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# CCS Demonstration in Developing Countries: Priorities for a Financing Mechanism for Carbon Dioxide Capture and Storage

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## Executive Summary

### CLIMATE CHANGE AND CCS

In facing the challenge of mitigating global climate change, world leaders have acknowledged that no single solution exists, and therefore, a portfolio of carbon dioxide ($CO_2$) reduction technologies and methods will be needed to successfully confront rising emissions. Due to their dependency on fossil fuels, the energy supply and industrial sectors are the greatest contributors to $CO_2$ emissions, accounting for 25.9 percent and 19.4 percent of the total respectively.[1]

In addition to efficiency improvements and enhancing clean energy use, one key option for limiting future $CO_2$ emissions from fossil fuel energy use is carbon dioxide capture and storage (CCS). CCS is a suite of technologies integrated to capture and transport $CO_2$ from major point sources to a storage site where the $CO_2$ is injected down wells and then permanently trapped in porous geological formations deep below the surface. Candidates for CCS technology include fossil fuel power plants; steel, cement, and fertilizer factories; and other industrial facilities.

### CCS IN DEVELOPING COUNTRIES

Despite often-aggressive programs to promote energy efficiency and deploy nuclear, renewable, and other low-carbon energy sources, many developing countries will still rely heavily on fossil fuel energy to power their development for decades to come. There is therefore a need for developing countries to create strategies that address fossil fuel emissions in a way that minimizes the costs of doing so, and consequently minimizes impacts to their national development goals.

CCS is currently the only near-commercial technology proven to directly disassociate $CO_2$ emissions from fossil fuel use at scale. Its deployment could potentially allow developing countries to gradually shift away from fossil fuels for energy and industrial needs with relatively little disruption to their long-term development strategies. If deployed as an interim measure, it could allow time for other alternative low-carbon technologies

**WRI and CCS**

This working paper is one in a series of publications that the World Resources Institute (WRI) has published on carbon dioxide capture and storage (CCS). Our work on this topic is not designed to endorse the technology, but rather to explore whether and how society might safely move forward with CCS projects as part of a broad climate mitigation strategy. In 2008, WRI published well-received Guidelines for Carbon Dioxide Capture, Transport, and Storage (see www.wri.org/publication/ccs-guidelines). This first attempt to develop best practices to responsibly implement CCS projects was based on a broad stakeholder process where WRI convened experts from academia, industry, and non-governmental organizations (NGOs) from the United States. In addition, WRI published guidelines for local community engagement on CCS projects in the fall of 2010. These had the input from experts and communities from nine countries around the world and cover potentially contentious issues for CCS project development in relation to disclosure of information, community engagement in the review and approval of plans, and public participation in general. Additional publications include briefs on CCS development in two critical markets: the European Union (EU) and China.

**WRI and the CCUS Action Group**

While WRI does not advocate or oppose the development of CCS, it does proactively engage with governments, international institutions, and businesses on this emerging technology. Through these engagements, WRI's objective is to ensure that, if pursued, CCS development must follow five key principles under any context: i) protect human health and safety; ii) protect ecosystems; iii) protect underground sources of drinking water and other natural resources; iv) ensure market confidence in emissions reductions through proper greenhouse gas accounting; and v) facilitate cost-effective and timely deployment of the technology. In this spirit, WRI joined the Carbon Capture Use and Storage (CCUS) Action Group to ensure these principles are upheld in the Group's recommendations to the Clean Energy Ministerial.

WRI led a workshop with CCUS Action Group members in October 2010 to discuss financing options for CCS in developing countries. Representatives from the governments of Australia, Canada, Norway, Scotland, the United Kingdom, and the United States, as well as participants from the Asian Development Bank, the Clinton Foundation, the Global CCS Institute, and the World Bank were present. The insights and conclusions from this meeting helped to identify the prevailing landscape and the views of key global actors who would likely be the main drivers in introducing new financing options for CCS development in developing countries; they therefore informed part of the framing and assumptions in this paper.

For information on the CCUS Action Group and its membership please see www.cleanenergyministerial.org.

to be developed and deployed, permitting fossil fuels to be gradually phased out. This strategy could assist developing countries to transition to a low-carbon economy in the next 15–50 years.

While CCS is potentially attractive to some developing countries, there has been limited development of demonstration projects in Africa, Asia, or Latin America due mainly to their high cost in the absence of expected profits or significant carbon financing. The International Energy Agency (IEA) estimates the total cost for a new average-sized coal-fired power plant that captures up to 90 percent of its $CO_2$ emissions to be US$1 billion over 10 years.

Existing financing for CCS is grossly insufficient to enable demonstration projects in developing countries. The few available funds are either spread over the full array of low-carbon technologies, or fall short of the magnitude or the mandate needed to propel commercial-scale CCS demonstrations forward. Current carbon offset mechanisms are not sufficient to spur CCS deployment in developing countries in today's context either. Overall, existing CCS financing mechanisms help grow capacity, but their support is insufficient to leverage enough funding from capital markets to implement projects in a non-OECD context.

The IEA CCS Roadmap proposes 50 CCS projects in developing countries in the next 10 to 20 years. As well as reducing the developing world's greenhouse gas emissions, accelerating CCS demonstration efforts in non-OECD countries can likely also improve technologies, increase efficiency, reduce uncertainty and risk, and initiate learning-by-doing at a lower cost than would be possible in OECD countries. The captured benefits from doing so will be more significant the sooner acceleration in CCS development in developing countries begins.

## ABOUT THIS PAPER: TOPICS OF DISCUSSION FOR FINANCING CCS IN DEVELOPING COUNTRIES

This paper seeks to promote the effective deployment of CCS demonstration projects in developing countries. Aimed at international policymakers and agencies engaged in CCS funding and deployment negotiations and discussions, the paper explores some of the key issues emerging around this critically important topic, and it presents a series of options and recommendations to international policymakers. WRI's aim is to assist the initial design of an effective approach for financing CCS demonstration projects in developing countries over the next 10 years. Below is a summary of the key topics and options explored in the paper.

## TOPIC 1: AIMS OF FINANCING CCS DEMONSTRATIONS IN DEVELOPING COUNTRIES

- The main goal for developed countries to provide financing for early-stage CCS demonstrations in developing countries should be to support non-OECD countries in fulfilling their share in global climate change mitigation efforts.

- A financing mechanism for CCS in developing countries should aim to foster tangible $CO_2$ emission reductions through a clear focus on storage goals. The level of ambition for $CO_2$ storage should support current CCS deployment requirements in developing countries. While it is impossible to objectively ascertain what proportion of this total a dedicated OECD country–funded CCS financing mechanism should support, it is evident that developing countries will need support for a significant share of these projects.

- Implementing CCS demonstrations that lead to the storage of 45–60 million tons carbon dioxide ($MtCO_2$) over 10 years could significantly spur the research and deployment rates needed for CCS development to take off in developing countries.

## TOPIC 2: ELIGIBLE COSTS FOR FINANCING

- Most CCS demonstration projects will operate in conjunction with new or existing power plants or industrial facilities that may also function without the technology. Funding for CCS demonstrations can therefore be structured around whole projects—including the non-CCS components of the facility under consideration—or just the specific CCS components that would enable the facility to effectively capture and store its carbon dioxide emissions.

- Funding should only be eligible to finance incremental costs incurred as a result of $CO_2$ capture, transport, and storage efforts—not the full cost of the project.

## TOPIC 3: PROJECT ELIGIBILITY CRITERIA

- ***Project objectives:*** Finance should be primarily directed toward projects that either actively store $CO_2$ or directly provide the basis for near-future $CO_2$ storage locally, avoiding duplication with other existing funding mechanisms.

- ***Project scales and types:*** To maximize both near-term and future storage, eligible project types should cover geological site characterization and integrated CCS projects, both at the pilot and commercial demonstration scales.

- ***Project sectors:*** CCS projects in fossil fuel power plants are likely to be the largest recipients of funding. However, some industrial $CO_2$ sources may present advantages that could facilitate timely and cost-effective development of CCS projects in developing countries. "Low-hanging fruit" projects in industrial facilities with high-purity $CO_2$ streams can advance infrastructure and technologic know-how in developing countries at a fraction of the cost of implementing CCS at a power plant. Funding criteria should therefore not discriminate against industrial sources of $CO_2$.

- ***EOR and other CCUS projects:*** Enhanced oil recovery (EOR) and other carbon capture, usage and storage (CCUS) projects have multiple advantages for early CCS development and can result in the net storage of $CO_2$, warranting their inclusion in financing opportunities. However, awarding of CCS financing to CCUS projects should occur only where projects are managed and monitored with the aim of permanent $CO_2$ storage.

- ***Additional project requirements:*** Funding criteria should stipulate that awarded projects employ sound procedures for CCS site selection, operation, and stewardship. Site selection must be based on specific geologic characteristics. Awarded projects must also have monitoring plans in place for both the operational and the post-closure stewardship phase and ideally demonstrate local government support and local community buy-in.

### TOPIC 4: PROJECT SELECTION PROCESS

- In order to make the selection process as equitable and objective as possible while maximizing CCS deployment goals, projects that meet funding demonstration objectives should be awarded on a competitive basis under a points-based system to judge applications. Such system should reward, among other factors, storage efficiency, geographic diversity, and contribution to wider CCS advancement in developing countries.
- The selection system should also favor improving knowledge of storage opportunities through projects implemented in deep saline formations, since they represent the largest knowledge gap and the largest storage potential in the future.

### TOPIC 5: FINANCING MECHANISM CHARACTERISTICS

- Significant attention has been focused on creating an international public fund solely dedicated to CCS, or a CCS window within a larger fund that may also finance other pre-commercial, low-carbon technologies in developing countries. Additional research is needed to ascertain the pros and cons of different structures in a developing country environment. However, there are several advantages of adopting a CCS-only mechanism for the early demonstration phase, instead of having CCS in direct competition with other technologies for the same pool of funds.
- In order to meet the IEA-recommended storage goal of 45–60 million tons of $CO_2$ in 10 years, a CCS fund needs to be able to invest or leverage total investments of US$5–8 billion and have the capacity to disburse its resources effectively over the same period.
- A CCS fund should employ strong early-mover and $CO_2$ storage incentive provisions to leverage its goals. A 10-year storage incentive on a rising scale could be applied to ensure project operators act to permanently reduce emissions.

## 1. Climate Change and CCS

### THE CLIMATE CHANGE SITUATION

**Entering 2011, global atmospheric $CO_2$ levels have nearly surpassed an average of 390 parts per million (ppm), a 40 percent increase over pre-industrial levels of 280 ppm.**[2] This represents both the highest total and fastest acceleration of atmospheric $CO_2$ levels in the past 400,000 years.[3] The parallel warming of the climate system, evidenced by rising average global temperatures and global average sea level and increased aberrations in weather patterns, is consistent with the modeled effects of increasing atmospheric $CO_2$ levels resulting from anthropogenic greenhouse gas emissions.[4] The extent of climate change impacts will likely depend upon peak atmospheric concentrations and the resulting warming effects. Under the Cancun Agreements,[5] signatory nations agreed on the need to reduce greenhouse gas emissions to a level that would hold average global temperature increase below 2ºC in comparison to pre-industrial levels. This would be achievable, with medium to high probability, by stabilizing atmospheric $CO_2$ concentrations between 350 and 400 ppm, according to the latest climate models.[6] Failure to do so risks more dramatic climate change that could instigate more devastating impacts. These impacts include more common extreme weather events and stress on fresh water and agricultural supplies, which threaten the political stability, health, and living standard of numerous countries and peoples, especially in the developing world.

### $CO_2$ EMISSIONS MITIGATION AND CCS

Though developed countries are largely responsible for historical anthropogenic $CO_2$ emissions, all nations are vulnerable to climate change impacts.[7] To successfully limit and significantly reduce future emissions, developed countries must take the lead, but developing counties must also take robust action to shift to a low-carbon economy and reduce emissions, with support from developed countries to address key barriers currently preventing them from doing so.[8]

**In facing the challenge of climate change, many world leaders have acknowledged the scientific findings that no single solution exists for mitigating climate change;**[9]

**therefore, a portfolio of $CO_2$ reduction technologies and methods that meet the needs of each locality will be needed to successfully confront rising $CO_2$ emissions.** Each nation has different emission profiles, and while $CO_2$ accounts for over 75 percent of anthropogenic greenhouse gas emissions, it derives from multiple sectors, each of which must undertake methods to reduce emissions.[10] Of all sectors, the energy supply and industrial sectors are the greatest contributors to $CO_2$ emissions, accounting for 25.9 percent and 19.4 percent of the total, respectively.[11]

**In addition to efficiency improvements and enhancing clean energy use, one key option for limiting future** $CO_2$ **emissions from fossil fuel energy supply is CCS.** CCS is a suite of technologies integrated to capture and transport $CO_2$ from major point sources (e.g., fossil fuel power plants; steel, cement, and fertilizer plants; and other industrial facilities) to a storage site where the $CO_2$ is injected down wells and then trapped in porous geological formations deep below the surface. If a site is selected carefully, designed and executed properly, and well managed over the long term, the probability of significant $CO_2$ leakage from the storage reservoir is low and any health and safety risks of CCS are minimized.[12]

At present, the individual technology components utilized in a CCS project are mature relative to many emerging clean energy technologies. $CO_2$ separation and capture is already widely applied on a commercial scale for use in the food and beverage industry, as well as in other industrial uses; $CO_2$ transport by pipeline is a mature industry in some regions, such as the United States; and technologies for storage site selection, injection, and monitoring are well developed across the petroleum industry. However, power plant–scale integration of all technologies comprising a CCS project is still at a developmental stage. In order to evaluate CCS's potential to play an effective role in the portfolio of climate mitigation solutions, commercial-scale demonstration projects are needed to test the technology in a variety of contexts.

**International organizations have repeatedly cited CCS as a potential major tool to achieve $CO_2$ emission reductions.1**[3] Despite being a fledgling industry, full-scale CCS application is considered by many studies, including by the IEA and the Intergovernmental Panel on Climate Change (IPCC), a key option to reduce emissions for the next 15–50 years if advances can be made that adequately address existing uncertainties and enable widespread development.[14] According to scenarios developed by the IEA, CCS could contribute 19 percent of all anthropogenic $CO_2$ emission reductions globally by 2050, if atmospheric $CO_2$ concentrations are stabilized in the most cost-effective manner.[15] This level of deployment entails establishing 100 CCS projects around the world by 2020.[16] Similarly, the Major Economies Forum (MEF) laid out a CCS Technology Action Plan that included supporting the G8's former commitment to launching 10 commercial-scale projects by 2010.[17]

**In many projections, CCS deployment plays a large role in limiting $CO_2$ emissions from developed as well as developing countries.** Of the overall 3,400 CCS projects necessary by 2050 according to IEA scenarios, 65 percent would need to be located in developing countries.[18] The MEF Technology Action Plan for CCS recommended that 4 of the 10 commercial-scale projects should be in developing countries. Estimates from some developing countries themselves have assigned a similar importance to CCS. Models produced by Chinese experts show that China can stabilize its annual $CO_2$ emissions by 2030 through energy efficiency and fuel substitution, but a future decrease in annual $CO_2$ emissions after the 2030 peak will only occur if CCS is implemented in the next few years and then reaches significant commercial-scale deployment post-2030[19]

## 2. CCS in Developing Countries

**If global average temperatures are to be kept from rising above 2ºC, significant emission reductions must come from both developed and developing countries.[20]** The path to national development has historically been tied to energy-intensive fuel sources and industries, a trend that continues today. The energy demand and energy-driven $CO_2$ emissions accompanying rapid economic growth in developing countries have more than doubled in the last two decades, with non-OECD countries now being responsible for over 50 percent of annual global $CO_2$ emissions.[21] While per capita emissions are still relatively low in developing countries and may not ever reach the current per capita levels of some developed countries, the recent economic growth episodes in major developing countries like China and India have set their emissions on a steep upward path.[22]

While developing countries are not historically responsible for the bulk of $CO_2$ emissions, their rapidly rising fossil-fuel $CO_2$ emissions need to be curbed alongside those of developed countries if the global climate change problem is to be addressed effectively.[23] At the same time, national development goals are likely to continue to be the top priority in developing countries, and any climate mitigation strategies carried out by them will reflect such goals.[24] Along with renewable energy and energy efficiency implementation strategies, CCS may be one potentially attractive technology for reducing emissions while pursuing national development goals.

## ATTRACTIVENESS OF CCS TO FOSSIL FUEL–DEPENDENT DEVELOPING COUNTRIES

**Despite often-aggressive programs to promote energy efficiency and deploy nuclear, renewable, and other low-carbon energy sources, many developing countries will still rely heavily on fossil fuel energy, especially coal-derived power, to fuel their development.** Between 2000 and 2008, coal supplied approximately 55 percent of incremental electricity generation in developing countries, compared to just over 10 percent for developed countries.[25] In many regions, fossil fuels are relatively cheap compared to most low-carbon options;[26] their use is consequently widespread and national energy infrastructures are typically designed accordingly, making any rapid shift to other energy sources extremely difficult. Furthermore, many industries are dependent on technologies that "lock-in" fossil fuel usage. Newly constructed coal-fired power plants often have an expected operational lifetime of more than 30 years,[27] fixing in fossil fuel dependencies for decades to come, lest developing countries deal with significant stranded asset risks and capital costs arising from a quick shift in national infrastructures. Given the development needs and trends of non-OECD countries as well as the cost of shifting national energy sources and corresponding infrastructure, it is expected that many developing countries will maintain or increase their total fossil fuel consumption in the medium term.[28] They therefore are seeking to develop strategies that address this source of greenhouse gas emissions in a way that minimizes the costs of doing so, and consequently minimizes impacts to their national development goals.

**CCS is the only near-commercial technology proven to directly disassociate $CO_2$ emissions from fossil fuel use at scale, and it could allow developing countries to gradually shift away from fossil fuels for energy and industrial needs with relatively little disruption to their long-term development strategies.**[29] While efficiency improvements increase the energy extracted and utilized during fossil fuel consumption, $CO_2$ is still emitted. Thus far, CCS is the only technology that directly reduces the amount of $CO_2$ emitted per unit of fossil fuel used in large-scale facilities, allowing for $CO_2$ emission reductions without halting fossil fuel usage. This unique aspect of CCS may increase its attractiveness to some developing countries from the cost-saving, stranded asset risk, and energy security standpoints, even if other co-benefits such as job creation potential may be less significant for CCS than those associated with other low-carbon technologies such as solar or wind power generation.[30] Therefore, CCS deployment could be an interim measure to address $CO_2$ emissions from fossil fuel use in energy generation and industrial processes in developing countries, allowing time for other alternative low-carbon technologies to be developed and become cost-effective, permitting fossil fuels to be gradually phased out. This strategy could assist developing countries to transition to a low-carbon economy in the next 15–50 years, while utilizing their existing infrastructure and current energy supply matrix to maintain current growth rates.

## BARRIERS TO CCS DEVELOPMENT IN DEVELOPING COUNTRIES

**While CCS is potentially attractive to some developing countries, current efforts have been inadequate to reach the demonstration scales needed** (Table 1). There are only seven fully integrated, commercial-scale CCS projects in operation in the world today[31]—all in OECD countries or led by OECD-based companies (Table 2). One key reason for the limited development of demonstration projects is their overall cost in the absence of expected profits or significant carbon financing. Carbon dioxide emissions do not currently represent a real direct cost to emitters, and hence there is no effective demand for the technologies that will reduce them.

**Table 1: Partial list of significant CCS activities in developing countries**

| Country | Activity Details |
|---|---|
| China | Strong domestic CCUS research carried out, EOR development, multiple CO2 capture pilots, industrial CCUS research and development, IGCC with plans for CCS, extensive bilateral cooperation with United States underway, regulatory framework under development |
| Brazil | Research center established, initial bilateral technical cooperation with United States underway, EOR development, CCS pilot at bioethanol plant under study |
| South Africa | CCS Centre established, national storage atlas and roadmap completed, regulatory research beginning |
| Indonesia | Proposed CCS project under Japan's offset program |
| India | Small-scale capture and utilization projects for fertilizer underway |

Note: CCUS – carbon capture use and storage; EOR – enhanced oil recovery; IGCC – Integrated Gasification Combined Cycle

**Any integrated CCS project will have significant upfront capital costs for performing site-specific storage characterization, as well as constructing the capture facility and the transport and storage infrastructure**. In addition, operating $CO_2$ capture units imposes an added "energy penalty" on fossil fuel power plants due to the parasitic energy consumption needed to power the capture processes (see Topic for Discussion 2 on the next Section) and significant increases in water consumption. These penalties result in higher resource consumption per unit of energy generated, and their costs add up to sizeable barriers to entry on top of the significant capital and operational costs to run a CCS facility. Of the seven major commercial demonstration projects, published capital costs are typically well over US$100 million and operational costs are up to US$24 million per year. None of these projects involves capture from a power plant, which is generally considered more

**Table 2: List of current integrated commercial-scale CCS projects in operation**

| Site Name | Type | Location | Start Date | Cost of CCS (USD) |
|---|---|---|---|---|
| **Weyburn** | Capture: Coal Gasification Plant; Pre-combustion<br>Transport: Pipeline (330 km)<br>Storage: EOR (2.4 Mt/yr) | USA & Canada (EnCana) | 2000 | Cap: $127 M[a] (10.19/tCO2)<br>Op: $23.6 M ($9.85/tCO2) |
| **Snøhvit** | Capture: LNG Plant; Natural Gas Processing<br>Transport: Pipeline (160 km)<br>Storage: Offshore Deep Saline Formation (0.7 Mt/yr) | North Sea, Norway | 2007 | Unknown |
| **Sleipner** | Capture: Offshore Platform; Natural Gas Processing<br>Transport: Pipeline in same site<br>Storage: Offshore Deep Saline Formation (1Mt/yr) | North Sea, Norway | 1996 | Cap: $106 M[b]<br>Op: $7 M/yr[c] |
| **In Salah** | Capture: Natural Gas Processing Plant<br>Transport: Pipeline (14 km)<br>Storage: Deep Saline Formation/Gas Field (1.2 Mt/yr) | Algeria[d] | 2004 | Incremental Cost: $100 M[e] |
| **Salt Creek** | Capture: Natural Gas Processing<br>Transport: Pipeline (201 km)<br>Storage: EOR (2.4 Mt/yr) | USA | 2006 | Cap: Pipeline $27 M<br>Total $200 M[f] |
| **Val Verde $CO_2$ Pipeline** | Capture: Five Natural Gas Processing Plants<br>Transport: Pipeline (132 km)<br>Storage: EOR (1 Mt/yr) | USA | 1998 | Pipeline Cap: $27.6 M[g] |
| **Rangley EOR Project** | Capture: Natural Gas Processing<br>Transport: Pipeline (285 km)<br>Storage: Deep Saline Formation/Gas Field (1 Mt/yr) | USA | 1986 | Unknown |

Note: Mt/yr – megatons of $CO_2$ per year; km – kilometer; EOR – enhanced oil recovery; LNG – liquid natural gas; Cap – capital costs; Op – operating costs; M – Million
Source: GCCSI.

a Covers entire project, including plant, compression, pipeline, and IEA GHG Monitoring and Storage efforts as well as a 12.5 percent regulated rate of return on investments. Note: EOR facilities already present and not a cost; Torp, T. and K. Brown, 2004. $CO_2$ underground storage costs as experienced at Sleipner and Weyburn. Vancouver, Canada: GHGT-7. Online at: http://faculty.jsd.claremont.edu/emorhardt/159/pdfs/2006/Torp.pdf.

b Includes site characterization (US$1.9 M), compressor train (US$79 M), and injection well (US$15 M); Torp and Brown 2004.

c Includes fuel costs for operating separation processes and the $CO_2$ tax on that fuel; Torp and Brown 2004.

d Project led by BP in collaboration with Statoil and Sonatrach.

e Wright, I., 2010. In Salah demonstration project. Regional Carbon Sequestration Partnerships Annual Review Meeting, October 5–7, 2010. National Energy Technology Laboratory (NETL).

f Anadarko, 2002. Anadarko Petroleum completes Howell Corporation acquisition. Press release. Houston, Texas: Anadarko Investor Relations. Online at: http://www.anadarko.com/Investor/Pages/NewsReleases/NewsReleases.aspx?release-id=362064.

g Dunn, K., 2008. AES-carbon offset providers coalition (COPC) offset Hill briefing. Blue Source: A leading climate change portfolio. Online at: http://www.carbonoffsetproviders.org/resources/Dunn+BlueSource+$282$29.pdf.

### Table 3: List of cost estimates for early CCS projects[a]

| Source | Estimates |
|---|---|
| IPCC (2005) | New pulverized coal: Cost Avoided US$30–70/t$CO_2$; increase in electricity cost: 43–91 percent<br>New IGCC: Cost Avoided US$14–53/t$CO_2$; increase in electricity cost: 21–78 percent |
| IEA (2008) | US$40–90/t$CO_2$ abated |
| IEA (2010)[b] | Pilot to large scale: Avg. US$1 billion investment per project over the next 10 yrs |
| IEA (2011) | Post-combustion capture (OECD only) average US$58 with range US$40–69/t$CO_2$ avoided<br>Pre-combustion IGCC US$43 with range US$29–62/t$CO_2$ avoided<br>Oxy-combustion average US$52 and range US$27–72/t$CO_2$ avoided |
| GCCSI (2009) | Pulverized Coal (Super and ultra supercritical): US$87–91/t$CO_2$ avoided<br>IGCC: US$81/t$CO_2$ avoided |
| Bhargava (2010) | Standard coal, no CCS: ~$0.7 M/MWh total costs; US$0.05/kWh<br>Supercritical + CCS: ~US$1.4 M/MWh total costs; US$0.09/kWh<br>IGCC + CCS: ~US$1.6M/MWh total costs; US$0.11/kWh |
| Al-Juaied and Whitmore (2009) | First of a kind plant: US$100–150/t$CO_2$ (capture only) |
| Gao (2010) | IGCC China: incremental capital cost of US$65–106 M (60–100 percent capture)<br>Expected electricity tariff without incentive: US$94–113/MWh (60–100 percent capture) |
| Coal Utilization Research Council[c] | $17.3 B/yr incremental cost for early adopter 45 GW (30-yr plant life) over 20 yrs $4.5 B/yr incremental cost for pioneer plant 10 GW (30-yr plant life) over 15 yrs |
| Lignite Energy Council[d] | $1 B/yr incremental capital cost for 10 yrs for five retrofit and five new demos with storage<br>$3.8 B/yr incremental capital cost for 10 yrs for seven integrated projects (>600 MW) |
| McKinsey (2008)[e] | New Project: 0.6–1 billion additional cost per plant; US$78–118/t$CO_2$ abated |
| UK-China NZEC (2009)[f] | IGCC: 0.5 billion; Pulverized coal: 0.7 billion; Retrofit: 0.9 billion<br>New IGCC China: ~US$42/t$CO_2$ avoided |
| COACH (2009) | New IGCC China: US$33–40/t$CO_2$ avoided |

Note: B – billion; GW – gigawatt; IGCC – Integrated Gasification Combined Cycle; M – million; MW – megawatt; yr – year

a Current figures are focused on coal-fired power plants unless otherwise stated. CCS projects that include capture from industrial sources such as cement, iron and steel, ammonia, and natural gas processing offer lower capture costs because of the high purity of emitted $CO_2$.

b Not specific for developing countries; covers entire project costs, including but not limited to incremental CCS costs.

c Angielski, S. and K. Obenshain, 2010. Senator Dorgan CCS Pathways Initiative: Coal Utilization Research Council (CURC) and Edison Electric Institute (EEI) letter to Interagency Task Force on CCS. 1 July. Online at: http://www.whitehouse.gov/sites/default/files/webform/dorganresponsetaskforce.pdf.

d Angielski and Obenshain 2010.

e Based only on high-level assessment of labor and steel costs in developing countries, which were determined to be 15 percent less expensive; covers entire project costs, including but not limited to incremental CCS costs.

f Covers entire project costs, including but not limited to incremental CCS costs.

expensive than capture from natural gas processing and high-purity industrial sources of carbon dioxide, although these costs will likely drop for new projects over time as capture processes become more efficient and project scales increase with commercial deployment of CCS.[32]

**The estimated cost of avoided $CO_2$ via CCS falls anywhere in the range of US$30–118 per ton (t) for coal-fired power plant projects** (Table 3).[33] For example, a new Integrated Gasification Combined Cycle (IGCC) plant with CCS in China would experience an increase of US$65–106 million in capital costs, which would translate to an electricity tariff of US$94–113/megawatt-hour (MWh) and overall costs between US$33–40/t$CO_2$ avoided, including capital and operational expenditures.[34] Including incremental costs of CCS, the IEA estimates the total cost for a new average-sized coal-fired power plant that captures up to 90 percent of its $CO_2$ emissions to be US$1 billion over the next ten years.[35]

**At present, the onerous burden of CCS on operators makes projects prohibitively expensive under any scenario without public support**. Because CCS technology is still at the pre-commercial stage and is unable to generate profits on its own in the absence of regulations that penalize $CO_2$ emissions, there is little incentive for developing countries and their enterprises to act on CCS research and development. As a general rule, developing countries lack the necessary resources to unilaterally effect investments of such magnitude in novel technologies at the scales needed.

**On top of the financial hurdles, other barriers exist in developing countries, many of which deter government action and potential financiers.** Developing countries currently lack regulatory frameworks to govern the development of CCS; in fact, only a few developed countries such as Australia, the European Union, and the United States have drafted or enacted regulations for implementing CCS projects in their jurisdictions. The regulatory uncertainty in developing countries around the unique aspects of CCS projects greatly increases the difficulty and risk of CCS operation. Although concerns vary by country, other common issues include the ability to enforce any environmental regulations once established, clarification regarding intellectual property rights issues, procedures for engaging local communities around CCS projects, and the need for a framework around post-closure stewardship of a project, including liability and provisions for long-term monitoring. Similarly, property, title, and security issues are all critical for financiers who already have general concerns regarding investments in emerging markets, such as political, macroeconomic, regulatory and credit risks.[36] Without proper technical assistance, firsthand experience, and a guarantee of funding, commercial-scale CCS demonstrations are unlikely to be carried out in developing countries on the scale needed for robust learning of the technology's potential under present market conditions.

**A wait-and-see attitude by developing countries toward technological development has limited potential in the case of CCS.** Governments and private actors in developing countries often wait for developed countries to refine technologies and then transfer them at lower costs.[37] However, this strategy has limited value to CCS, since it is highly context-specific and requires domestic capacity and understanding of both the individual technologies and whole process chain in a given locale, in addition to the unique local regulatory issues and geological conditions.[38] Although some of its components may be transferrable, CCS as a whole cannot be imported or exported at this time.[39] This is especially true for $CO_2$ storage, where intimate knowledge of local geology for selecting, operating, and monitoring storage sites is often a domestic capacity or prerogative that cannot be directly transferred from abroad. Therefore, for CCS to take place effectively, each project location (and in many cases its corresponding regulatory jurisdiction) will need to individually pursue some level of CCS preparation and development, notwithstanding the benefits arising from knowledge sharing and potential mimicking of existing plants.

**Lastly, the sheer risk, complexity, and uncertainty involved in CCS—operationally, financially, legally, and with respect to approval—currently deter individual companies in any country from assuming responsibility for entire projects.** Even companies based in developed countries are reluctant to take on the full burden of demonstrating CCS at scale alone. At this stage, CCS is not a process that can be effectively packaged and shipped ready-for-use by any single entity. The scale and integration across traditionally separate industrial sectors make CCS projects challenging ventures locally, and in the near term, they will be best met through the collective experience of building and operating commercial-scale demonstration CCS facilities in a variety of settings through the cooperation of many partners, both industrial and governmental.

## INSUFFICIENCY OF FINANCING MECHANISMS AS A KEY BARRIER TO CCS

**While there is financing for CCS, it is grossly insufficient to advance CCS deployment in developing countries.** Partial financing of CCS development in developing countries is currently available from a number of sources (Table 4); however, the scale of funding per project application is typically less than US$10 million. The few funds with greater resources are either spread across low-carbon technologies, or still fall short of the magnitude or the mandate needed to propel commercial-scale CCS demonstrations forward. An example of the former is the Clean Technology Fund. The latter situation is illustrated by the World Bank and Asian Development Bank, which both operate CCS-dedicated funds but are unable to single-handedly sustain or leverage any significant CCS demonstration projects given the scale of funding needed.[40] Table 4 sets out some available funding mechanisms that could be used to finance CCS projects in developing countries, but funding applications for these often require approximately two years to be processed and awarded.

**Current carbon pricing mechanisms are not currently sufficient to spur CCS deployment in developing countries.** CCS is eligible for support through carbon financing under the European Union's Emissions Trading System (ETS) rules, and tentatively under the United Nations Framework Convention on Climate Change's (UNFCCC's) Clean Development Mechanism (CDM).[41]

**Table 4: Partial list of existing financing options for clean energy technologies in developing countries[a]**

| Source | Type | Funding (USD) |
|---|---|---|
| **Global Environmental Facility (GEF) Trust Fund[b]** | Assists developing countries to fulfill United Nations Framework Convention on Climate Change (UNFCCC) targets through grants for projects related to biodiversity, climate change, etc. Grant financing requested by host government. Co-financing of policy implementation and pilot and demonstration of new technologies. Has supplied some grants to CCS projects. | Application scale: $3 M |
| **Special Climate Change Fund (SCCF)[c]** | Funds projects directed toward adaptation, capacity building, technology transfer, and climate change mitigation. Operated by the GEF. | Total pledge: $60 M |
| **Least Developed Countries Fund (LDCF)[d]** | Helps least developed countries (LDCs) cover their costs of implementing National Adaption Programmes of Action (NAPAs). Managed by the GEF. | Total pledge: $224 M |
| **Clean Development Mechanism (CDM)[e]** | CCS is tentatively included in CDM, pending review and specifications. Inclusion would mean carbon credits can be purchased by investors on a per ton of $CO_2$ stored basis. | Dec. 2010 market avg $13/tCO_2$ |
| **European Union Emissions Trading Scheme (ETS)** | Carbon credits purchased by investors per ton of $CO_2$ avoided through storage. | Dec. 2010 market avg $18/tCO_2$ |
| **Clean Energy Financing Partnership Facility (CEFPF)** | Established by the Asian Development Bank with support from Australia, Japan, Norway, Spain, and Sweden to support clean energy projects in developing countries through grants and loans. | Pledge: $60.2 M<br>2013 Target: $2 B<br>App scale: $10 M |
| **Asian Development Bank (ADB) CCS Fund** | Funded by the Australian Government as a CCS-specific sub-fund of larger CEFPF. | CCS pledge: $21.9 M<br>App scale: $1 M |
| **Global CCS Institute (GCCSI)** | Established and funded by the Australian Government, GCCSI is able to provide grants for CCS projects directly, as well as provide funding for other activities like capacity building. It also provides funding to other entities such as the ADB or the Clinton Climate Initiative for future disbursement. | Average annual disbursements: $50 M |
| **Clean Technology Fund (CTF)** | Help developing countries transition to low-carbon development through multilateral development bank (MDB) grants and loans. Co-finances concessional donor loans requested by host governments, and promotes scaled-up financing for demonstration, deployment, and transfer of low-carbon technologies. Provides risk mitigation for new entrants. | Total pledge: $4.3 B<br>Application scale: $200 M |
| **Strategic Climate Fund (SCF)** | Along with CTF, SCF is the other Climate Investment Fund (CIF) initiated under the UNFCCC. It serves as an overarching framework to finance targeted programs in developing countries to pilot new climate or sectoral approaches with scaling-up potential. CCS could fall under their pilot program funding. | CIF total: $2 B |
| **World Bank Capacity Building CCS Trust Fund[f]** | Funds capacity building and knowledge sharing assistance for CCS. Provides carbon asset creation services. | Total capital: $8 M |
| **Carbon Partnership Facility (CPF)** | Because CDM incurs high transaction costs, the CPF objective and business model are based on the need to prepare large-scale, potentially risky investments with long lead times and support long-term investments in an uncertain market. "Learning by doing" approaches are an essential aspect of the CPF. | Total capital: $200 M |

a Gao, L., 2010. Economic analysis for demonstration projects. Asian Development Bank (ADB) TA-7286 – People's Republic of China (PRC): Carbon Dioxide Capture and Storage Demonstration – Strategic Analysis and Capacity Strengthening. Draft; Kulichenko-Lotz, N., 2010. Financing CCS deployment in developing countries. Washington D.C.: World Bank; Climate Investment Funds (CIF), 2009. CIF financial status as of January 26, 2009. Online at: http://www.climateinvestmentfunds.org/cif/sites/climateinvestmentfunds.org/files/CIF_Financial_Status_Jan_26_2009_0.pdf.

b Multilateral funds under the coordination of the UNFCCC; implemented by the World Bank.

c Multilateral funds under the coordination of the UNFCCC.

d Multilateral funds under the coordination of the UNFCCC.

e At the UNFCCC meeting in Cancun in December 2010, CCS was tentatively approved for inclusion in the Clean Development Mechanism (CDM), depending on the satisfaction of multiple technical requirements currently under review; UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), 2010. Carbon dioxide capture and storage in geological formations as Clean Development Mechanism project activities: recommendation of the SBSTA. SBSTA thirty-third session, 30 Nov to 4 Dec 2010; multilateral funds under the coordination of the UNFCCC; implemented by the World Bank.

f Implemented by the World Bank.

However, the current price of carbon credits on both markets (typically ranging from US$13–18/$tCO_2$)[42] falls well short of the current estimated minimum CCS costs shown in Table 3. Despite analyses that estimate achieving emission reduction goals would be about 70 percent more expensive without the use of CCS over the long term,[43] the current gap between carbon credit prices and CCS costs in early-stage demonstrations is apparently too large to spur the necessary investments. Hence, carbon finance through offset mechanisms will be able to play mostly a complementary role to other financing sources for CCS.

**Overall, existing CCS financing mechanisms help grow capacity, but their support is insufficient to leverage enough funding from capital markets to implement projects.** Immediate and targeted financing by developed countries is necessary to grow local capacity in developing countries and lay the groundwork for realizing potential benefits of large-scale CCS deployment in the future. International fora such as the Clean Energy Ministerial (CEM) and the G8 may be in a unique position to provide leadership that would enable greater and more directed financing for CCS to grow in developing countries.

### TIMING TO DEVELOP CCS IN DEVELOPING COUNTRIES

**Ultimately, if CCS is to play its potential role in climate change mitigation efforts, action in developing countries needs to begin now.** Individual project planning typically requires three to four years before construction can begin;[44] thus, any decision to deploy CCS will face a delay between its inception and operational action. With the current technological capabilities, understanding, and overall preparation involved in projects of such magnitude, this delay could stretch up to a decade or more, especially in the absence of experience in CCS projects in most developing countries.

**Accelerating CCS demonstration efforts in non-OECD contexts can improve technologies, increase efficiency, lower costs, reduce uncertainty and risk, and initiate learning-by-doing.**[45] These potential benefits can accrue upon all aspects and actors involved in CCS projects, ranging from technical improvements that will benefit CCS in general, to the creation of regulatory frameworks and improved understanding of storage potential in individual developing countries. These developments can also benefit developed countries by establishing the groundwork for a CCS market that would benefit from economies of scale, and potentially lower the costs of technological development since projects in developing countries are generally cheaper to implement than similar endeavors in an OECD context.[46] For these reasons, OECD countries have an additional incentive to support CCS in developing countries, apart from the global benefit arising from non-OECD countries reducing their carbon dioxide emissions from fossil fuel usage. In all of these, the captured benefits will be more significant the sooner acceleration in CCS development in developing countries happens.

**The IEA CCS Roadmap sets out implementation of 50 CCS projects in developing countries in the next 10 to 20 years; for this to happen, preparation needs to begin soon.** The IEA CCS Roadmap projects that 3,400 plants will be needed globally by 2050, and that developing countries will account for 64 percent of all captured carbon dioxide emissions by then.[47] It envisages project implementation beginning mid-decade, with the potential for dramatic increases in deployment rates from 2020 onward as a wave of new coal-fired power plants are installed in developing countries to fuel increased energy demand and older plants are replaced by new facilities that could incorporate $CO_2$-capture technologies in their design. However, the odds of such increases in CCS deployment rates will be slim if political will to curb greenhouse gas emissions cannot be mustered and a strong push to develop CCS in developing countries does not start soon.[48]

## 3. Topics of Discussion for Financing CCS in Developing Countries

Having highlighted the immediate need for developed countries to fund a financing mechanism for CCS in developing countries, the next area to explore is key issues and strategic goals around its implementation. This section draws from the current international debate,[49] exploring key topics and presenting a series of options and recommendations to international policymakers. The objective is to assist in the initial design of an effective approach for financing CCS demonstration projects in developing countries over the next 10 years.

### TOPIC 1: AIMS OF FINANCING CCS DEMONSTRATIONS IN DEVELOPING COUNTRIES

Any funding support for CCS demonstrations in developing countries must be clear about its intentions from inception. Defining the larger objectives will directly affect the mode and procedures through which funding will be disbursed. For reasons explained under Topic 5, a CCS-specific approach presents many advantages for financing initial-phase CCS development efforts in developing countries, and is therefore the generally assumed aim for this paper.

**The main goal for developed countries to provide financing for early-stage CCS in developing countries should be to support non-OECD countries in contributing to global climate change mitigation efforts.** Under the international debate on climate change carried out in the UNFCCC context, Annex I (industrialized) countries have committed to fund and support climate change mitigation efforts in non–Annex I (developing) countries.[50] Funding CCS demonstration efforts in non-OECD countries would be in line with this collective goal, and could also help demonstrate existing Annex I country commitments on technological transfer, climate finance, and promotion of local capacity in non–Annex I countries.

**A financing mechanism for CCS in developing countries should aim to foster tangible $CO_2$ emission reductions through a clear focus on storage goals.** Given the fluid nature of CCS project costs, risks, and variety of project types and scales that could be considered, it is not efficient to seek a fixed number of awarded projects as an outcome measure for a funding mechanism. Instead, given limited financial resources and the fact that not all developing countries are suited for demonstration projects at present, the preferable approach is to target a desired amount of $CO_2$ stored. This not only provides flexibility, but also keeps the focus on proving a measurable impact on $CO_2$ emissions, rather than on reaching an artificial number of project awards.

**The level of ambition for $CO_2$ storage should support current CCS deployment requirements in developing countries so they can fully test and potentially achieve the mitigation potential of the technology within their economies over time.** In order to meet global climate change mitigation objectives by 2050 (see Section 1), the IEA in its BLUE map scenario[51] has projected that the total incremental investment in CCS—including incremental capture, transport, and storage costs—needed over the next 10 years in a non-OECD context is US$17.3 billion. This level of investment is projected to yield around 50 projects (10 in the power sector and 40 in industry and upstream applications) that are capable of collectively storing 116 $MtCO_2$ per year by the end of this period.

While it is impossible to objectively ascertain what proportion of this total should be supported by a dedicated OECD country–funded CCS financing mechanism, it is evident that developing countries will need support for a significant share of these projects. Assuming that the current CCS development momentum achieved in OECD countries can be replicated in a non-OECD context (as is the case with many other technologies, such as supercritical coal and wind power generation),[52] implementing CCS demonstrations leading to the storage of 45–60 $MtCO_2$ over 10 years could significantly spur the research and deployment rates needed for CCS development to take off in developing countries.[53]

## TOPIC 2: ELIGIBLE COSTS FOR FINANCING

Most CCS projects will operate in conjunction with new or existing power plants or industrial facilities that may also function without the technology. Funding for CCS development can therefore be structured around whole projects—including the non-CCS components of the facility under consideration—or just the specific CCS components that would enable the facility to effectively capture and store its carbon dioxide emissions.

**Table 5: What CCS funding should cover**

| Elements to be Covered by Funding |
|---|
| Incremental capital costs for CCS components, labor, and resources (see Appendix) |
| Incremental operational costs associated with CCS operation (see Appendix) |
| Loss of electricity revenue or cost of additional fuel consumption due to the energy penalty |
| Unexpected down time/switch off due to CCS |
| Down time/loss of revenue associated with retrofit |
| Reducing costs of licenses/guarantees to industry to protect intellectual property (IP) |
| Interest payments on any upfront loans |
| Return for any private investors |
| Contingency |
| Underwriting of other risk |
| Costs of added legal and regulatory procedures necessary to conduct CCS |

**The incremental costs of CCS are the added capital, operating, energy penalty, and extraneous costs** (Table 5). For $CO_2$ capture only, the incremental capital costs are defined here as the incremental difference in capital cost between the best available power plant without $CO_2$ capture (e.g., a supercritical pulverized coal plant) and a power plant of equivalent electricity output that includes $CO_2$ capture. For a retrofit, the amount is simply the incremental cost to install the $CO_2$ capture equipment onto the existing facility.[54] The cost of sequestration—including transport, injection, and storage—is a necessary addition to this cost. (See this paper's Appendix for other definitions of incremental costs, for comparison purposes.) Upfront costs for storage would include not only the capital cost of storage facilities but also storage site characterization activities. Where there are preexisting sequestration facilities, costs would include any necessary modifications to equipment. In addition to the capital costs are incremental annual operations and maintenance costs resulting from CCS, as well as long-term monitoring costs associated with the storage site. As for the energy penalty, the incremental costs would be equivalent to the added resource and operation costs incurred by the plant to make up for efficiency loss (e.g., grams of coal per kilowatt-hour [kWh]) plus the opportunity cost of any lost output not regained. Determining the actual efficiency of a CCS operation is straightforward, but selecting a baseline to judge it against is more complicated.[55] To promote the highest storage rate and minimize error in approximating the energy penalty, awarded projects should be allowed by their governments to operate at baseload capacity.

**Funding should only be eligible to finance incremental costs incurred as a result of $CO_2$ capture, transport, and storage efforts—not the full cost of the project**. The goal of the proposed financing mechanism is to have an impact on CCS in developing countries, and this is best achieved by restricting funding to CCS-associated costs. Non-CCS components would remain eligible for traditional public or private financing mechanisms and/or aid.[56] In turn, this would enable a higher number of CCS projects to be pursued, and potentially more $CO_2$ to be stored.

## TOPIC 3: PROJECT ELIGIBILITY CRITERIA

Within the frame of the eligible costs, there are still numerous types of activities and projects that could qualify as incremental CCS costs. In order to focus on its specific goals, and maximize the impact of its limited funds, a financing mechanism for CCS in developing countries must therefore make choices on eligibility criteria.

### Project objectives

**Finance should be primarily directed toward projects that either actively store $CO_2$ or directly provide the basis for near-future $CO_2$ storage locally and avoid duplication with other existing funding mechanisms.** Carbon dioxide storage is the intended end of CCS and presents the greatest gaps in the current CCS capabilities of developing countries. Therefore, supporting projects that involve storage should be the main goal of a financing mechanism. Furthermore, while funding should be available to cover financial gaps for projects with financing incentives already in place, it should not directly overlap with other public funding sources. A potential criterion to define a project's eligibility for funding in the presence of other public financing could be an assessment of whether the project would be financially capable of proceeding in the absence of the funding award.

### Project scales and types

**In order to maximize near-term and future storage, eligible project types should cover geological site characterization and integrated CCS projects, both at the pilot and commercial demonstration scales** (Table 6). Each of these project sizes can bring about considerable gains for CCS development. Pilot and demonstration projects both actively store $CO_2$ underground and promote overall CCS technology, human capacity, and logistical development. Meanwhile, geological site characterization identifies specific locations next to current or near-future $CO_2$ sources, directly enabling the possibility for near-term $CO_2$ storage.[57] Some projects with economic potential may only need storage site knowledge to proceed on their own. One qualified storage site also can frequently accommodate multiple $CO_2$ capture sources. Therefore, comparatively inexpensive geological site characterizations can leverage future storage, maximizing the impact of an international financing mechanism.

**Table 6: Eligible project types and outcomes**

| Project Type | Outcome |
|---|---|
| Geological Site Characterization | Should provide an in-depth characterization of potential geological reservoirs at a specific location in reasonable proximity of current or near-future $CO_2$ sources, including the potential storage capacity, proof of a caprock and other geological features that will ensure the containment of $CO_2$ in the reservoir, and evidence of the reservoir's injectivity. Thorough site characterization is essential for safe and effective CCS, and discovering qualified sites allows for storage projects to commence with any current or future power and industrial plants in reasonable proximity of the site. |
| Integrated CCS Pilot Project* | Capture, transport, and storage at a small scale in order to prove and practice integration of component technologies and to gain experience in $CO_2$ storage and monitoring. Can be used to develop capacity and test ability in certain component technologies. Should store CO2 but in smaller amounts and for shorter periods than demonstrations. |
| Integrated CCS Demonstration* | Capture, transport, and storage at a commercial scale (usually defined as 1 $MtCO_2$ per year or more) to both store significant volumes of $CO_2$ as well as to test, prove, and improve on all component technologies. Demonstrations will provide impetus for developing technical and non-technical frameworks and standards for the many obstacles that confront CCS on multiple dimensions. |

* Front-End Engineering and Design (FEED) studies can be funded as an incremental cost within pilot and demonstration projects.

**Only Front-End Engineering and Design (FEED) studies conducted as necessary prerequisites for an already planned or awarded project should be eligible for support as incremental costs.**[58] FEED studies are detailed activities performed in the early stages of a project to determine its feasibility and to develop the initial plant design and its corresponding cost estimates. Costs for FEED studies usually run in the tens of millions of dollars; these studies may be carried out in the initial phase of an existing project that has already been confirmed to set the details for its construction, operation, and decommissioning plans; conducted as part of a project that is still pending details before a final investment decision can be reached; or performed without a firm connection to any existing project. The latter are called stand-alone FEED studies and should not be eligible for funding. Funds that can support FEED studies for exploratory projects already exist (Table 4), and many stand-alone FEED study projects have no certainty of being implemented in the near future.

## Project sectors

**CCS projects in fossil fuel power plants are likely to be the largest recipients of funding.** Fossil fuel power plant CCS projects represent the largest potential for total $CO_2$ emission reductions. As coal use is responsible for a large share of $CO_2$ emissions in many developing countries, CCS projects capturing $CO_2$ from power plants will likely represent the largest share of a funding portfolio over the medium term. Amid the strong and evolving debate on how to reconcile the need to expand energy access and the need for developing economies to shift into a low-carbon energy matrix, multilateral development banks (MDBs) typically still devote a significant share of their loan portfolios to investments in coal-fired power plants in developing countries with limited alternative energy options.[59] Some funding agencies and MDBs also have provisions against financing certain industrial projects, making it difficult for them to financially support CCS projects in some industrial segments.[60] Taken together, these constraints could potentially further increase the proportion of power-related projects in the CCS financing mechanism portfolio by reducing the competitiveness of some types of industrial CCS projects seeking a funding award compared with those able to count on MDB funding support.

**Some industrial $CO_2$ sources may present advantages that could facilitate timely and cost-effective development of CCS projects in developing countries**. Industrial emission sources amenable to CCS include those of coal-chemical, iron and steel, cement, ammonia, and fertilizer plants, in addition to the natural gas processing plants currently associated with active commercial CCS projects. Because some of these industrial facilities emit high-purity $CO_2$ streams at large scales, they would allow for cheaper $CO_2$ capture processes than those needed to capture coal-fired power emissions.[61] There are several potential "low-hanging fruit" projects in industrial facilities with high-purity $CO_2$ streams that can be leveraged to progress infrastructure and technologic know-how in developing countries at a fraction of the cost of implementing CCS in a power plant.[62]

**Funding criteria should therefore not discriminate against industrial sources of $CO_2$, or directly favor fossil fuel power generation projects.** Keeping a sector-neutral approach would not only allow for "low-hanging fruit" industrial CCS projects to be awarded in a first phase, but also for the fund to receive a large share of power-generation project applications over time. While there are legitimate concerns about financing industrial enterprises that may already have sufficient economic incentives to conduct CCS projects, including provisions against such enterprises in the project selection process can eliminate them as candidates, focusing public funding on projects where market failures are more significant.

### EOR and other CCUS projects

**There is a group of CCS projects that produce economic returns through the production of fossil fuels.** This category includes enhanced oil recovery (EOR), enhanced gas recovery (EGR), and enhanced coalbed methane recovery (ECBMR), although EOR is the predominant type. These projects, together with a handful of other small-scale industrial processes, are usually collectively referred to as Carbon Capture Utilization and Storage (CCUS) projects.[63] Some developing countries are pushing CCUS as the way to develop the technology in the short term, because its economic returns can alleviate the high incremental costs associated with CCS and increase domestic fossil fuel production, which has the co-benefit of added energy security. However, in the absence of incentives or regulations to sequester $CO_2$ itself, and because they must purchase $CO_2$ at a significant cost from third parties, private EOR projects seek to minimize the amount of $CO_2$ injected in an oil field and are not concerned with performing extensive monitoring for safety and storage assurance purposes.

**EOR and other CCUS projects have multiple advantages for early CCS development and can result in the net storage of $CO_2$,[64] warranting their inclusion in financing opportunities.** CCUS projects offer benefits beyond economic return and energy security. For one, the local geology at EOR sites is already well understood. Thus, site selection and characterization costs are considerably smaller and require only a fraction of the time when compared to CCS storage sites developed from scratch. CCUS projects also provide the opportunity to practice $CO_2$ injection and understand the mechanisms of $CO_2$ subsurface movement while simultaneously growing capacity for storage monitoring at lower costs. Similar to low-cost industrial projects, the near-term benefits to CCS learning generally justify financing the incremental costs of CCUS storage, provided some conditions are met.

**Awarding of CCS financing to CCUS projects should occur only where projects are managed with an aim of permanent $CO_2$ storage.** Projects that are economically desirable on their own and will occur without funding should not qualify for any financial assistance beyond support for extensive and active monitoring. These projects—along with EOR projects that alleviate but do not fully offset costs of integrated CCS demonstrations—should be available for additional financing, as long as conditions are incorporated to ensure safe and secure storage. First, stipulations should be set to emphasize $CO_2$ storage. One measure is to require the project to inject the greatest amount of $CO_2$ that can be securely stored at the site. Second, any $CO_2$ produced with enhanced gas and oil recovery procedures should be separated and reinjected in the geologic formation. Third, injection must be monitored and verified to qualify for funding. Another option that has been utilized in the United States is a hybrid approach, in which EOR is done with adjacent injection in saline formations, promoting early experience and long-term understanding of geologic storage of $CO_2$. By employing appropriate restrictions on financed CCUS projects, the greatest returns can be achieved for CCS learning, while still generating positive economic returns for investors.

### Additional project requirements

**Funding criteria should stipulate that awarded projects employ sound procedures for CCS site selection, operation, and stewardship.** One essential criterion is that site selection be based on specific geologic characteristics of the storage site. Proper and thorough site selection greatly limits risk and is the single most important step in ensuring injected $CO_2$ remains isolated from the atmosphere. Awarded projects should also have plans in place for both operational and long-term monitoring. Other criteria include conducting risk and environmental impact assessments and planning for long-term stewardship, including the availability of resources for long-term monitoring.[65] By meeting these core standards, projects will greatly limit risk and provide positive learning experiences.

**Awarded projects should already have received official support from their local government, exhibit compliance with all existing local regulations, and ideally demonstrate the buy-in of host communities.** Even the best and safest projects will be unlikely to achieve their goals without formal government approval and the buy-in of local communities.[66] Given the financial and technical scale of projects, uncertainties in capture and storage, and the general lack of CCS-specific regulation, host governments will be intimately involved in approving and regulating any CCS project in their country. In a similar fashion, several CCS projects in developed countries have been cancelled or delayed due to public opposition. While complicated to demonstrate objectively, and potentially difficult to foster in an early-stage demonstration phase in developing countries, funding criteria should prioritize projects that have taken steps to gain the buy-in from host communities. As a result, financial resources can be allocated to projects that have the best odds of being realized.

**Projects receiving funding should make key information available to the broader international community for CCS learning, effectively and proactively sharing knowledge.** The essential reason for public financing of new technologies is to enable critical learning where private agents are not willing to do so on their own. The benefits from the acquired knowledge of awarded projects should accrue not only in the host country but in the entire developing and developed world. For this to happen, funding awards should be conditional on having lessons from awarded projects be shared widely, respecting provisions for intellectual property where warranted. The Global Knowledge Sharing Framework coordinated by the Global CCS Institute (GCCSI) presents a framework that could potentially be used as a base for knowledge sharing requirements in funding awards.[67]

Finally, given the necessity of seizing the window of opportunity for CCS to make the greatest impact in climate mitigation, projects must develop quickly. Hence, **projects should be awarded financing only when they can be operational within the timeframe of finance availability.**

## TOPIC 4: PROJECT SELECTION PROCESS

A funding mechanism for CCS in developing countries will need to decide which projects it will support under which circumstances, and provide a clear and transparent decision-making process. An evolving portfolio of CCS projects will lead to additional considerations for new projects being funded, and the project selection process must also accommodate the iterative nature of its award decisions over time.

**In order to make the selection process as equitable and objective as possible while maximizing CCS deployment goals, projects that meet funding demonstration objectives should be awarded on a competitive basis.** After fixing the eligibility requirements, it is likely that more applications will be submitted than can be supported with the available resources. Pursuing an adequately designed competitive awarding process will raise the efficiency of funds disbursement and reduce information asymmetries between project developers and funders. These will likely be substantial in the early phases of CCS development in developing countries and will only be reduced once real CCS projects are carried out in that context.[68] Employing other selection methods such as quotas or centralized planning will lead to suboptimal distribution of funds and invite both politicization and bureaucratic delays. In addition, competitive bidding entices developing countries to contribute to project financing because the more incentives they offer domestically, the more likely domestic projects are to be awarded financing. Potential domestic incentives are listed in Table 7.

**Table 7: Possible domestic incentive policies for CCS[a]**

| Domestic CCS incentives |
|---|
| Tax exemptions |
| Subsidization of capital cost |
| Waiving of permit fees |
| Low-interest loans/loan guarantees |
| Electricity tariff premiums |
| Allowance of unrestricted baseload plant operation |
| Limited liability/insurance |
| Technical support |
| Ease of access |
| Ease of sanctioning process |
| Creating rewards for low-carbon operation |
| Developing pilot/demonstration-specific regulatory framework |

a Gao, L., 2010. Economic analysis for demonstration projects. Asian Development Bank (ADB) TA-7286 – People's Republic of China (PRC): Carbon Dioxide Capture and Storage Demonstration – Strategic Analysis and Capacity Strengthening. Draft; Bhargava, A., 2010. CCS demonstration in developing countries – analysis of key issues and barriers. Carbon Sequestration Leadership Forum (CSLF) Annual Meeting: Warsaw, 2010; list also compiled from the authors' previous research.

**A points-based system to judge competitive applications can be used to optimize the underlying financing mechanism's objectives.** Such system should reward, among other factors, storage efficiency (e.g., in $MtCO_2$ per US$ funded), geographic diversity, and contribution to wider CCS advancement in developing countries. The decisions for exactly which factors should be considered and the weight they would carry can be at the discretion of concerned parties from both developing and developed countries, so long as they are designed to best meet the financing objectives (discussed in Topic 1, above) in an efficient manner. However, a vital aspect of the competitive bidding project selection format is that it is open to all eligible projects: a project's application should determine its worthiness. Therefore, no sector, developing country, or capture, transport, or storage technology should be explicitly excluded. The overall portfolio balance should be an explicit part of the award decision process and clearly reflected in the points system for full transparency of award decisions.

**The project selection system should favor improving knowledge of storage opportunities through storage demonstrations and geological site characterizations of deep saline formations.** In addition to utilizing depleted or abandoned oil, gas, and coal-bearing formations for CCUS, $CO_2$ storage can also take place in deep saline formations, and (potentially) basalt formations. Although depleted or abandoned hydrocarbon reservoirs present the lowest-cost options in the near term and require the least amount of additional geological investigation, the future of CCS lies in deep saline formations, which will likely store the bulk of future emissions because of their vast storage capacity—somewhere around 60–90 percent of global total, according to the IPCC.[69] As projects get awarded over time, funding should encourage (but not explicitly require) that at least two thirds of the total $CO_2$ stored (30–40 $MtCO_2$) should be through projects that utilize deep saline formations, in order to develop local capacity and expertise in this key geologic makeup for CCS. One way to achieve this under a competitive process is to include a sliding incentives scale that takes into account the current proportion of saline formation projects in the evolving portfolio composition.

## TOPIC 5: FINANCING MECHANISM CHARACTERISTICS

International financial support for CCS in developing countries can be structured in several ways and provide a variety of financial products to help catalyze CCS demonstrations or geologic site characterization efforts. International public finance may be used to fund capital or operational costs, leverage other forms of finance, and mitigate risks associated with developing CCS projects in a non-OECD context. This paper does not describe the various possible forms of finance in detail, but sets out some basic features that should be considered by OECD governments and international institutions as they develop and implement mechanisms to fund CCS projects in developing countries.

Among several potential financing structures, significant attention has been given to creating an international public fund solely dedicated to CCS, or a CCS window within a larger fund that may also finance other pre-commercial, low-carbon technologies in developing countries.[70] This paper draws on this general fund-based financing structure (as opposed to other potential financing schemes, also described in Table 8) as an illustrative example when discussing its topics and defining funding priorities. Additional research is needed to ascertain the pros and cons of different structures specifically in a developing country environment.

**There are several advantages of adopting a CCS-only mechanism for the early demonstration phase, instead of having CCS in direct competition with other technologies for the same pool of funds.** Despite the efficiency gains of being technologically agnostic when financing innovative climate change mitigation technologies,[71] the inclusion of CCS into a broader technology fund—or any other mechanism that would put CCS in direct competition with other technologies for the same resources—may not bring about enhanced development of CCS. Project applications would likely favor more mature technologies with less risks and/or higher returns associated, as already is the case.[72] CCS projects require long-term management of the storage site and present unique liability issues. Therefore, project developers and financiers selecting projects are likely to prefer technologies with fewer uncertainties, especially given the significant governance challenges

**Table 8: Partial list of potential funding types**

| Mechanism | Pros | Cons |
|---|---|---|
| CCS fund | Specific CCS fund for grant funding that can be applied at a scale necessary to promote major CCS actions. Scope for other donors to contribute either bilaterally or multilaterally, including companies. Smaller CCS funds are already in place and are quickly adaptable. | Can have longer application processes. |
| Carbon finance (CDM/ETS) | Market based so will identify lowest cost storage opportunities and encourage innovation by operators to lower costs. | Too small at present to support incremental CCS costs on its own. Uncertain future. |
| Capital grants/ loans/tax credits | Capital costs are a major source of incremental CCS costs, especially for non-power projects. | Does not cover full spectrum of CCS costs, and CCS does not provide returns on investment, so repayment of loans is still a loss. Tax credits too small. |
| Contract for difference | Is flexible in supporting incremental operating costs and energy penalty. | Many CCS projects operate at a loss, and therefore these contracts may not necessarily be efficient cost-wise. |
| Green Bonds Market | Market based so will identify lowest cost storage opportunities and encourage innovation by operators to lower costs. | CCS operates at a loss, so still leaves no incentive for companies to undertake projects. Would only apply to a limited range of CCUS projects that would be economic. |
| Global Environment Facility (GEF) | Has supported demonstration projects, local capacity building and institutional development. Has a technical assessment panel. Has the capacity for funding countries to scope their CCS requirements under "technical assistance." | If it was to support pre-commercial technologies such as IGCC with CCS, it would need to be increased tenfold and institutional arrangements would need to be changed. Technical assessment panel is not as objective as the one in the Montreal Protocol as the secretariat does the assessment. GEF is official development assistance (ODA) classifiable—80 percent of a project should score as ODA. CCS not likely to be considered as it does not have "short-term development" qualities. GEF serves other environmental conventions so there may be extra requirements that CCS does not fit. |
| Clean Technology Fund (CTF) | Set up as model for climate funding. Run by the World Bank. U.S. support and contributions. | Currently not available for CCS demonstration, can be used for ultra supercritical plants built as capture ready. Developing countries, particularly China and India, have been reluctant to apply for funding. Country-led approach means countries choose what they want to spend the funding on. Governing board unlikely to accept technology-led approach. Public funding is used to leverage in-country private finance; therefore, may not be suitable for CCS |
| Nationally Appropriate Mitigation Actions (NAMAs) | Can be bilateral and multilateral. | Suboptimal distribution. Subject to further bureaucracy. |
| National aid programs | | CCS projects likely do not qualify. |
| Commercial banks—risk spreading mechanisms | | Would only support projects that are economic, which are limited. |
| Certificates for reinjecting $CO_2$ during gas processing | Lowest cost CCS activity, since CO2 is already separated from gas and infrastructure is already present. | Not a significant contributor to global $CO_2$ emissions, so impact is limited. |
| Bilateral aid | Allows flexibility for each country to act independently and maximize their contribution in their preferred way. | Would be in the best interest of the individual countries and not necessarily that of $CO_2$ storage or the CCS industry. Will likely end up with suboptimal outlay of resources and not address the costlier but equally important issues such as capture at power plants and storage in deep saline formations. |

often found in developing countries. In addition, the specific provisions needed to assure private financing for a CCS project will not be the same as those needed to stimulate the development of other technologies. Grouping different pre-commercial technologies under the same competitive funding scheme would require complex provisions to allow for a level playing field without picking winners a priori, which would nullify the efficiencies of competition and defeat the purpose of a joint fund. Lastly, just as developing countries need domestic capacity in operating complicated and unique CCS projects, the implementer needs specific expertise in the appraisal of the technological, safety, and financial merits of CCS projects in a developing country context. A CCS-specific fund or resource window would assist in building in-house CCS expertise to help guide financing in the optimal manner.

**In order to meet the recommended storage goal of 45–60 million tons of $CO_2$ in 10 years, a CCS fund should be capable to provide or support total investments of US$5–8 billion,**[73] **and have the capacity to disburse its resources effectively over the same period.** Depending on the project type and the financial instruments chosen, international public funding could cover all or part of the incremental capital and operating costs associated with CCS and should leverage additional debt and equity investments by other parties.[74] Financial support may come in the form of capital grants, loans, partial risk guarantees, or insurance contracts. The choice and combination of these should vary according to the project and to the current composition of the fund's portfolio. The leveraging component of any funding modality is of paramount importance not only to bring the greatest possible resources to CCS demonstrations, but also to involve other parties in the CCS space from the beginning—building their capacity to further develop CCS projects in developing countries once the fund has ceased its operations.

**Funding applications should be allowed for at least 10 years, and funds should be available to the end of the payback period.**[75] CCS projects are generally developed over very long timelines, both from the planning and operational standpoints. Keeping project applications open for 10 years provides support for meeting the IEA projections of launching 50 CCS projects by 2025, and is still short enough to encourage early movement from developing countries. The current uncertainty of revenue from CCS projects due to the lack of regulatory frameworks and robust carbon offset markets reinforces the need of long funding timeframes that would bring stable cash flows in the likely absence of other revenues during the operational phases of projects, allowing more funds to be mobilized from private investors.[76]

**A CCS fund should employ strong early-mover incentive provisions to leverage its goals.** CCS deployment is time sensitive in two ways: i) global climate change mitigation goals require quick development and deployment of the technology, and ii) early action is also accompanied by higher costs due to underdeveloped technology and regulatory frameworks. An incentive for early movers also compensates for the learning-by-doing positive spillover that later entrants are able to capture from pioneers' investments, helping to neutralize potential wait-and-see attitudes. Counter incentives to delays in project implementation could also be set in place through modified sunset provisions applied to funds not utilized within the awarded funding window, encouraging project developers to stick to their schedules. Any funds not committed after 10 years should be returned to funders, or shifted to other climate change mitigation funds.

**Funding regulations should be flexible enough to allow for debt-to-equity ratios to act as incentives for different types of projects.** While an overall target of 70:30 debt-to-equity ratio is normal for large financing projects and could in principle be an adequate average ratio for the whole fund, individual projects could be allocated differently to incentivize certain actions over others in specific contexts, such as stimulating private equity investment in CCUS projects that will generate positive economic returns earlier. This would require experienced fund managers to evaluate the evolving portfolio composition and adjust the funding terms to incentivize specific types of projects on the margin.

**Lastly, it is imperative that there are incentives in place toward $CO_2$ storage.** In addition to preferring projects with the highest storage efficiency, a 10-year storage incentive on a rising scale could be applied to ensure project operators act to permanently reduce emissions and that financing will have the greatest climate change mitigation impact.

## 4. Conclusion

International policymakers and agencies are debating how to accelerate the development of CCS demonstrations in developing countries. The costs involved are significant, and the current global economic situation does not allow for frivolous spending on the part of any government. The question of how to best direct resources at CCS demonstrations in a non-OECD context is therefore of paramount importance. This paper explores key issues surrounding this question, including i) goals for OCED countries in providing funding, and ii) criteria for how CCS projects in developing countries should be selected to receive such financial support. The paper does not thoroughly investigate the optimal structure for a funding mechanism for CCS demonstrations in developing countries; however, it does highlight some general characteristics that should be present in such a mechanism and points a way forward for further research and analysis on this topic.

Without financial support from industrialized nations, the majority of developing countries are unlikely to take significant steps toward CCS development in the foreseeable future. International fora such as the Clean Energy Ministerial, the G8, and the Carbon Sequestration Leadership Forum can and should be leveraged to muster the political will to determine and act upon the best way to elicit such support. Only by conducting CCS demonstrations in developing countries (as well as in developed countries) will the merits of the technology be fully assessed, enabling deployment in the countries that choose to pursue CCS.

## Appendix

### Table A1: Existing definitions for incremental cost

| Source | Definition |
|---|---|
| EPRI (Specker et. al. 2009) | Incremental costs include the incremental capital costs for adding $CO_2$ capture and compression equipment as well as the costs of $CO_2$ transportation, measurement, and monitoring for the lifetime of the project. This currently does not include, but could also include, the added costs of purchasing replacement power for any lost output. |
| David and Herzog (2000) | Divide cost inputs into original and incremental, all related to electricity output and efficiency and $CO_2$ for incremental section. Normal costs inputs include the capital cost ($/kWh), cost of electricity with normal operation and maintenance (mills/kWh), and the heat rate (LHV). For the incremental costs, these include incremental capital costs, costs of electricity due to operation and maintenance, and the energy requirements of the capture process (kWh/kg) |
| CO2CRC IEA Summer School (Wiley 2009) | $CO_2$CRC looks at incremental costs from the perspective of overall cash flow because cash flows allow for costs to change over time, the effects of taxes or other costs can be added or changed over time; and full lifetime economies can be complete. Some less apparent factors that using cash flows can also account for are the discount rate and the lifetime of projects. Typical incremental costs include capital, operational, and abandonment (see Table A2 for examples). The $CO_2$CRC focuses primarily on the cost of electricity (COE) as they production unit which reflects the sum of the additional incremental inputs necessary for $CO_2$ capture. It is important to remember that this cost is not equivalent to the incremental price, which includes tariffs, network costs, and goods and services tax retail margins. Energy penalty is also considered as an input. |
| IPCC Special Report (2005) | Incremental costs will be very specific and will be determined in part by the approach and assumptions made, primarily with respect to the reference plant selected. IPCC expresses the energy requirement associated with $CO_2$ capture as the additional energy required to produce a unit of useful product, such as kWh electricity. Upstream costs are typically not included in incremental costs of CCS (e.g., additional infrastructure costs for coal transportation). An important factor to note when looking at incremental costs is whether the plant with CCS has the same net electricity output as the reference plant (meaning added fuel consumption and great $CO_2$ emissions) or if it is derated to provide auxiliary power. Some variables that go into equations determining incremental costs are: total capital requirements, fixed charge factor, fixed operating costs, variable operating costs, net plant heat rate, unit fuel costs, plant capacity factor, hours of operation, and net plant power. The major expenses however, are considered to be the additional capital expenses and the increase in the cost of electricity production. |
| MIT Future of Coal | Focuses only on the incremental COE, which is defined as the increase in total COE for a capture case with respect to the baseline, no-capture plant |
| DOE FutureGen | For the restructured FutureGen applications, the U.S. Department of Energy (DOE) agreed to cost share for incremental costs. They defined incremental costs and the additional cost of implementing CCS and other FutureGen goals on the Demonstration Unit when compared to a state-of-the-art facility without such technology. Incremental costs include but are not limited to:<br>· Gasifier or boiler modifications<br>· Turbine modifications to account for high-hydrogen combustion<br>· $CO_2$ separation, compression, pipeline transport, and injection<br>· CCS operating costs for the duration of the demonstration<br>· Monitoring, measurement, and verification<br>· Incremental cost of reducing sulfur, NOx, particulate matter, and/or mercury emissions below permit levels<br>· Site characterization, permitting, acquisition of mineral rights required, and liability insurance<br>· Cost-sharing is allowed for the costs to produce electricity as it is an incremental cost after CCS. Thus lost net output will not be reimbursed but the input and operational costs to generate additional energy to overcome the energy penalty are supported. |

### Table A1: Existing definitions for incremental cost (continued)

| Source | Definition |
|---|---|
| **Sen. Dorgan Report (Angielski and Obenshain 2010)** | Incremental CCS Capital Costs. Total incremental capital costs for only $CO_2$ capture is defined as the incremental capital cost difference between the best current power plant without $CO_2$ capture (e.g., a supercritical pulverized coal plant) and a power plant of equivalent electricity output that incorporates $CO_2$ capture; or in the case of a retrofit, the incremental capital cost to apply the requisite $CO_2$ capture equipment onto an existing unit. Some incremental capital cost estimates include the cost of transport, injection, and storage, while others include these costs in the estimates for additional operating expenses (see definition below).<br>Incremental Operating & Maintenance (O&M) Costs. In addition to the capital costs necessary for the construction or retrofit of capture technology, there are incremental annual O&M costs due to CCS. These costs could include replacement or maintenance of chemical catalysts, energy costs associated operating the CCS equipment, equipment maintenance over the life of the plant to operate the $CO_2$ capture equipment, $CO_2$ transportation via pipelines, $CO_2$ injection, and monitoring of the $CO_2$ injection sites.<br>In collecting information from a series of various studies, the definition of incremental costs from those studies varies greatly. This includes the inclusion and exclusion of operating costs, energy penalty, lifetime of project operation, etc. |
| **IEA Cost & Performance of CO2 Capture from Power Generation (Finkenrath 2011)** | Overnight costs are used as the indicator for capital costs. Assumptions for incremental costs include:<br>· Pre-construction costs: includes miscellaneous costs such as permitting, environmental reporting, land rights, mineral rights, and facilities that are all directly incurred by the project owner;<br>· Engineering, procurement, and construction costs: required total process capital;<br>· Contingency costs to cover uncertainties.<br>Levelized cost of electricity over the course of the plant's lifetime is then used to compare and is based on operational inputs such as net power output, net efficiency, $CO_2$ emissions, and the overnight capital costs with and without CCS for plants that are similar. |

### Table A2: List of some incremental costs of CCS

| Project Phase | Capital Cost | Operational & Maintenance Costs |
|---|---|---|
| **Capture** | · Capture Facility<br>· $CO_2$ Compressors<br>· Onsite Pipelines for $CO_2$ Transport<br>· Land-Purchase for Capture Facility | · Added Fuel Consumption<br>· Capture Agent Replenishment<br>· Maintenance, Repairs, and Monitoring<br>· Energy Penalty |
| **Transport** | · Pipeline Construction<br>· Pipeline Right-of-Way Permits/Land Purchase<br>· Compressors | · Maintenance, Repairs, and Monitoring |
| **Storage** | · Site Characterization<br>· Well Construction<br>· CO2 Injection Pump<br>· Storage Monitoring Equipment<br>· Storage Facilities | · $CO_2$ injection<br>· Injection Monitoring<br>· $CO_2$ Plume and Subsurface Monitoring<br>· Other Monitoring<br>· Maintenance and Repairs |
| **Other** | Legal and Regulatory Costs | |

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## Notes

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54 Angielski, S. and K. Obenshain, 2010. Senator Dorgan CCS Pathways Initiative: Coal Utilization Research Council (CURC) and Edison Electric Institute (EEI) letter to Interagency Task Force on CCS. 1 July. Online at: http://www.whitehouse.gov/sites/default/files/webform/dorganresponsetaskforce.pdf; see also the Appendix for a more detailed discussion of different definitions of "incremental cost."

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57 In some cases, characterization may reveal that a site is unsuitable for CO2 storage. These outcomes are expected and can still contribute valuable information and experience for CCS at that project locality.

58 Similar to the above note, some FEED studies may reveal projects to be unsuitable. Thorough application review should limit the number of projects for which this potentially occurs.

59 The vigorous discussion around how the World Bank should revise its energy strategy is a good example. The World Bank's own approach paper on the matter, and the Bank Information Center's (BIC's) analysis of the same subject both provide insight on the developing debate; BIC, 2011. World Bank energy strategy review. Online at: http://www.bicusa.org/en/Issue.48.aspx; The World Bank Group, 2009. Energy strategy approach paper. Sustainable Development Network. Online at: http://siteresources.worldbank.org/EXTESC/Resources/Approach-paper.pdf.

60 For instance, World Bank operating regulations do not allow it to support coal-to-liquid (CTL) projects. Hence, China's CTL plant with CCS in the Ordos Basin would not be eligible under World Bank criteria.

61 Zakkour and Cook 2010.

62 Zheng et al. 2010.

63 On a clarification note, the CCUS Action Group adopted the term "CCUS" in its name to have a wider scope in its recommendations to the CEM, allowing for the possibility of usage of CO2 in addition to its underground storage; the Group has no direct relationship with CCUS projects as defined here, or intention to limit its deliberations to EOR-related activities.

64 IPCC 2005.

65 Forbes, S., P. Verma, T. E. Curry, S. J. Friedmann, and S. M. Wade, 2008. Guidelines for carbon dioxide capture, transport, and storage. Washington D.C.: WRI. Online at: http://www.wri.org/publication/ccs-guidelines; Seligsohn, D., L. Yue, S. Forbes, D. Zhang, and L. West, 2010. CCS in China: toward an environmental, health, and safety regulatory framework. Washington D.C.: WRI.

66 S. Forbes, F. Almendra, and M. Ziegler, 2010. CCS and community engagement: guidelines for community engagement in CCS projects. Washington D.C.: WRI. Online at: http://www.wri.org/publication/ccs-and-community-engagement.

67 Available from GCCSI at: www.globalccsinstitute.com.

68 The World Bank is establishing its CCS work program in developing countries, and a significant part of its initial efforts are determining the real costs of CCS activities in a non-OECD context. An update of their current activities, including preliminary cost estimates (based on proxies calculated from assumed discounts over CCS projects in OECD countries, and the consequent need for real projects in developing countries to act as case studies) can be found at: http://www.cslforum.org/publications/documents/Warsaw2010/Kulichenko-PG-WorldBankPresentation-Warsaw1010.pdf.

69 IPCC 2005.

70 The CCUS Action Group meeting in Kyoto in October 2010 served to demonstrate a clear consensus between the national governments and the international institutions present. In that meeting, all parties agreed

that the best way to foster CCS development was through a financing mechanism solely dedicated to CCS. There was no consensus whether this should be a new fund or a window within an existing fund, since each formulation has its own advantages and disadvantages (e.g., a new mechanism could be more easily tailored from the bottom-up for CCS development, while a window within an existing fund would have lower cost in the setup process).

71 Tawney, L. and L. Weischer, 2011. Innovation and technology transfer: supporting low carbon development with climate finance. Working paper. Washington D.C.: WRI. Online at: http://pdf.wri.org/working_papers/innovation_and_technology_transfer.pdf.

72 Bhargava 2010.

73 As mentioned earlier, the IEA projects that the total incremental investment in CCS needed over the next 10 years in a non-OECD context is US$17.3 billion, yielding around 50 projects (10 in the power sector and 40 in industry and upstream applications) capable of collectively storing 116 MtCO2 per year by the end of this period. Assuming the technology costs keep constant over the development of these projects, incremental investments of US$5–8 billion would therefore potentially bring the storage of 33–55 MtCO2 annually in this context. The estimate of 45–60 MtCO2 captured takes into account the implementation rollout of these demonstrations linearly over time. Using a different approach, IEA's recommended annual CCS investment from 2010 to 2020 is US$1.25–2.25 billion; taking the current range of costs of US$30–150 per tCO2 avoided for CCS over different phases and contexts of CCS project development (see Table 3), a storage goal of 33–266 Mt can potentially be achieved over 10 years. On the other hand, the Asian Development Bank projects that total investments of US$5 billion would be sufficient to launch three to five commercial-scale CCS demonstrations in developing countries, each storing over 1 MtCO2 per year; this would lead to a rough estimate of 30–50 Mt of CO2 stored in 10 years of operations.

74 The Asian Development Bank estimates that US$5 billion committed by developed countries could generate an additional US$2 billion in project finance from multilateral development banks, and leverage an additional US$6 billion in private investment; Bhargava 2010.

75 Stern, N., 2007. Stern review on the economics of climate change. London: UK Treasury. Online at: http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/sternreview_index.htm.

76 For an additional discussion on the current challenges of leveraging private investment in CCS projects, see Climate Group (2010).

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