Rethinking CCS - Strategies for Technology Development in Times of Uncertainty

Jan Eide
MIT Energy Initiative

This MIT study[1] develops a realistic roadmap for moving ahead with the development of carbon dioxide capture and storage (CCS) technology in the current context of weak climate policies and tight public finances. The premise of the study is that the external circumstances for developing CCS technologies have changed dramatically over the past four years, and decision makers worldwide consequently need to significantly rethink their CCS policy.

Four years ago there was a strong belief that stringent climate policies would be enacted globally, and a number of organizations worldwide laid out ambitious roadmaps for the rollout and deployment of CCS. The IEA states for example that hundreds of CCS projects need to come online by 2025, and thousands more by 2050 (see figure 1).

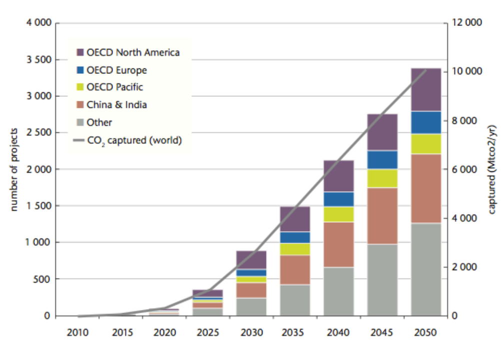

Figure 1: IEA CCS roadmap. Soure: IEA (2009)

Yet many of the assumptions on which the roadmaps where based upon are no longer valid, and the most notable of the altered external circumstances are:

1. ***Lack of comprehensive climate policies.*** Climate policies are required to create markets for CCS technologies, and the chances of strong climate policy being enacted in the near-term are remote. As a result, private investment in CCS will be limited at best.
2. ***Tight public finances***. CCS demonstration projects are highly dependent on government incentives, and more so given the lack of near-term climate policy. Austerity measures are therefore a serious threat to technology development.

[1] Eide J., "Rethinking CCS – Strategies for Technology Development in Times of Uncertainty" M.I.T. Masters Thesis, June (2013).
[2] The IEA for example continues to maintain a goal of limiting global temperature increase to 2^0C, and work their way backward to determine what actions need to be taken today.
[3] Mostly to solar PV ($25 billion), wind ($21 billion), and bioenergy ($15 billion). Source: IEA (2012). *World Energy Outlook 2012* pg 234

Current roadmaps are therefore poorly adapted to reality. These roadmaps work backwards from unrealistic aspirational goals[2], ignoring current political and economic realities. **By contrast, this study starts by recognizing the current political and economic situation and explicitly determines *a realistic roadmap* in moving CCS forward.**

Despite the challenging short-term realities, CCS continues to be a key mitigation option that will need to be available if large emission reductions are required in the future. Despite the significant threat posed by climate change, worldwide energy demand is growing and most of that growth continues to be supplied by fossil fuels. The growing demand for energy, and particularly fossil-fuel fired electricity, is particularly striking in emerging economies. Figure 2 clearly shows how Chinese and Indian electricity generation from coal (and by extension, CO_2 emissions) will continue to increase. This highlights the need for CCS technologies that can provide low-carbon electricity from fossil fuels. **Electricity generation from renewables received $64 billion in subsidies in 2011 worldwide[3], and a global CCS demonstration program with a cost of only a fraction of those subsidies does not seem an unreasonable investment.**

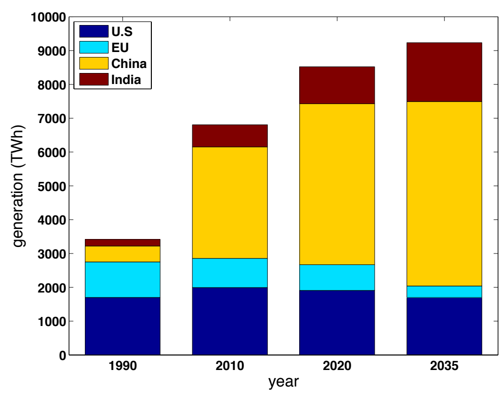

Figure 2: Electricity generation from coal in select regions[4]

While there have been a number of successful CCS demonstration projects worldwide, there is disappointment in the larger than anticipated number of project cancellations. Table 1 provides an overview of U.S. CCS demonstration projects. It is probable that most of the projects listed as "under development" will eventually be cancelled. One way of adapting to the challenging realities is through **much stronger coordination of demonstration efforts**. **With limited public funds available, international coordination could lower the financial burden on individual nations, and avoid**

---

[2] The IEA for example continues to maintain a goal of limiting global temperature increase to 2^0C, and work their way backward to determine what actions need to be taken today.

[3] Mostly to solar PV ($25 billion), wind ($21 billion), and bioenergy ($15 billion). Source: IEA (2012). *World Energy Outlook 2012* pg 234

[4] IEA (2012). *World Energy Outlook 2012* annex A

unproductive overlap between demonstration programs. However, pooling demonstration funds in some sort of international fund is likely to be politically challenging. A small group of countries could nonetheless agree on a joint demonstration strategy. Each country could for example commit to a specific aspect of CCS, and in aggregate they could explore the different aspects that are needed for commercial scale power generation with CCS.

Table 1: Large-scale U.S. CCS projects (> 1 MT CO_2/year). Source: MIT CSI database[5]

Project	Company	Source	CO_2 Fate	Status
U.S. Power Projects				
Kemper County (MS)	Southern	Coal Power	EOR	Under construction
TCEP (TX)	Summit Power	Coal Power	EOR	Under development
WA Parish (TX)	NRG	Coal Power	EOR	Under development
HECA (CA)	SCS	Coal Power	EOR	Under development
Trailblazer	Tenaska	Coal power	EOR	Under development
FutureGen 2.0 (IL)	FutureGen Alliance	Coal Power	Saline	Under development
Mountaineer (WV)	AEP	Coal power	Saline	Cancelled
Antelope valley (ND)	Basin Electric	Coal power	EOR	Cancelled
Taylorville (IL)	Tenaska	Coal power	Saline	Cancelled
Sweeny Gasification (TX)	ConocoPhillips	Coal power	Saline/EOR	Cancelled
Plant Barry (MS)	Southern	Coal power	EOR	Pilot operating, full-scale plant on hold
U.S. Industrial Projects (stimulus money)				
Decatur (IL)	Arthur Daniels Midland	Ethanol Plant	Saline	Operational since Nov 2011
Port Arthur (TX)	Air Products	Hydrogen Plant	EOR	Operational since Jan 2013
Lake Charles (LA)	Leucadia Energy	Methanol Plant	EOR	Under development

Technology development initiatives and demonstration projects are needed because challenges remain for both capturing and storing CO_2. Adding CCS to a fossil fuel-fired power plant would almost double the production cost of electricity[6], and with stringent climate policy lacking the technology might never be adapted in the marketplace unless costs are reduced. As a result, **policy makers should increase the effort to develop novel capture processes and capture methods that hold the promise for significant cost reductions**. Because funding is limited the effort to develop breakthrough concepts should therefore focus more on pilot-scale development. The lower cost of such projects (less than $100 million) would allow for a wider portfolio of technologies to be explored and developed, thereby significantly increasing the overall chance of success. Moreover, there is a **need for commercial-scale projects to address the concern over how to integrate the power plant and the capture system,** since the large steam extraction of a post-combustion capture system can affect power plant

[5] http://sequestration.mit.edu/tools/projects/index.html
[6] See for example Finkenrath M. (2011). Cost and performance of carbon dioxide capture from power generation. International Energy Agency (IEA) Energy Papers, No. 2011/05, OECD Publishing.

flexibility and operability. **For storage, uncertainty still remains over whether or not a sufficient number of reservoirs exist to safely and securely store gigatons of CO_2 a year**. Recent scientific articles[7] on the risks surrounding geologic CO_2 storage have introduced uncertainty around the viability of long-term storage. While initial field tests provide reason for optimism (i.e. the experiences from Sleipner and Snøhvit), only large-scale testing in a variety of heterogeneous reservoirs can provide definite answers.

The goal of policy makers worldwide should be to address the main questions and potential showstoppers facing CCS as a mitigation technology. **The study concludes that overcoming these roadblocks can be summarized as three key goals: (1) Lower the cost of capture, (2) Lower the uncertainty surrounding commercial-scale performance of CO_2 capture at power plants, and (3) Demonstrate the viability of long-term CO_2 storage at scale in geologic formations.**

In the absence of near-term climate markets it is difficult to raise sufficient funds to address these three goals. Investors and policy makers have therefore been searching for other uses of captured CO_2, particularly Enhanced Oil Recovery (EOR). **One example of the importance of EOR can be found in the U.S., where all but one of the ongoing power projects are planning to sell their captured CO_2 for EOR** (see Table 1)**.** Yet the cost of CO_2 capture from power plants is higher than EOR operators are willing to pay, and public subsidies are therefore still needed for CCS demonstration projects to come online. While EOR can be viewed as an existing market to allow for initial development of capture technologies at lower cost, **it is important to remember that EOR is not the endpoint, but rather a stepping-stone**. For CCS to have an impact on climate change, it will need to store billions of tons (gigatons) of CO_2 a year. The cumulative storage potential in EOR fields is insufficient to reach this level. **Therefore, gaining experience with storage formations with large potential storage volumes (i.e. saline formations) is critical to fully develop CCS as a climate mitigation technology.**

A number of jurisdictions worldwide have proposed or are considering CO_2 emission standards[8] that require coal-fired power plants to partially capture CO_2 in order to have approximately the same emissions as an uncontrolled natural gas-fired power plant. Using a stochastic generation expansion model to conduct an in-depth analysis of power sector investments under different emission standards, we show how these decisions change with different natural gas and EOR prices (i.e., the price EOR operators are

[7] See for example Zoback M, Gorelick S. (2012). Earthquake triggering and large-scale geologic storage of carbon dioxide. *Proceedings of the National Academy of Sciences* , **109**, 10164-10168.

[8] U.S. Environmental Protection Agency (EPA) in April 2012 proposed new source performance standards that would limit CO_2 emissions from new fossil fuel-fired power plants to 1,000 lbs/MWh. A final ruling was expected in April 2013, but has now been delayed. The UK government has proposed a CO_2 emission standard of 450 g/kWh[8] as part of the Electricity Market Reform, and the European Commission recently mentioned CO_2 emission standards as one potential way of incentivizing CCS projects in Europe.

willing to pay for CO_2)[9]. **The key result of this analysis is that the currently proposed CO_2 emission standards are more likely to result in a shift from coal to natural gas, rather than incentivize investment in CCS. This hold true even with very high EOR prices** (see Figure 3).

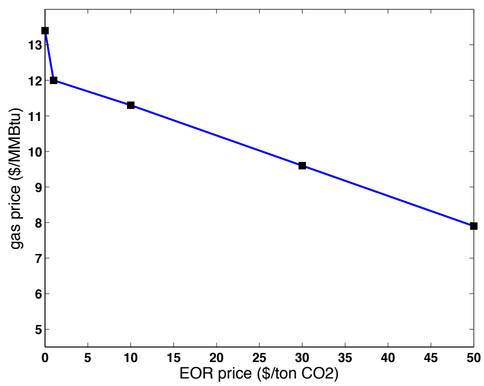

Figure 3: Natural gas price where coal-fired power plants with CCS enter the generation mix for EPA's proposed 1000 lbs CO_2/MWh emission standard

Two additional insights can be gained by running a similar analysis for different emission standards (i.e. both higher and lower than the currently proposed standards):

First, **granting a limited number of coal-fired power plants a higher CO_2 emission standard could be one way of bringing CCS power plants online in challenging times.** At the very least it could lower the need for very large incentives. The lower capture percentages needed to comply with higher emission standards would result in lower costs, which in turn could make up for the today's lack of adequate incentives or stringent climate policy. **A way of scaling political ambitions to political reality could therefore be to grant a small number of coal plants a higher emission standard contingent on them installing CCS.** The additional CO_2 emissions from these plants would have negligible impacts on climate change, but the technology development they would facilitate could be important in the future if more stringent climate policies were enacted.

Second, **if strict emissions standards are enacted that also require natural gas-fired power plants to partially capture CO_2, then CCS will likely be deployed on natural gas-fired power plants before coal-fired power plants**. This holds particularly true for the U.S, where natural gas prices are low. If emission standards are envisioned to gradually become tighter, then policy makers should also focus on demonstrating the

[9] The model uses a linear interpolation of key CCS cost parameters based on results in the 2011 National Energy Technology Laboratory report "*Cost and performance of PC and IGCC plants for a range of carbon dioxide capture*". The model also highlights the importance of considering uncertainty when analyzing CCS investments, and results differ notably depending on whether probability distributions over parameters are considered or not.

commercial-scale feasibility of CCS on natural gas power plants. None of the demonstration projects listed in Table 1 are at natural gas power plants.

With limited funds available for technology development there is a striking need to ensure that limited resources are allocated strategically. This study therefore developed a stochastic dynamic programming algorithm with Bayesian learning to determine the optimal allocation of funds across a portfolio of demonstration projects in order to maximize knowledge acquisition. The study limits the types of possible CCS demonstration projects to four, with two types of capture and two types of storage (see Figure 4). The number of high-purity CO_2 sources is small relative to the number of fossil fuel-fired power plants, and the cumulative storage potential in EOR fields is small compared to that of non-EOR formations. Consequently, if CCS is to operate at a gigaton-per-year scale necessary to mitigate climate change, the bulk of the projects are probably going to capture CO_2 from power plants and store it in non-EOR formations (the lower right quadrant). The model therefore assumes that policy makers are most interested in reducing the uncertainty in power generation capture and non-EOR storage.

These highly stylized projects are chosen because they have significantly different costs, and also contribute differently to learning. CCS projects are the most expensive, but also contribute the most to learning. CCUS projects are cheaper, but contribute less to learning about storage in non-EOR formations. HP-CCS projects are less expensive than CCUS projects, but contribute less to learning about power generation capture. Finally, HP-CCUS projects are the least expensive, but also contribute the least to learning. Since "knowledge" is hard to model quantitatively, the study assumes that reducing cost uncertainty correlates to acquiring knowledge. The optimization model therefore determines the combination of these four projects that over time minimizes uncertainty in the average cost of CCS projects.

	High-purity capture	**Power generation capture**
EOR storage	**HP-CCUS** **Learning:** - Less learning about capture - Less learning about storage **Cost** - Least expensive	**CCUS** **Learning:** - Learn about capture - Less learning about storage **Cost** - Expensive
Non-EOR storage	**HP-CCS** **Learning:** - Less learning about capture - Learn about storage **Cost** - Less expensive	**CCS** **Learning:** - Learn about capture - Learn about storage **Cost** - Most expensive

Figure 4: CCS project types

The model results are highly dependent on two different concepts: uncertainty and variability. Uncertainty in the average cost is due to a lack of knowledge and experience, and it will decrease as more knowledge is gained from demonstration plants. Variability is due to how observed costs will vary around the average, even after accounting for the site-specific heterogeneities of individual projects. Variability will persist even when there is enough knowledge to determine the average cost with confidence**. The key takeaway is that if there is significant variability, more observations will be needed in order to reduce the uncertainty.** Similarly, if there is little variability, then any observed cost will likely be close to the actual mean and less cost observations are needed. For the results shown here, **we took the variability in storage costs as being greater than the variability in capture costs.** This is based on the observation that accounting for site-specific heterogeneities is harder for geologic storage than for CO_2 capture from power plants. So **while the *uncertainty* is likely to be greater in capture costs than storage costs, the fact that the *variability* is smaller means that it is easier to "learn" about capture costs than storage costs.**

The key takeaway from the model is that due to the difference in variability, more storage demonstration projects than capture demonstration projects are needed to fully develop CCS as a viable mitigation option. Current proposals to shift investments to solely projects with EOR storage (CCUS) are only optimal if the uncertainty in storage costs is very low. **As a result, relying almost exclusively on projects with EOR storage is not a sound long-term strategy for developing CCS as a climate mitigation technology.** A balanced approach, with projects demonstrating both CO_2 capture at power plants as well as CO_2 storage in non-EOR formations is the most appropriate strategy for moving CCS forward in challenging times.

The goal of many of the current CCS roadmaps calls for large-scale deployment of CCS on power plants by 2020. However, these unrealistic ambitions that do not consider the current political and economic realities threaten the future of CCS rather than help it. **This study has concluded that the changed external circumstances should warrant considerable change in CCS policy worldwide. The key components of these changes are:**

1. ***Demonstration programs incorporating EOR should be viewed as a stepping-stone. A sound long-term policy for developing CCS as a mitigation technology must move beyond EOR storage. The focus on long-term, large-scale CO_2 storage projects in saline formations needs to be strengthened.***
2. ***More efforts are needed to demonstrate the feasibility of CCS on natural gas-fired power plants***

3. ***A stronger focus is needed on pilot-scale projects (vs. large-scale demonstrations) of novel capture technologies that hold the promise of significant cost reductions***
4. ***Current emission standards proposed for coal-fired power plants will not incentivize CCS projects. Looser standards can result in CCS at coal-fired power plants, while tighter standards may incentivize CCS at gas-fired power plants.***
5. ***There is a need for much stronger international coordination of demonstration efforts***

CCS holds tremendous promise as a climate change mitigation technology, and climate change is too much of a challenge to ignore. By following the recommendations in this study, policy makers worldwide can ensure that we continue to move forward in challenging times.