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Carbon dioxide capture and storage: Seven years after the IPCC special report

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Carbon dioxide capture and storage (CCS) entails separating carbon dioxide from coal-, biomass- or gas-fired power plants or other large industrial sources, transporting the carbon dioxide by pipeline, injecting it deep underground, and storing it indefinitely in geological reservoirs including depleted oil and gas fields, and saline aquifers. CCS is envisioned to reduce carbon dioxide (CO_2) emissions to the atmosphere when applied to large facilities that use fossil fuels. Applied to biomass, it may also lower CO_2 concentrations in the atmosphere while supplying energy.

The publication of the United Nations Intergovernmental Panel on Climate Change (IPCC) (2005) Special Report on CCS (SRCCS) raised the profile of CCS, particularly among the expert community dealing with international climate policy (Meadowcroft and Langhelle 2009). The expert community now commonly sees CCS as a major option for reducing global emissions of CO_2. The technology plays a major role in long-term scenarios where there is significant reduction in greenhouse gas emissions (Clarke et al. 2009; IEA 2010a). For CCS to play such a major role, the separation, transport and storage would have to handle large volumes of CO_2, and involve huge investments in facilities and infrastructure.

The SRCCS conveyed some key insights. First, it clearly indicated that in principle, CCS is technically feasible. It also found that subsurface endowments of geological storage are probably massive, but regionally distributed and still highly uncertain.

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The management of storage risks was deemed critical given the varied nature of geological structures and the potential risks and environmental impacts of CCS. The cost of CCS applied to power generation was assessed to be dominated by the cost of capture, and that cost added to the cost of electricity. However, even with the high costs of CCS, the economic potential was estimated to be large in scenarios where there was a significant price on carbon or equivalent incentive. In regions with sufficient accessible storage potential, and if cost-effectiveness of CO_2 reductions is the core criterion, CCS was assessed to be cost competitive with other options for deep reductions in greenhouse gas emissions.

At the time of the preparation of the SRCCS it was recognized that the literature on CCS was limited, but growing rapidly. In particular, literature – and experience—was very limited on public acceptance of CCS and on specific environmental risks of CCS, limiting the assessment of these topics. In the meantime, new developments arose. Compared to when the SRCCS was published, the main developments have been threefold: first, climate policy did not materialise in many parts of the world, leading to low incentives for CCS; second, costs of CCS turned out variable but in general higher than initial estimates; and third, public acceptance turned out to be a significant barrier.

Five years after the publication of the SRCCS we invited papers to be submitted for this special issue on topics that have evolved since its preparation. While this special issue does not give a full update, it does go into new developments concerning CCS that had not benefited from extensive discussion in the SRCCS, such as the public perception of CCS, embedding CCS in the energy system, and challenges faced by CCS demonstration projects.

Following soon after the publication of the SRCCS, the International Energy Agency (IEA) and the Carbon Sequestration Leadership Forum (CSLF) – in response to the 2005 Gleneagles Group of 8 (G8) invitation to provide information on CCS—developed a set of recommendations to address apparent barriers to progressing CCS (see, IEA 2010b) with 8 major recommendations regarding:

1. demonstrating CCS
2. taking concerted international action
3. bridging the financial gap for demonstrations
4. creating value for CO_2 for commercialization of CCS
5. establishing legal and regulatory frameworks
6. communicating with the public
7. infrastructure
8. retrofit with CCS capture

Emphasis was put on moving forward on demonstrating CCS recognizing that a “financial gap” exists between added costs of CCS and realizable financial benefit from CO_2 reduction (IEA 2010b). Barriers notwithstanding, the IEA (2008) also produced the “blue map scenarios” with emission reductions occurring at a pace and scale to approach the climate goal of staying below 2° centigrade global mean temperature rise later expressed in the United Nations Framework Convention on Climate Change Copenhagen Accord (UNFCCC 2009). CCS is a prominent contributor to emission reduction in such scenarios and in scenario analyses costs of achieving such reductions would go up significantly if CCS were infeasible (Clarke et al. 2009). In 2009, the Global CCS Institute was initiated, an institution aimed at facilitating demonstration of CCS. In 2011—6 years after publication of the SRCCS – the Conference of Parties (UNFCCC 2011) accepted CCS in the Clean Development Mechanism through agreement of its modalities and procedures.

In this issue, Court et al. provide an overview of the issues and barriers faced by CCS projects recognizing that the number of projects would need to increase by several orders of magnitude over the next two decades for CCS to reach the promise described by the IEA scenario. Court et al. examine a wide range of challenges and pay particular attention to water use and management in CCS—a topic barely touched in the SRCCS. In addition, Stigson et al. identify discrepancies between perceptions of CCS technology with industry stakeholders and the experience of attempts to implement CCS demonstrations, and identify what they refer to as a *cognitive gap*. Industry stakeholders identify barriers to CCS as primarily finance- and policy-related, however Stigson et al. find demonstrations cancelled because of technical and public perception issues.

Over the last 7 years, however, the financial gap appears to have widened and not narrowed. The cost of CCS has been impacted by inflation in the construction of industrial facilities (Hamilton et al. 2009), as well as energy prices and fuel costs, and with the closer examination of costs in the many demonstrations that are being considered cost estimates have risen (GCCSI 2011; NETL 2007; EPA 2010). Furthermore, the long lifetime of power plants combined with the goal of deep reductions of greenhouse gas emissions has increased focus on the retrofit of power plants (MIT 2007), and retrofit presents additional technology and economic challenges (MIT 2009). In this issue, Chalmers et al. explore if flexibility in power generation – e.g. by turning CO_2 capture on or off, or storing CO_2 solvent for later regeneration – in retrofit coal power plants increases the value proposition for retrofit CCS. Chalmers et al. find that flexibility can provide advantages under some CO_2 and electricity price combinations. However, the prospects for high and reliable carbon prices are not expected in the near-term to be sufficient to justify investment in CCS, leaving an emphasis on demonstrations.

With the high-level focus on demonstrating CCS has come further research on what might be achieved by demonstrations. Pilot and demonstration projects worldwide are addressing some technical gaps in knowledge and experience in areas such as site selection, monitoring, and local risk assessment. However gaps remain in demonstrating long-term, safe storage of large-scale, integrated CCS projects. Reviewing the long list of projects compiled by the Global CCS Institute (GCCSI 2011) reveals a diversity of projects. However, the portfolio includes only eight operating large scale integrated projects of which none involve CCS applied to power generation and all involved either storage via enhanced oil recovery (EOR), and/or capture from natural gas processing. Unfavourable economics of CCS is leading to the cancellation of large-scale projects applied to power generation (c.f. Wald and Broder 2011) while projects with more favourable economics involving EOR are finding more success and greater attention (see, e.g., EPA 2010). This is leading to some learning, but less than if the full-scale demonstration portfolio were more diverse. From a social science perspective, the Russell et al. paper in this issue examines the role of large-scale CCS demonstrations, recognizing that scrutiny of these demonstrations will be intense and technology demonstration will be viewed as a political activity. Russell et al. develop a social science research agenda as a set of questions to be applied to demonstrations that may clarify what we should expect, and not expect, from demonstrations.

The institutions shaped to deal with CCS may be important enablers for CCS or may form barriers to CCS. Consistent with the IEA (2010b) recommendation to establish legal and regulatory frameworks, there have been recent developments of such frameworks as surveyed by the IEA (2010c). Institutions are important for the development of infrastructure, and in this issue Heitmann et al. review the recent literature on CCS-related infrastructure throughout Europe and discuss the policy issues that would need to be addressed if CCS were to be deployed widely in the coming decades. They find a CCS infrastructure of pipelines and storage sights over multiple jurisdictions leads to coordination challenges, which could be overcome in an economically beneficial way if governments would incentivise infrastructure aspects like over-dimensioning of pipelines. They review factors for policy coordination needs and recommend that both EU and national policy frameworks are set up for CCS to address transportation issues.

Public acceptance has become a pivotal issue for recent CCS projects in, for example, the Netherlands, Germany, Denmark, Australia and the USA. In this issue, Anderson et al. find that delay or cancellation of energy infrastructure projects—from wind farms to nuclear power plants and more recently CCS—because of community resistance are common, yet some communities accept such projects with relative ease. They draw lessons on public participation from Australia's Otway CCS Project. The acceptance of the project by the community was found to be in part thanks to the skill building in the community, which allowed the community to negotiate the project developer into addressing the community's concerns. As the project developer responded to those concerns in time, the project was ultimately accepted.

There are differing perspectives on what are the barriers (e.g. economic, institutional, acceptance, and technical) to CCS projects and, moreover, what is the need for CCS in relation to other options for addressing climate change. In this issue, Stigson et al. compare stakeholder perceptions of the CCS deployment obstacles gathered though a survey to case studies of early CCS demonstration plants. Stigson et al. find the obstacles that have actually contributed to the failure of many proposed CCS projects are not always consistent with the perceived obstacles. They conclude that better understanding of obstacles to CCS could lead project proposals with higher likelihood of success. Finally, Viebahn et al. carry out an analysis of the need for CCS in the German power sector, and find that under some conditions—with improvement of end use efficiency and deployment of renewable energy—CCS may not be needed in Germany. However, CCS may have an important role if such a scenario for Germany would not come true.

The research published in this issue shows that the understanding of CCS has moved beyond the assessment in the IPCC SRCCS. It addresses many issues associated with the eight challenges implicit in the IEA (2010b) recommendations to the G8 listed above. The analysis is sobering on the one hand—more hurdles are in the way of CCS than reported 7 years ago – but encouraging on the other, as to some barriers and uncertainties, solutions are proposed. How quickly – or even if – the challenges will be met in the future is uncertain. Recognizing this uncertainty improves our understanding of CCS and contributes to designing and managing the portfolio of actions to meet these challenges as well as to better manage CCS as one option in the portfolio of options available for society to address climate change, energy, and other pressing societal issues.

It is with sadness that we report that Stewart Russell - the co-author of one of the papers in this special issue - passed away in 2011. He is greatly missed by co-authors and collaborators.

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