Rethinking CCS –
Moving Forward in Times of Uncertainty

"In order to keep moving ahead in these times of uncertainty, the CCS community will need to focus on the critical issues, find channels to increase coordination and collaboration, and identify instruments to fund the necessary R&D."

A Demonstration Project Sponsored by the Shenhua Group of CO_2 Capture from a Gasification Unit with Storage in a Saline Aquifer

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INTRODUCTION

Fossil fuels help drive the world economy because they are abundant and relatively inexpensive. They accounted for 81% of the global energy supply in 2010, and unless aggressive new measures are taken to reduce CO_2 emissions, they are projected to retain a 75% share in 2035.[1] Carbon Capture and Storage (CCS) is the only technology available to drastically reduce CO_2 emissions from fossil fuels that also allows the world to continue to reap their benefits without the negative impacts associated with climate change.

In early 2009, there was a strong belief that strict climate policies would be enacted, creating a demand for low carbon technologies, including CCS. President Obama was just elected and a climate bill looked likely to be enacted in the U.S. Internationally, there was great anticipation that the Copenhagen Conference of the Parties (COP) would result in a successor agreement to the Kyoto protocol. On both accounts, the conventional wisdom proved to be wrong. This has resulted in great uncertainty surrounding the future course of climate policy worldwide. Therefore, there is a need to rethink the path forward for CCS.

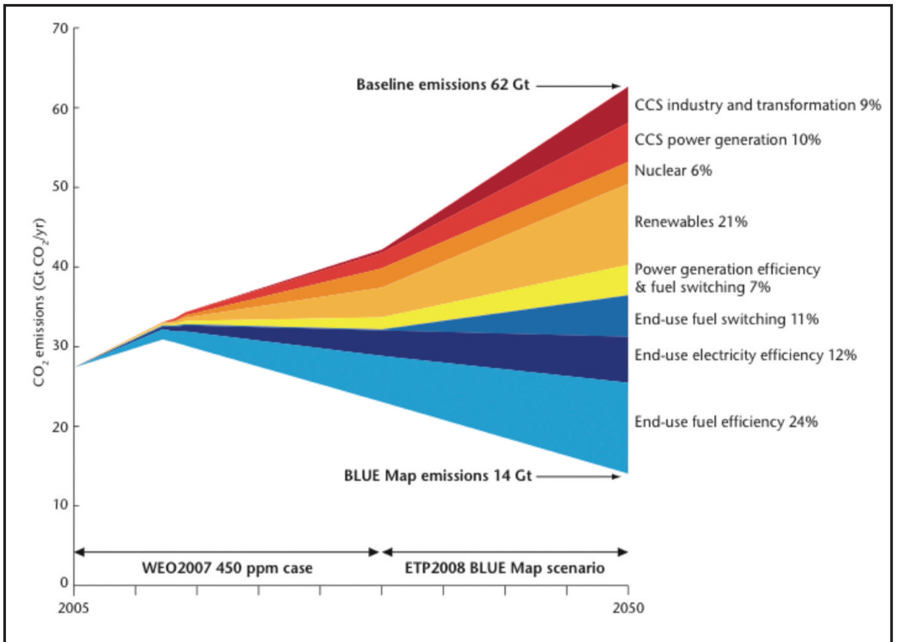
WHERE CCS STANDS TODAY

All the necessary components of a CCS system are in commercial use today. However, there is no CCS industry today because the components do not currently function together in the manner required for large-scale CO_2 mitigation. The challenge for CCS to be considered commercial is to integrate and scale up these components.[2]

Capture of CO_2 using amines was invented in the 1930s. Today, a number of companies provide commercial capture systems for natural gas processing plants or slipstreams from coal-fired power plants.[3] Large-scale CO_2 transport has been done commercially for decades. For example, in the U.S. there are currently 3,600 miles of CO_2 pipelines, transporting around 50 million tons of CO_2 per year from natural sources to enhanced oil recovery (EOR) operations, where it is injected into

TABLE 1. Share of Fossil Fuel CO_2 Emissions Appropriate for CCS. Adapted from (IPCC, 2005) Table 2.3[7]

Source	Share
Coal power plants	59.7%
Natural gas power plants	11.3%
Other power plants	7.0%
Cement	7.0%
Refineries	6.0%
Iron & Steel industry	4.0%
Petrochemical industry	2.0%
Other	0.6%



Source: IEA, *Energy Technology Perspectives* (2008a).

FIGURE 1. IEA Blue Map Scenario. CCS Represents 19% of Emissions Reductions[9]

oil reservoirs.[4] Large-scale injection (~1 million tons per year) of CO_2 into other geologic formations is currently undertaken at a handful of locations globally, most notably at In Salah (Algeria)[A], and Snøhvit and Sleipner (Norway).

Nonetheless, uncertainty still exists regarding the capability of CCS as a key mitigation technology. Questions about the viability of large-scale CO_2 storage have been raised in the scientific literature.[5,6] While many experts have responded that these concerns are overstated, only long-term, large-scale storage demonstrations can provide definitive answers. Commercial-scale capture on operating power plants has yet to be undertaken, leading to uncertainty regarding scale-up and integration of existing technologies. Furthermore, costs are still high and a significant R&D effort is needed to bring them down. If public policy in the future calls for large-scale emissions reductions, it is important today to advance the state of readiness of CCS and determine what role it can play in a climate mitigation portfolio.

The development of CCS, like many energy technologies, requires significant lead times. Past experiences from developing clean energy technologies suggest that several decades are often required before a new concept is commercially adopted.[3] While significant restrictions on CO_2 emissions may be off in the future, there should be a sense of urgency to get on with the task of developing low carbon technologies like CCS right now.

CCS has been discussed as an option to reduce CO_2 emissions for a number of large, stationary sources (see Table 1). The largest target group for CCS is coal-fired power plants at about 60%. Electricity generation from coal almost doubled from 1990 to 2010, and the projected increase in generation up to 2020 is almost twice that of wind and solar photovoltaics.[1]

Coal was responsible for 43% of global CO_2 emissions in 2010[1], and in a carbon-constrained world the only option for coal without CCS is not to use it. Therefore, if CCS is to be used for large-scale climate mitigation, it is clear that technology development should focus on applying CCS to power plants, with a particular emphasis on coal-fired plants.

LONG TERM OUTLOOK FOR CCS

The long-term need for CCS remains strong. Climate change continues to be a significant threat, and recent research suggests the challenge is growing more, not less, serious.[8] Simultaneously, worldwide energy demand, particularly in emerging economies, is growing rapidly. Much of the current, and future, demand for energy will continue to be supplied by fossil fuels, further increasing atmospheric CO_2 concentrations. Consequently, there is a strong long-term need for technologies that can supply low-carbon energy from fossil fuels. The International Energy Agency (IEA) projects in its Blue Map scenario that if the world wants to halve global CO_2 emissions by 2050, then CCS will account for 19% of total emissions reductions[9] (see Figure 1). CCS is not the only mitigation technology available, yet a number of studies have shown it could have significant importance in future technology portfolios.[10] Such studies are nonetheless uncertain, and modeling results should therefore be treated with caution. On the one hand, actual costs of CCS may end up being considerably higher than those anticipated today, and other disruptive technologies are hard to incorporate in models.

On the other hand, there could be a disruptive advance in CCS technology. The benefit of investing in CCS is that it increases the number of potential technologies to mitigate climate change. It has been shown that it is important to maintain a portfolio of low carbon technologies, and excluding CCS could add significantly to mitigation costs.[11]

TABLE 2. Selected Large-scale* Integrated Power Plant CCS Projects[15]

Project	Company	Source	CO_2 Fate	Status
UK Competition				
White Rose	Alstom	Coal Power	Saline	Awaiting award
Peterhead	Shell and SSE	Gas Power	Depleted Gas	Awaiting award
U.S. Power Projects (Clean Coal Power Initiative plus stimulus money)				
TCEP (TX)	Summit Power	Coal Power	EOR	Under development
Kemper County (MS)	Southern	Coal Power	EOR	Under construction
WA Parish (TX)	NRG	Coal Power	EOR	Under development
HECA (CA)	SCS	Coal Power	EOR	Under development
FutureGen 2.0 (IL)	FutureGen Alliance	Coal Power	Saline	Under development
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
Selected Other Projects				
Mongstad (Norway)	Statoil	Gas Power/Refinery	To be determined	Pilot operating
Boundary Dam (Canada)	SaskPower	Coal Power	EOR	Under construction

* Large-scale means on the order of a million tons of CO_2 per year.

CCS DEMONSTRATION PROJECTS

In order to pave the way for large-scale deployment of CCS technology, several organizations have set out roadmaps that describe the path that needs to be taken over the next several decades. The IEA states that 100 CCS projects are needed by 2020, and close to 3500 by 2050.[12] The leaders of the G8 countries pledged in 2008 that 20 large-scale demonstration projects should be launched by 2010 and large-scale deployment should start in 2020.[13] The U.S. goal is to have five to ten commercial scale demonstration plants online by 2016[4], and the European Commission in its recently released Energy Roadmap 2050 projects power plants with CCS to account for 19-32% of power generation in 2050.[14]

A limited number of demonstration projects are currently moving ahead (see Table 2), but despite a number of successes, we are falling short of the ambitious goals laid out in the roadmaps mentioned above. Many cancellations over the past two years show how changing short-term realities are challenging CCS technology development. However, there is nothing inherent in CCS as a mitigation technology that caused projects to cancel. The primary reason for project cancellation, at least in the U.S., was that the lack of climate policy led to an absence of clear commercial markets. Without these markets, utilities were reluctant to go ahead with billion-dollar investments.

While a few projects are still active, the bleak short-term realities for CCS market potential have resulted in no new projects being announced. With stringent climate policy delayed, it is more difficult to keep CCS development moving forward at an adequate pace. When climate policy is finally enacted, it will be beneficial to have CCS commercially available. Even though this moment may be a decade or two away, with no new projects announced there is a real risk that CCS technologies will not be commercially available when needed.

REASONS FOR SLOW PROGRESS

Three short-term factors are changing the political and economic realities of CCS development, contributing to the slowed momentum described above.

First, there are a lack of comprehensive climate policies. CCS is dependent on climate policies to drive it, and the political environment for climate policy is unwelcoming. The future of a global, legally binding emissions reductions agreement is uncertain, no comprehensive climate bill is likely to pass through the current U.S. Congress, and the allowance price of the European Emissions Trading System (ETS) is far too low to incentivize CCS investment. While some markets exist for the utilization of CO_2 (i.e., EOR), their magnitude is much smaller than markets needed to abate climate change. Therefore, in the longer-term, there is no substitution for climate policy to create markets for CCS.

Second, tight public finances are challenging the economics of demonstration plants. While companies may support some R&D efforts, given the lack of imminent climate policy, their support will be limited. CCS demonstration projects are highly dependent on government subsidies, and austerity measures are therefore a serious threat to technology development. One example is the U.S. debate over automatic spending cuts, the so-called "sequester". These cuts could potentially lower Department of Energy (DOE) funding by between $170 million and $400 million per year, the lower end of which is equivalent to approximately one third of the DOE's Fossil Energy R&D program.[16] While R&D spending cuts are not as immediate in Europe, the R&D spending is expected to decline as a result of the debt crisis.[17]

Third, the high costs of CCS demonstration projects. Most studies estimate that CCS would add 40-80% to the cost of electricity from coal and cost from $40-70/tonne CO_2 avoided.[18] The economics are made worse in that first-of-a-kind demonstration projects are significantly more costly than the projected n^{th} plant costs. In the absence of climate policy and with strained public finances, these high costs are an additional barrier to technology development.

RESPONSES TO THE CHALLENGING REALITIES

The UK has been a key player in developing CCS technology and initially had a £1 billion competition to build a coal-fired power plant with post combustion capture. Unfortunately, the competition ended in 2011 with no awards being made.[19] Nonetheless, the UK government continues to make £1 billion available for demonstration projects (see Table 2) and opened a new competition to a wider range of capture technologies in April 2012, hoping to have projects operational between 2016 and 2020.[20] In addition to the incentive provided by the competition, the Electricity Market Reform, likely to be enacted in 2013, will provide a guaranteed price of electricity for CCS through a contract-for-differences.[21]

In Europe the goal was to have twelve demonstration plants online by 2015. Six demonstration projects were awarded €1 billion in 2008 under the European Union (EU) stimulus plan, and another eight projects were to receive funding through the NER300 program.[22] Unfortunately, no CCS projects were funded in the first round of allocations announced on December 18, 2012, as projects failed to meet the requirements by the announcement deadline.[23] Although some CCS projects might receive funding in the second round of allocations, it is clear that the EU will fall short of its ambitious targets for CCS demonstration projects. In the current economic and political environment, only a small fraction of the projected 12 projects are likely to come into operation.

In the U.S., utilization of captured CO_2 has received increased attention in the absence of climate policy. Most notably, EOR has been viewed as a key potential market for CCS technology. The U.S. EOR market used 44.2 million tons CO_2 in 2009, with the availability of CO_2 supply being the biggest impediment to its growth.[24] Consequently, many actors are viewing EOR as a key driver in moving demonstration projects forward. There are four notable ways in which EOR can aid in the development of CCS: (1) by helping the economics of capture projects by putting a positive value on CO_2, (2) by building CCS infrastructure, such as CO_2 pipelines, (3) by developing capacity along the supply chain, including engineering services and equipment manufacturers, and (4) by shaping the regulatory environment, including the liability issue.

Despite potentially playing an important role, it is important to keep in mind that EOR should only be viewed as a stepping-stone, not an end goal. CCS on coal-fired power plants is too expensive for EOR revenues on their own to cover the cost, and public subsidies of some sort are likely to be needed to commercialize the technology. As a consequence, EOR cannot replace climate policy as the primary driver for investment in CCS. Equally important, while EOR projects can help develop the capture technologies, they will provide limited knowledge on storage reservoirs. Given the importance of proving the viability and safety of geologic CO_2 storage, policy-makers should be cautious about pursuing an EOR-only strategy for CCS development.[25]

A second important development in the U.S. is the Environmental Protection Agency's recently announced New Source Performance Standard (NSPS) for CO_2 emissions from new power plants. If finalized, the rule would require all fossil fuel-fired power plants to limit CO_2 emissions to 1000 lbs/MWh. As the target is unattainable for coal plants without capturing CO_2, the NSPS could potentially create a market for CCS technology. However, the target approximately equals the CO_2 emissions of a Natural Gas Combined Cycle (NGCC) unit. Consequently the emission standard is more likely to result in a shift from coal to natural gas, rather than incentivize investment in CCS. Even with the presence of EOR revenues, natural gas prices would have to be above \$9/MMBtu for coal-fired power plants with partial capture to be preferred over NGCC units.[25] By comparison, U.S. natural gas prices for power generation were \$4.42/MMBtu in November 2012.[26]

Home to the largest coal fleet in the world[1], China has received considerable attention as a future market for CCS technology. Given its considerably lower construction costs, some actors have also seen China playing a leading role in technology development. A number of projects are currently underway, most notably Alstom's 350 MW fuel combustion project in Daqing and the 400 MW GreenGen IGCC plant at Tianjin City. While China will likely be an important player if CCS is to be deployed at scale globally, it is unlikely on its own to foot the bill for CCS technology development. It would be a mistake to expect China to pick up the slack from scaled-back ambitions in the EU and the U.S. If Western electricity consumers are unwilling to foot the bill for funding CCS technology development, is it really realistic to expect the Chinese to be more amenable to the idea?

MOVING FORWARD

As a consequence of the changed external realities, the initial roadmaps for technology development may no longer be feasible, as witnessed by the many project cancellations. The long-term need for CCS remains unchanged, but moving CCS to commercial readiness will be challenging in the current political and economic environment. What can be done today to ensure the future viability of CCS as a mitigation technology? First of all, it is important to realize and acknowledge the new realities and understand that they pose serious challenges for CCS. Not acknowledging the political and economic realities, and not adjusting ambitions in response to them, could seriously threaten the future of CCS.

With fewer demonstration projects than initially believed, it is of increasing importance that public funds are spent strategically in order to overcome the barriers to commercialization. Many of the countries considered at the forefront of CCS development face the same challenges, and regions that once believed they would have five or ten demonstration projects may now only have one or two. Working together to get the most out of scarce resources therefore becomes increasingly important. A global demonstration program, funded by some international institution, is highly unlikely given the high cost of demonstration projects. If a government invests hundreds of millions of dollars in a project, it is likely to want it within its borders. Nonetheless, the challenging realities make a case for much stronger international coordination of demonstration programs. A smaller number of countries could agree on the key focus areas of technology development, and then each could focus their efforts where they believe they could best contribute. By coordinating efforts, one could avoid unproductive overlap between demonstration programs, thereby ensuring that limited resources are spent in a way that yields the highest returns.

A critical question is how to pay for the development of CCS. At least \$1-2 billion annually is likely to be required to support development of a portfolio of capture technologies, as well as large-scale storage projects. As discussed above, current markets are insufficient to finance such efforts. With the increasing pressure on public budgets, there is a striking need for a sounder base of funding, one that is not subject to annual appropriations from either a Congress or Parliament. While companies may support some R&D efforts, given the lack of imminent climate policy, their support will be limited. One option is to finance the CCS R&D effort through a small surcharge on electricity from fossil sources. For example, in the U.S., approximately \$20 billion could be raised over ten years by a \$0.9/MWh surcharge on coal-generated electricity and a $0.45/MWh surcharge on gas-generated electricity.

Finally, a CCS R&D program needs to have the right focus and the right scale. For developing capture technologies, much progress can be made in the laboratory and the pilot plant. However, many of the issues regarding geological storage may require large-scale demonstrations. We need to know what combination of projects in a CCS R&D portfolio will maximize learning about CCS as a mitigation technology. Because there is significant heterogeneity between storage reservoirs, initial results from an analysis we are conducting suggest that demonstration projects should focus more on the storage issues than the capture issues.[25]

EVEN WITH UNCERTAINTY, CCS MUST PROGRESS

In summary, these are challenging times for those trying to advance CCS technology, despite the soundness of the basic technology and the long-term need. In order to keep moving ahead in these times of uncertainty, the CCS community will need to focus on the critical issues, find channels to increase coordination and collaboration, and identify instruments to fund the necessary R&D. Ultimately, advanced technology will provide the solution to climate change and CCS is one of the primary technological options. It is critical to keep moving forward.

ACKNOWLEDGEMENTS

We would like to acknowledge the MIT Carbon Sequestration Initiative for their financial support of this research. The list of member companies can be found at http://sequestration.mit.edu/CSI/csi_participants.html.

We would also like to acknowledge our MIT colleagues Mónica Lupión, Sadia Raveendran, Holly Javedan, and Mary Gallagher for their input and assistance in preparing this manuscript.

NOTES

A. In Salah suspended injection in June 2011, after 7 years of operation.

REFERENCES

1. International Energy Agency, World Energy Outlook 2012, 2012, OECD Publishing.

2. H. Herzog, *Energ. Econ.*, **2011**, *33*, 597-604.

3. E. Rubin, H. Mantripragada, A. Marks, P. Versteeg, J. Kitchin, *Prog. Energy Combust. Sci.*, **2012**, *38*, 630-671.

4. Department of Energy, Report of the interagency task force on carbon capture and storage; Interagency Task Force on Carbon Capture and Storage, 2010: Washington, D.C.

5. C. Ehlig-Economides, M.J. Economides, *J. Petrol. Sci. Eng.*, **2010**, *70*, 118–125.

6. M.D. Zoback, S.M. Gorelick, *Proc. Natl. Acad. Sci.*, **2012**, *109*, 10164-10168.

7. IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2005; pp 442.

8. NCADAC, Draft Climate Assessment Report. National Climate Assessment and Development Advisory Committee. http://ncadac.globalchange.gov/ (accessed February 20, 2013).

9. International Energy Agency, Energy Technology Perspectives, 2008, OECD Publishing.

10. H.C. McJeon, L. Clarke, P. Kyle, M. Wise, A. Hackbarth, B. Bryant, R.J. Lempert, *Energ. Econ.*, **2011**, *33*, 619-631.

11. IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change (IPCC) [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1075.

12. International Energy Agency, Carbon Capture and Storage, 2009, IEA Technology Roadmaps, OECD Publishing.

13. Japanese Ministry of Foreign Affairs. G8 Hokkaido Toyako Summit Leaders Declaration. http://www.mofa.go.jp/policy/economy/summit/2008/doc/doc080714__en.html (accessed February 21, 2013).

14. European Commission, Energy Roadmap 2050, COM (2011) 885 final of December 15, 2011.

15. MIT Carbon Capture and Storage Technologies, Project Database. http://sequestration.mit.edu/tools/projects/index.html (accessed February 20, 2013).

16. M. Mourihan, Brief- Federal R&D and Sequestration in The First Five Years, 2012, AAAS analysis: Federal R&D and Sequestration, American Association for the Advancement of Science (AAAS).

17. Battelle and R&D Magazine, "2013 Global R&D Funding Forecast" 2012, R&D Magazine, December.

18. M. Finkenrath, Cost and Performance of Carbon Dioxide Capture from Power Generation, 2011, IEA Energy Papers, No. 2011/05, OECD Publishing.

19. C. Gough, S. Mander, *Energy & Environment*, **2012**, *23*, 367-374.

20. UK Government, CCS Commercialisation Competition. https://www.gov.uk/uk-carbon-capture-and-storage-government-

funding-and-support#ccs-commercialisation-competition (accessed February 15, 2013).

21. UK Government, Supporting detail: Electricity Market Reform. https://www.gov.uk/government/policies/maintaining-uk-energy-security—2/supporting-pages/electricity-market-reform (accessed February 15, 2013).

22. European Commission, Communication: Realising the Carbon capture and storage (CCS) demonstration programme, 2011, http://ec.europa.eu/governance/impact/planned_ia/roadmaps_2012_en.htm (accessed February 20, 2013).

23. European Commission, Questions and Answers on the outcome of the first call for proposals under the NER300 programme, 2012, European Commission MEMO/12/999.

24. B. Suresh with S. Schlag and T. Kumamoto, Carbon Dioxide, CEH Marketing Research Report, 2010, Chemical Economics Handbook (CEH) - SRI Consulting.

25. J. Eide, Rethinking CCS - Strategies for Technology Demonstration in Times of Uncertainty. Master's thesis, Massachusetts Institute of Technology (MIT), Cambridge MA, June 2013 (forthcoming).

26. U.S. Energy Information Administration, Natural Gas Data, http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm (accessed February 20, 2013).