

Country funding does not cross borders. The ACT coordinator enters into a contract with the project consortium’s Main Applicant. Subcontracts are entered into by each funding nation and that nation’s consortium participant.

Project monitoring and reporting follows the respective funding agency’s rules. The Main Applicants are requested to deliver annual progress and financial reports to the ACT Call Secretariat. A project observer from one of the participating funding organizations will be assigned to each project to monitor the progress in transnational cooperation on behalf of the

participating funding organizations and to provide a communication link between the project, the Call Secretariat and the EC.

While the ACT approach may not directly transfer to much larger pilot projects, certain lessons can be learned:

1. A collaborative, competitive framework can be designed that takes into consideration national funding restrictions. However, managing national funding restrictions adds complexity for both the governments and the project proponents.
2. Design and implementation of such a program requires considerable time, coordination, and cooperation by the collaborating countries. ACT no doubt benefitted from well-developed intergovernmental relationships along with an existing overarching framework governing planning, R&D, and collaborative activities in Europe.¹³⁷ Those frameworks and relationships will not exist for more global collaboration on large-pilots and therefore framework development may take longer.
3. ACT involved nine countries and the European Union in a broadly scoped CCS program. Large fossil-based power technology and CCS technology pilot projects may not involve as many countries which may simplify collaboration. Tailoring the collaboration for specific technologies or technology areas may provide further simplification.

IEA-GHG Weyburn-Midale CO₂ Monitoring and Storage Project (Weyburn-Midale Project)¹³⁸

The Weyburn-Midale Project was another highly successful multi-country collaborative research activity. Carbon dioxide transported by pipeline from the Dakota Gasification Plant in North Dakota to the Weyburn oil field in Saskatchewan enabled a life extension for the field while at the same time providing an excellent opportunity at Weyburn and the adjoining Midale fields to investigate the long-term fate and security of the injected CO₂. The Project had strong industrial support from the early days. National and provincial governments along with the industrial participants sponsored the project providing cash and in-kind contributions. Over its 15-year run, the Project produced invaluable data, knowledge, and tools for geological characterization, and CO₂ injection, monitoring, and storage.

The Project functioned through a management committee called the Lead Sponsors Executive Committee. The Committee met regularly to review and approve suggested research projects from research scientists at universities and research councils. The Petroleum Technology Research Centre (PTRC) in Saskatchewan chaired the Committee and was responsible for receiving and managing funding from the various sponsors, managing data collection and

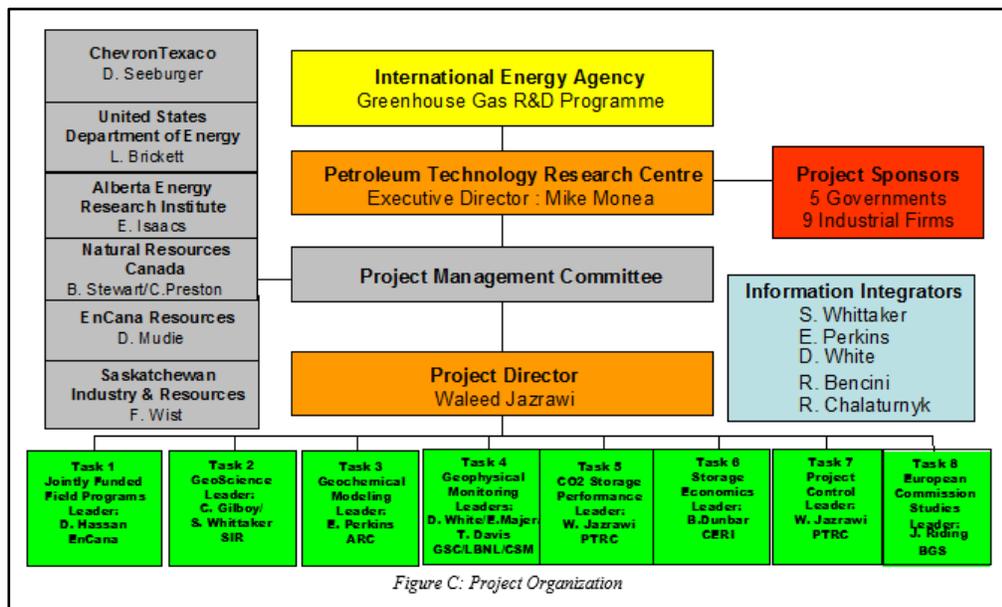
¹³⁷ The Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020) lays out the overarching rules for participation and dissemination of result for R&D activities supported by EU member states and non-member participants in the European Economic Area (EEA). ERA-NET is a subordinate scheme under Horizon 2020. ACT is a CCS initiative under ERA-NET. Detailed information about Horizon 2020 is available at: <https://ec.europa.eu/programmes/horizon2020/>

¹³⁸ Information about the Weyburn-Midale Project comes from published reports and discussions with individuals involved in the project.

storage, and, managing knowledge sharing among researchers and project funders. Government funding was provided to PTRC through various agreements and pooled to cover project cost without conditions limiting the funds to work by domestic entities.

The Weyburn-Midale organizational structure during the Project’s first phase is depicted in Figure 5-5.

Figure 5-5 Weyburn-Midale Project Organizational Structure



Source: Figure C "IEA-GHG Weyburn CO₂ Monitoring and Storage Project Summary Report 2000-2004." Image Courtesy of the Petroleum Technology Research Council (PTRC).

Weyburn-Midale differs from some large-pilots contemplated by this Study in that the Project did not set out to develop a particular commercially owned technology or technologies. Instead, the driver for the Project was the knowledge that would be obtained. Weyburn-Midale lessons learned include:

1. The project was conceived, developed, and matured through the combined efforts of industry and government thereby supporting the concept that the involvement of, and acceptance by, both the public and private sector on project design and objectives is important to the success of a collaborative research initiative.
2. The integrator role performed by PTRC is an important function seen in other successful collaborative project and programs. (e.g. Oxyfuel Technologies Pty Ltd. served as the integrator for the Callide Project and the ACT Call requires a Main Applicant to take the lead for the project consortium.)¹³⁹

¹³⁹ Task 3 participants commented on the importance of a private sector integrator.

3. Pooling of government funds without country restrictions provides flexibility and can be done when sponsor motivations align.
4. Weyburn-Midale was not created under the auspices of a multilateral agreement. The Project demonstrates that a formal agreement is not always necessary for successful collaboration if sponsors can otherwise arrive at a mutually acceptable arrangement.
5. Hybrid government/private sector project management can work in certain circumstances. However, it is noted that some Task 3 participants supported a clear division of authority where the project proponent manages project activities.

Other Approaches

Task 3 considered the concept of implementing a collaborative large-pilot program through organizations that are not government agencies. Such organizations may include non-profit research institutions, academia, private sector consortia, or, government created and owned companies. Governments have utilized this mechanism to conduct R&D programs and other initiatives. Examples are provided below.

CERC-ACTC. The United States -China Clean Energy Research Center (CERC) is a partnership to accelerate the development and deployment of advanced clean energy technologies. The CERC-Advanced Coal Technology Consortium (CERC-ACTC) is a collaboration between United States and Chinese consortia with the mission to facilitate a portfolio of smaller scale, joint R&D projects on fossil-based technologies including clean power generation, clean fuels, and CCUS. The West Virginia University Research Corporation (WVU) is the lead for the United States side and receives funding from the USDOE through a financial assistance cooperative agreement. CERC-ACTC's annual budget is \$5 million split equally between the USDOE and the private sector. USDOE funds are subject to annual Congressional appropriations. WVU recruits membership from private sector institutions and research universities in order to raise the matching funds required by the agreement. Consortium and project participants include utilities, industry, academia and research institutions from both countries. USDOE funds are used to issue calls for collaborative projects between United States and Chinese entities for United States supported CERC-ACTC activities. Collaborative project funding is separately funded by each country - United States and Chinese government funds go to United States and Chinese participants respectively. Collaborative interests in developed and shared intellectual property are handled through a bi-lateral Technology Management Plan protocol. Now in its 7th year, the CERC-ACTC is funding R&D into pressurized oxy-combustion, chemical looping, post-combustion carbon capture, base-load control and grid strategies to deal with intermittency, advanced coal conversion technologies, and algae-based CO₂ absorption.¹⁴⁰

¹⁴⁰ Information about CERC and CERC-ACTC and its programs and projects is available at U.S.-China Clean Energy Research Center, http://www.us-china-cerc.org/Advanced_Coal_Technology.html (last visited May 18, 2017).

ANLECR&D. The Australian National Low Emission Coal Research and Development (ANLEC R&D) initiative was launched in 2010 by the Australian Government for the purpose of implementing a nationwide program for low emission coal research and development. ANLEC R&D is a not-for-profit organization funded by Australia's Department of Industry, Innovation and Science and by ACALET through Australia's COAL21 Program. The organization's mission includes developing – through applied R&D - the knowledge and skills needed to reduce the investment risk of low emission coal technology, and hence accelerate development and deployment in Australia. ANLEC R&D's portfolio exceeds AU \$100 million covering over 25 institutions throughout Australia.¹⁴¹

ERIC and ECCSEL. European Commission Council Regulation No 723/2009 of 25 June 2009, established a “Community legal framework for a European Research Infrastructure (ERIC).”¹⁴² The Regulation was motivated by the need for a legal framework that would facilitate and stimulate the establishment and operations of new research infrastructure at the Community level. ERICs are established by scientific and technology field. They are international organizations with separate legal personality. An ERIC's authority includes the right to acquire, own and dispose of movable, immovable and intellectual property; conclude contracts; and, be a party to legal proceedings. The following entities may become ERIC members: (a) Member States; (b) associated countries; (c) third countries other than associated countries; and (d) intergovernmental organizations. Entities seeking to establish an ERIC must apply to the Commission and at least three Member States must be included. Other entities may join later. Thirteen ERICs have been approved by the Commission and, as March 2017, the ERIC website shows that four applications are pending. The European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) is being structured as an ERIC. ECCSEL's stated mission is “to implement and operate a European distributed, integrated Research Infrastructure initially based on a selection of the best research facilities in Europe for CO₂ capture, storage and transport research.” Countries will form an infrastructure HUB. Some existing facilities will be upgraded and new facilities are planned to be added. Infrastructure will be funded by national funds from different countries. Researchers wishing to use ECCSEL infrastructure will seek research support from countries. Space is allocated by a HUB Committee based on researcher proposals.¹⁴³

Oxburgh Report. Although not a project or program, it is also worth noting the 2016 Report to the United Kingdom Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on CCS.¹⁴⁴ As an alternative to earlier approaches that were not

¹⁴¹ Information about ANLEC R&D and its programs and projects is available at Australian National Low Emissions Coal Research Development, <http://anlecrd.com.au/> .

¹⁴² ERIC information and the Regulation is available at: https://ec.europa.eu/research/infrastructures/index_en.cfm?pg=eric-landscape (last visited May 18, 2017).

¹⁴³ ECCSEL, About ECCSEL, <http://www.eccsel.org/Sections.aspx?section=480> (last visited May 18, 2017).

¹⁴⁴ Parliamentary Advisory Group on CCS, Lowest Cost Decarbonisation for the UK: The Critical Role of CCS, Report to the Secretary of State for Business, Energy and Industrial Strategy from the Parliamentary Advisory Group on Carbon Capture and Storage (CCS) (Sept. 2016), file:///C:/Users/bad/Downloads/Parliamentary_Advisory_Group_on_CCS_-_Final_report.PDF

successful, the Advisory Group recommended establishment of a CCS Delivery Company (CCSDC) that would initially be government owned, but could later be privatized. The CCSDC would be responsible for managing the full-chain CCS risk and for development of common CO₂ transport infrastructure which could be accessed by power companies and other emitters for a fee. The recommendation states that *“The CCSDC will comprise two companies: “PowerCo” tasked with delivering the anchor power projects at CCS hubs and “T&SCo” tasked with delivering transport and storage infrastructure for all sources of CO₂ at such hubs.”*¹⁴⁵ The Report finds that CCS technology and its supply chain are fit for purpose and that full chain CCS cost can achieve £85/MWh under conditions set out in the report – thereby being price competitive with other forms of clean electricity. The Report encourages early decisions and indicates that there is no need to wait for additional international projects or technology development.

Lesson learned from the slate of other approaches include:

1. It is not uncommon for governments to use non-governmental entities to implement program initiatives both large and small. Accordingly, the approach may be an option worthy of consideration for large-pilots.
2. A portfolio of pilot projects will require a large amount of combined government support – theoretically in the multibillion-dollar range. The non-government entity approach may present a convenient vehicle to attract non-governmental support to help underwrite project cost (e.g. voluntary industry levies).

5.3.4. Impact of changing national policies and priorities on long term projects

Large-scale CCS projects can suffer from changing national policies and priorities. Task 3 participants remarked that sustained political support is important for success. To the extent countries can, in the near term, establish technology development and CCS capacity development as long term strategic policy, technology development and deployment efforts will benefit. Nevertheless, changing priorities are a fact of life that is beyond the scope of this Study to address. However, there may be ways to structure collaboration on a large-pilot program to reduce the impact of policy cycles on projects and project developers.

Large-pilots may have less exposure to changing priorities than demonstration projects due to the fact that they are smaller in size, less expensive, easier to permit, and theoretically shorter in duration. The last point may be particularly important since longer projects are more susceptible to policy cycles.

One option to shorten project duration discussed earlier in the Report is to design the collaboration so that all government support is awarded concurrently or near concurrently rather than sequentially. Concurrent funding permits a project financial investment decision earlier than sequential funding thereby reducing the development phase of a project.

¹⁴⁵ *Id.* at 5.

Scoping pilots so that they are as simple as possible while still achieving program objectives may also shorten project duration. For example, certain technologies and components may be successfully tested at large-pilot scale without integration into a system that produces electricity or other marketable products. Simple reduces cost, reduces permitting time, and may create more host site options. But simple also reduces the opportunity for revenue streams that can offset project cost. And, as noted earlier, integrated systems with multiple technologies may provide greater opportunities for project teams to divide the work to satisfy country domestic funding restrictions. Compromises between time and economic must be considered.

Requiring project proposals, teaming arrangement, and private sector cost-sharing to be as mature as possible at the proposal stage could also shorten the project development period. However, fully configured projects involve considerable effort, time, and cost on the part of the project proponents which may reduce interest. A two-stage proposal process like that used by ACT and other governments may be more suitable where pre-proposals are first submitted, evaluated, and selected followed by full proposals from the selected projects.

Project implementation through a non-government entity, as discussed in Section 5.3.3, may also provide some measure of insulation from changing priorities if sufficient funds are committed in advance to allow the entity to manage policy fluctuations.

5.3.5. Management of intellectual property rights.

Intellectual property rights (IPR) are viewed as a potential issue for multilateral collaboration. During Phase 1 of the Study and again in Phase 2, it was observed that countries fundamentally approach IPR in a similar fashion in their financial support agreements:

1. Technology developers retain background IPR.
2. Technology developers receive (or are able to receive) exclusive rights to exploit newly developed IPR subject to country specific and project specific reservations.
3. Knowledge sharing and public dissemination of non-proprietary project information is encouraged and often required in government support agreements.

Furthermore, collaborating countries and regions have long resolved IPR issues among themselves in their formal Science and Technology Agreements and through other agreements.

Despite the seemingly common philosophy, it is nevertheless perceived as an area that can hinder project development if not addressed early in the process.¹⁴⁶ This may be due to IPR complexity and the stakes involved. Lessons learned from past activities suggest that the impact of IPR issues on large-pilot projects may be mitigated if:

¹⁴⁶ See, L.D. Carter, *Technical Workshop Report, An Industry View: Advancing the Next Generation of Coal Conversion Technologies* at 21 (Nov. 18-19, 2014), https://media.wix.com/ugd/80262f_0e0ffae694454287ad5a14998327d3f2.pdf.

1. Countries follow their normal practice of resolving intergovernmental IPR issues in the collaborative agreement – taking into consideration the interests and concerns of technology developers and other project stakeholders.¹⁴⁷
2. Government IPR requirements are fully explained to prospective project proponents in advance; and,
3. Project team members are required to resolve their IPR agreements early on in the process such as with the ACT Call which requires a signed consortium agreement prior to project start addressing among other things the consortium’s IPR arrangement, or CERC through its bi-lateral Technology Management Plan executed by both governments and subsequently by the members of the United States and Chinese Consortia.¹⁴⁸

5.4. Effective Collaborative Models

This Section describes models that may prove effective for multilateral collaboration on large fossil-based power and CCS technology pilot project. Variants or additional models may also be effective. Features that should be weighed when evaluating models include:

Concurrent award of financial support. Concurrent support reduces project financial risk and reduces the time required for projects to reach a financial investment decision thereby benefiting funding governments and project developers. It is reflected in all of the models outlined below through various approaches.

Ability to accommodate national requirements. The presumption is that like-minded countries will explore flexibilities in their requirements to further collaborative objectives. Nevertheless, models that cannot satisfy essential funding country requirements should be viewed unfavorably.

Early resolution of conflicting requirements. Projects will benefit if intergovernmental conflicts are resolved in the collaborative framework rather than reserved for post-project selection. Models that include early identification and resolution of issues would be more favorable.

¹⁴⁷ During Task 3 discussion, it was noted that jurisdictional issues related to disputes can arise when multiple sovereigns are involved. In the IPR arena, international agreements have addressed disputes among participants. For example, Article I.D. in the IPR Annex to the United States – European Science and Technology Agreement states: “Disputes concerning intellectual property arising under this Agreement should be resolved through discussions between the relevant participants, or, if necessary, the Parties. Upon mutual agreement of the Parties, the participants may submit a dispute to an arbitral tribunal for binding arbitration. Unless the participants agree otherwise in writing, the arbitration rules of UNCITRAL shall govern.” Agreement for Scientific and Technological Cooperation Between the European Community and the Government of the United States, Annex Intellectual Property Art. I.D., Dec. 5, 1997, [http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:21998A1022\(01\)&from=EN](http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:21998A1022(01)&from=EN).

¹⁴⁸ Several Task 3 participants noted that the CERC Technology Management Plan greatly facilitated collaboration. Technology Management Plan (Regarding the exploitation of Intellectual Property Rights) for the CERC-ACTC (Aug. 19, 2011), http://www.us-china-cerc.org/pdfs/CERC-ACTC_TMP_19_Aug_2011.pdf

Time required for framework development. Information developed during Phase 1 of this Study suggests that countries supporting advanced technology development are targeting 2025-2035 for technology deployment.¹⁴⁹ By that standard, pilot testing, and in most cases, commercial demonstration must occur within the next 10-20 years. Global climate objectives favor even faster development and deployment. Collaboration that takes many years to develop may not be very useful, hence, framework complexity and the time to reach agreement should be considered.

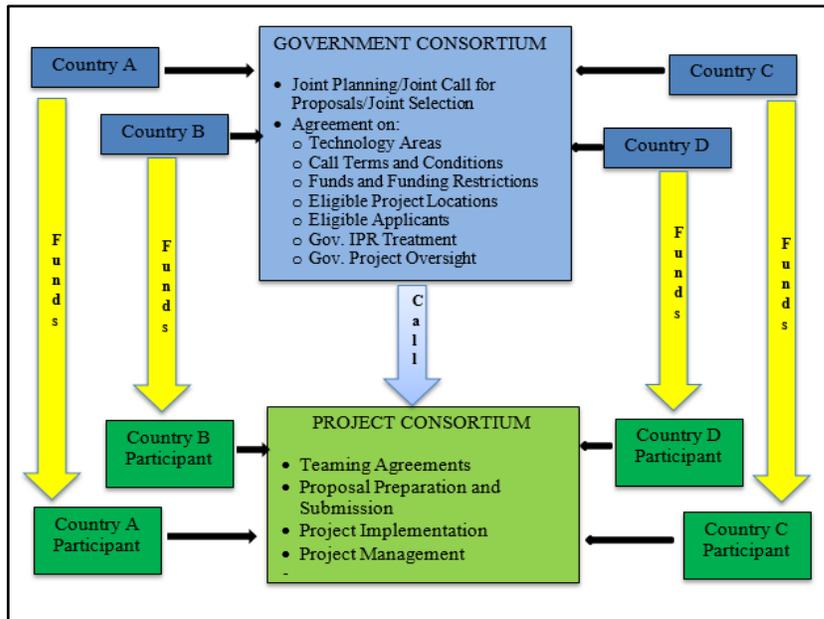
Ability to limit project impact from changing national priorities. While difficult to achieve, collaborative frameworks that limit the risk of changing national priorities would be more favorable.

Acceptability to industry stakeholders. Task 3 Participants recognized the importance of public support and the responsibility of governments for development of collaborative frameworks and project oversight. However, participants also saw value in industry involvement and industry led projects. Collaborative frameworks that do not take into consideration industry perspectives may be less acceptable private stakeholders

5.4.1. Joint planning, combined call for proposals

Joint planning with a combined call for proposals is an ERA-NET type approach where countries may agree on such matters as scope, eligible applicants, eligible project locations, terms of the call, process, evaluation and selection criteria, funding and funding restrictions, IPR treatment, and government oversight of the projects. Calls may be technology area or technology specific to accommodate varied national interests. If national funding is restricted to in-country entities, funding could be provided through agreements between each country and their project participant as depicted in Figure 5-6. Or, if countries agree to pool their funds without absolute restriction to in-country entities, funds could be transferred to a single country who would contract with the project consortium or alternatively each country could directly fund the consortium.

Figure 5-6 Joint Planning, Combined Calls for Proposals



¹⁴⁹ See Phase 1 Report, Task 4. op. cit.

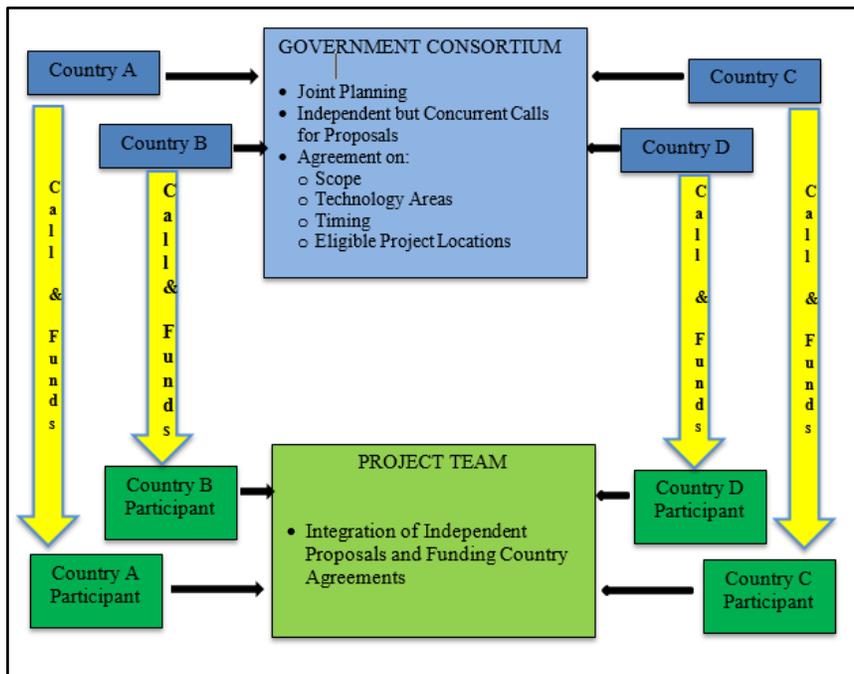
Large projects often need multiple government sponsors for financial viability. This model has the significant advantage of added certainty for both the project proponents and the countries. Intergovernmental conflicts can be resolved in advance in the collaborative framework. Proponents and governments know how much support a project will receive at selection thereby avoiding the need for a project to seek support from individual country sponsors with potentially conflicting requirements that must be reconciled. Concurrent funding should also reduce risk in a project's financial plan. Together, these features can lead to shorter project implementation time and a higher probability of success. Flexibility in domestic funding restrictions can further facilitate projects.

The most significant disadvantage of the model is the time it would take to develop a collaborative multilateral agreement. Many complicated issues must be resolved by the collaborating countries. Furthermore, the model deviates from normal procurement and grant practices which may present challenges for some countries.

5.4.2. Joint planning, independent calls for proposals

Joint planning with independent calls for proposals, depicted in Figure 5.7, may be viewed to contain the minimum features needed for effective collaboration. Countries agree on matters such as scope, technology areas, timing, and eligible project locations and then independently, but concurrently, issue calls within their interest areas. Projects are selected without country coordination. Countries fund their selected projects.

Figure 5-7 Joint Planning, Independent Calls for Proposals



The model leaves many matters to the discretion of the collaborating countries including selection process, funding amounts and restrictions, applicant eligibility, IPR treatment, and project oversight.

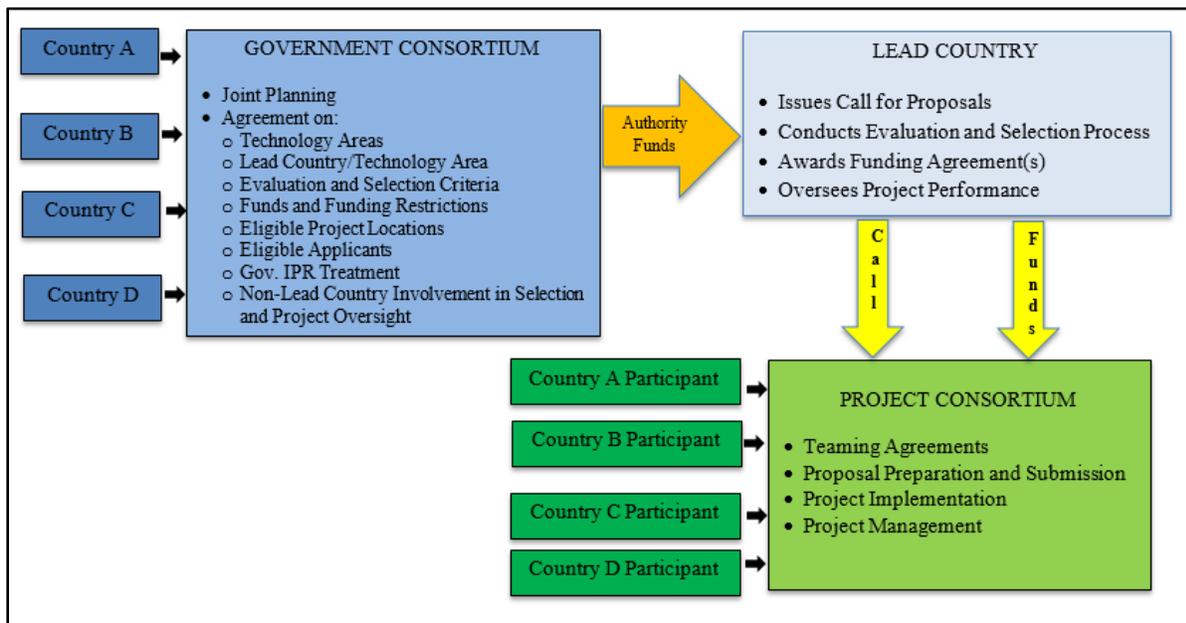
The approach has not been not endorsed by any Task 3 participant, but it is presented here because it may be the easiest and quickest for countries to implement since it avoids the most contentious questions and it has less impact on existing procurement and grant processes than

other models. The model is not ideal for large-pilot projects requiring multiple country funding since projects must be successful in multiple venues and then reconcile conflicts between the requirements of each country. Uncertainty and the risk of project financial viability is greater than in a joint call approach. Risk and uncertainty may be reduced if countries resolve additional matters as part of their collaboration.

5.4.3. Pooled funding in a lead government

With the pooled funding model, depicted in Figure 5-8, countries agree on matters such as scope, eligible applicants and project locations, evaluation and selection process, funding and funding restrictions, IPR treatment, and oversight. The collaborators also agree on a single country to take the lead for a technology area, issue the call for proposals, awards contracts or grants, and oversee project implementation. Country funds are transferred to the lead government.

Figure 5-8 Pooled Funding in Lead Government



The model provides the distinct advantage of a single interface point between the countries and the project proponents and, like the joint planning/combined call approach, also provides a higher degree of financial certainty and less risk at project selection. It also eliminates redundancy in country procurement or grant activities.

As with the other models that require countries to cede substantial independent authority, the most significant disadvantage of the model is the time it would take to develop a collaborative multilateral agreement. Countries must also have the authority to transfer to, and receive funds from, another sovereign. During Task 3 discussions, it was noted by a participant that the pooled approach was considered but found to be too much of a reach. The approach may also be less attractive to project developers who are comfortable with home country processes.

5.4.4. Global Pilot Project Organization.

With the Global Pilot Project Organization, depicted in Figure 5-9, collaborating countries enter into a multilateral agreement to establish a new international organization with the authority to receive funds from governments and third parties and use those funds to establish a portfolio of large fossil-based power and CCS technology projects.

The Organization would have legal personality meaning that it has, among other rights, the authority to acquire and own property, contract, and sue and be sued. The role of the collaborating countries in managing the organization and the organization's authority and governance would be established in the agreement and organizational documents.

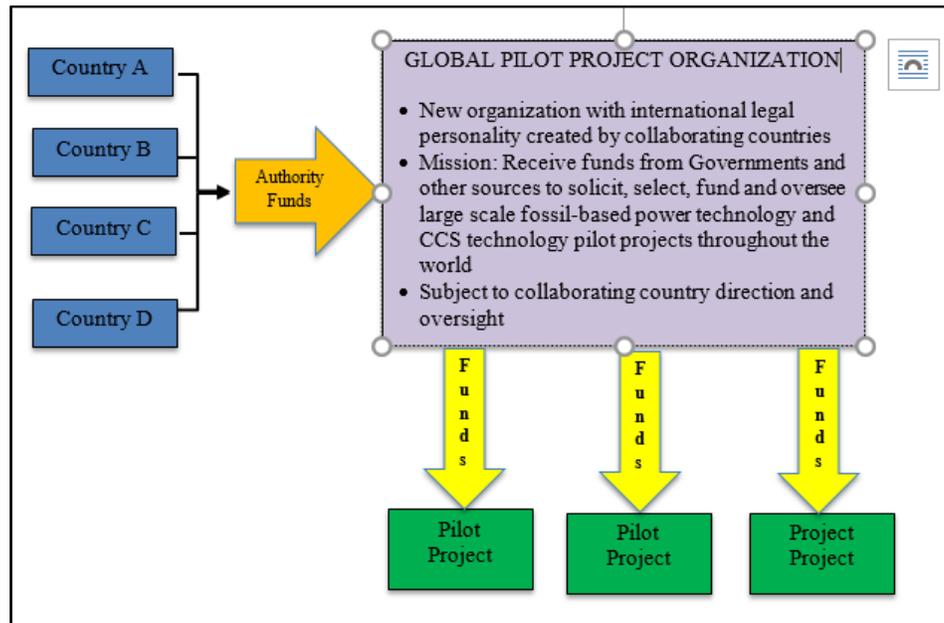
This type of model has been used for major multilateral research initiatives, such as CERN (The European Organization for

Nuclear Research) and ITER (The International Fusion Energy Organization for the Joint Implementation of the ITER Project).¹⁵⁰

The model shares common beneficial features with the pooled funding model. It provides a single interface point for governments and project proponents, a higher degree of financial certainty and less risk at project selection. It eliminates redundancy in country procurement or grant activities. It may also afford a measure of insulation from policy and priority cycles if sufficient country funds are committed in advance to allow the organization to manage fluctuations

Initiatives such as CERN and ITER could be characterized as long-term fundamental research. A key issue with the model is whether it can be tailored to be effective for a large applied research program the purpose of which is to test, develop and ultimately deploy privately owned

Figure 5-9 Global Pilot Project Organization



¹⁵⁰ Information about CERN can be found at <https://home.cern/about>; Information about ITER can be found at: <https://www.iter.org/>.

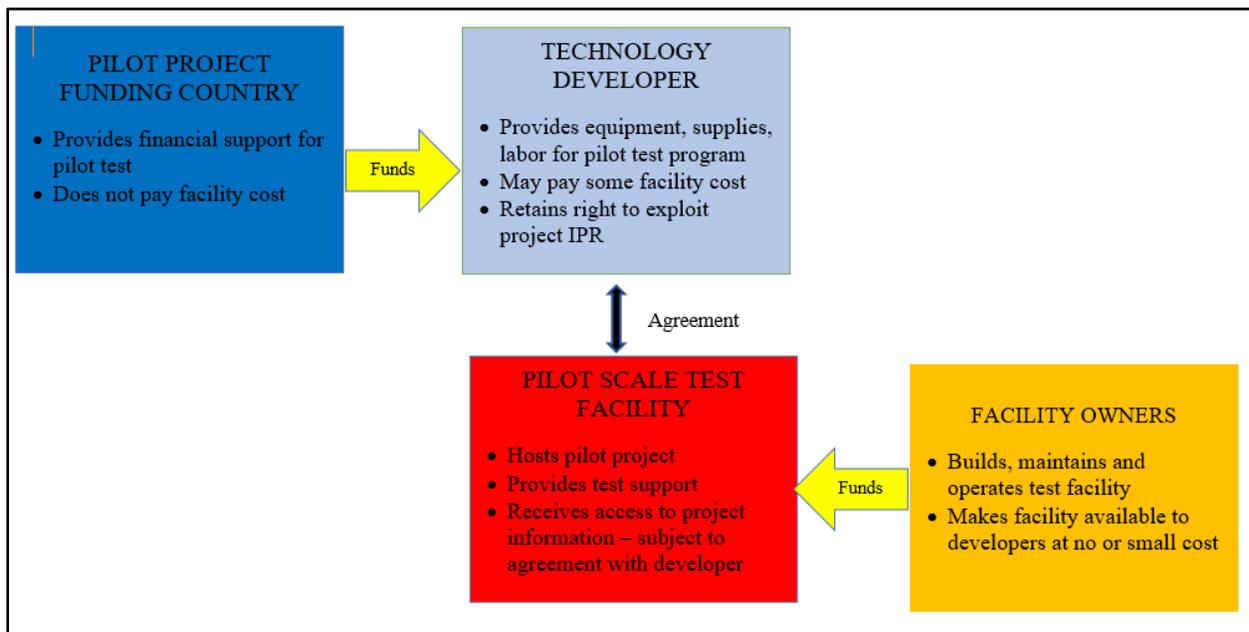
technologies within finite timeframes. Here again, the significant disadvantage of the model is the substantial time it would take to develop the agreement. The relationship and governance structure would be complex and require countries to cede considerable authority to the Organization. Going from concept to agreement may take many years.

An alternate approach that may produce similar results and be faster to implement would have countries individually provide support to a common private sector entity or nonprofit organization who would manage a large-pilot plant portfolio for a particular technology area. The entity would issue the call for proposals and enter into funding agreement with the selected projects. The Countries must still resolve the material matters addressed in the other models and impose the mutually agreeable rules and requirements upon the implementing entity. They must also justify the support under their own laws, regulations, and procurement or grant processes.

5.4.5. National Test Facility

Existing test centers have already proven the model depicted in Figure 5-10 to be effective for collaborative R&D projects.

Figure 5-10 National Test Facility



Beneficial features of the test facility model include:

1. The facilities are established by the host countries as an efficient mechanism to test new technologies and further program and policy objectives.
2. The platforms are available for testing of private sector technologies, including technologies from entities outside of the host country.
3. Country funding restrictions can be mitigated or avoided by the allocation of cost between the test facilities and the technology developers and their sponsors.

The primary questions with the model in the context of large-scale pilots are whether it can be extended to more platforms and to larger power and CCS technology pilots in the range contemplated by this Study.

Where a single technology type needs to be piloted and integration into a power plant is not considered to be crucial (e.g. in terms of learnings, experience, performance, etc.), having a platform for technology evaluation that is accessible by a range of technology suppliers is most cost-effective as resources can be shared. The model has worked well for post-combustion CO₂ capture testing with facilities like TCM and NCCC. Given that there are multiple suppliers of first generation technology and ample ongoing work on the next generation technologies, there could be a high need for such platforms. The model may also work, for example, for pre-combustion pilots where CO₂ and H₂ separation technologies might be evaluated for syngases before and after the shift.

The single platform model for technology evaluation becomes more complicated for new energy cycles or processes where, for example, there is significant recycling of gas streams, and/or where there are significant benefits anticipated from the integration of technologies such as gas separation, combustion, heat transfer. Additionally, the economic advantages gained from platform reusability may also be limited for larger energy cycle pilots.

5.5. Next Steps

The purpose of this Study was to explore multilateral collaboration as an option to support large-scale, fossil-based power and CCS technology pilot projects. The Study does not presume how governments should approach collaboration.

A possible next step for governments considering formal collaboration on large-pilot projects may be to test the thesis of this Study by engaging each other, technology developers and technology users to assess whether:

1. There is sufficient common interest among country groups in fossil-based power and CCS technologies to warrant collaborative initiatives at the large-pilot scale;
2. There is a pathway to resolve potential framework barrier issues in a reasonable timeframe that will allow such projects to contribute to desired deployment timeframes; and,
3. Technology developers and users have an interest in participating in collaboratively funded projects.

6. Appendices

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