International Center for Climate Governance

Advances and slowdowns in Carbon Capture and Storage technology development

Aurora D'Aprile, ICCG

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Abstract

With the significant long term goal of holding the increase in the global average temperature to well below 2°C and "to pursue efforts to limit the temperature increase to 1.5°C", the outcome of COP21 raised attention on the portfolio of technologies needed to achieve consistent emission reductions and to reach "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". Carbon capture and storage (CCS) technology, after having been hailed as a promising mitigation option around a decade ago, is undergoing a grueling path to stay on top of the expectations. The opportunities and constraints in deploying large-scale carbon capture and storage systems are of the utmost actuality, as the technology promises to get rid of up to 90% of the most common greenhouse gases produced in industrial and energy plants before they reach the atmosphere (or even to achieve "negative" emissions, if combined with biomass). Despite potential benefits, CCS development and deployment have proceeded at a far slower rate that what was expected, and CCS is struggling to emerge as a sound low-carbon choice for governments and investors. Based on recent existing literature, this reflection explores the main progress and deadlocks in CCS's difficult path.

Introduction: Enter Carbon Capture and Storage

With the long term goal of holding the increase in the global average temperature to well below 2°C and "to pursue efforts to limit the temperature increase to 1.5°C", the Paris Agreement puts renewed attention on the portfolio of technologies needed to achieve consistent emission reductions and reach "a balance between anthropogenic emissions by sources and removals by sinks" in the second half of this century.

Renewable energy sources are experiencing a "golden age", with cheaper prices and mature development leading to a record high in global investment of USD328.9 billion in 2015.[1] By contrast carbon capture and storage (CCS) technology, after having been hailed as a promising mitigation option around a decade ago, is undergoing a grueling path to stay on top of the expectations and emerge as a sound low-carbon choice for governments and investors.

CCS includes a range of technologies to sequester carbon dioxide from fossil fuel plants and industrial facilities (blast furnaces, cement plants, steel mills, fertilizer production and gas-processing units), transport it to a designated storage site and bury it in onshore or offshore deep geological formations (depleted oil and gas fields or saline formations), in a way that guarantee it will remain trapped permanently.

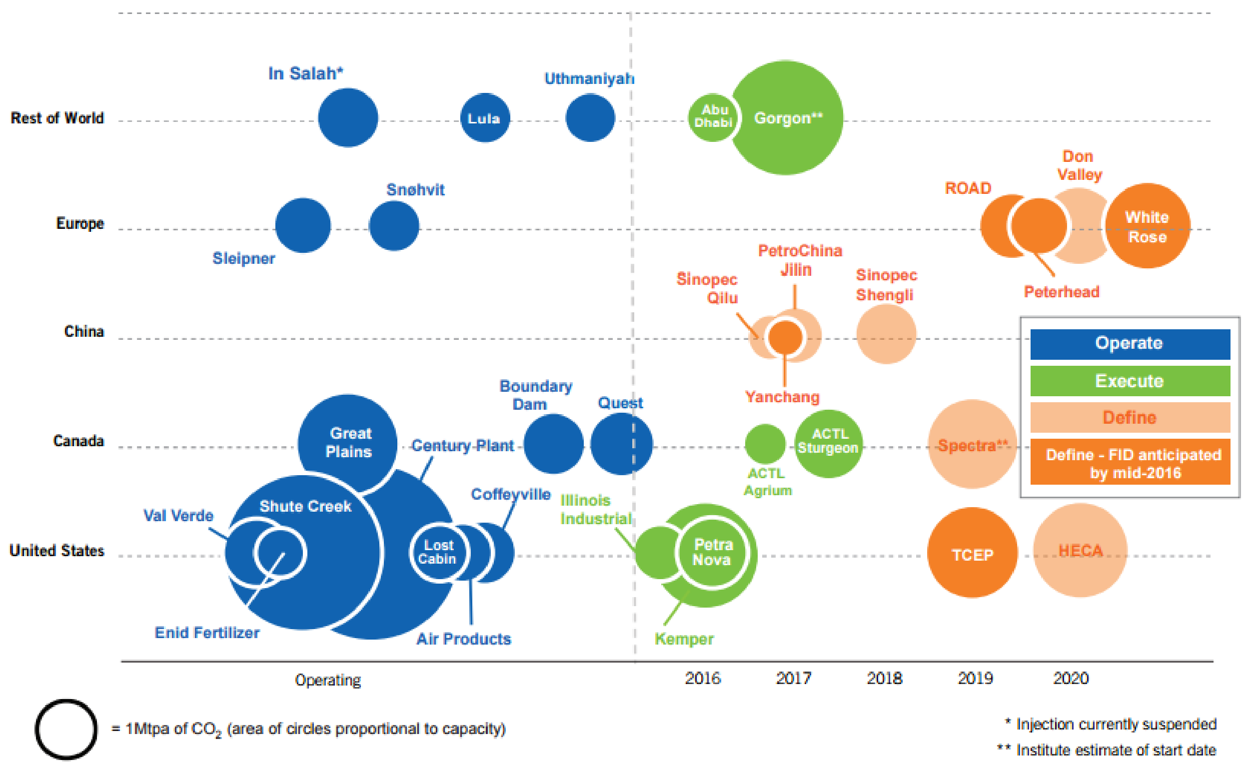


Image: Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by region and project lifecycle stage. Global CCS Institute, The global status of CCS 2015: summary report, Fig. 4

The potential of CCS is widely recognized: many global climate models cannot reach concentrations of about 450 ppm CO_2eq by 2100 (corresponding to the 2°C target) without CCS. Moreover, IPCC scientists observed that mitigation costs become consistently higher if CCS is excluded from the mitigation scenarios.[2]

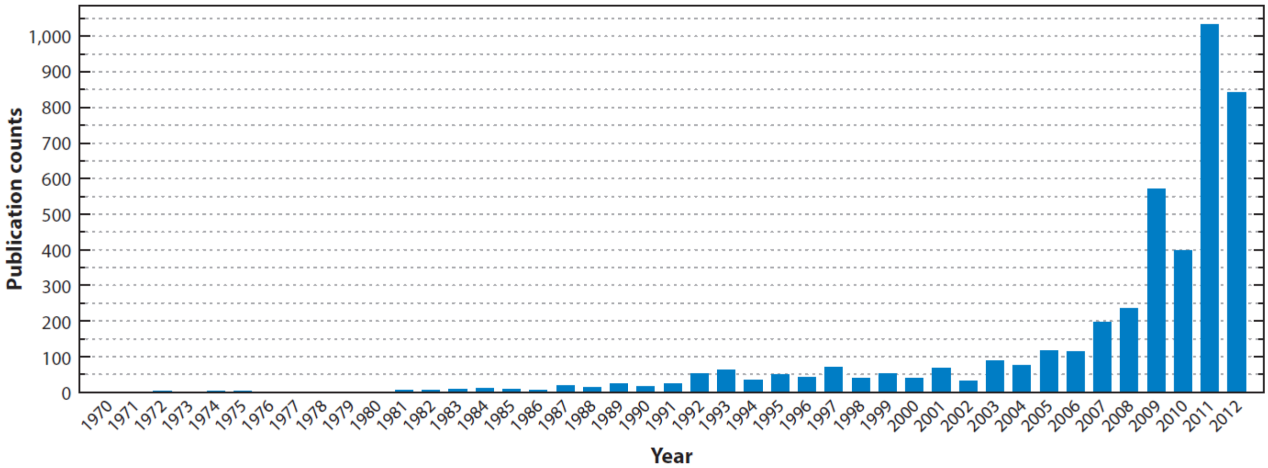
Currently there are 15 large-scale CCS projects in operation worldwide that have captured a total 28 million tonnes of CO_2 in 2015, mainly from industrial plants.[3] With seven projects due to become

[1] BNEF, Clean energy investment by the numbers – End of Year 2015, January 2016
[2] IPCC, Synthesis Report, Fifth Assessment Report (AR5), 2014
[3] Global CCS Institute, The global status of CCS (2015)

operational in 2016-2017 and a further 23 in different stages of planning, the total potential number currently amounts to 45, with an estimated capture capacity of 80 Mtpa.[4]

CCS: Steps forward & back

In the last decade (and since the publication of IPCC's landmark Special Report on CO_2 Capture and Storage in 2005) CCS technologies have been increasingly addressed by **academic research**, with a consistent acceleration in recent years, bringing CCS out of the domain of climate "science fiction" to be properly explored among all low-carbon solutions on the table.



Publication counts related to CCS (search terms: CO_2 capture and storage) from the Web of Science 1970–2012. Source: H. C. de Coninck and S. M. Benson: Carbon Dioxide Capture and Storage: Issues and Prospects in Annual Review of Environment and Resources 2014. 39. Note from original source: The peak figures in 2009 and 2011 are due to conference papers at the Greenhouse Gas Control Technologies (GHGT) conferences in 2008 and 2010, respectively.

The greater attention paid, mainly driven by government spending on CCS R&D, have led to both technical and non-technical advancements and strengthened the scientific basis essential to assess the potential and the weak points of the technology.[5]

Running almost parallel to the diffusion of CCS research, the establishment of **bilateral and multilateral initiatives** from both governments and private actors has also seen some substantial steps forward worldwide.

In July 2014, the United States and China, the two top global GHG emitters, signed eight partnership agreements to increase climate cooperation, half of which concern CCUS (carbon capture, utilization, and storage) demonstration projects.[6] The two countries are the top ranking worldwide per number of large scale CCS projects in operation, execution or definition stages: the United States currently features 13 projects and China 9 (although none of the Chinese projects are in operation yet).[7]

The Carbon Sequestration Leadership Forum (CSLF), the only international ministerial body focused on the development and deployment of CCS technologies, has gradually increased its members to 24 countries plus the European Commission. During the latest annual CSLF gathering in Saudi Arabia, in November 2015, ministers recognized the advances made highlighting that "R&D portfolios have grown, international collaboration has expanded, and the world's first large-scale

[4] Ibidem
[5] H. C. de Coninck and S. M. Benson, : Carbon Dioxide Capture and Storage: Issues and Prospects, in Annual Review of Environment and Resources 2014. 39, pp. 243–270
[6] U.S. Department of State, Media note: Key Achievements of U.S.-China Climate Change Cooperation Under the Strategic and Economic Dialogue (July 9, 2014)
[7] MIT Carbon Capture and Sequestration Technologies Program, CCS Project Database, online at: https://sequestration.mit.edu/index.html

CCS project in the power sector commenced operation".[8] Well aware that the progress made so far is not sufficient, CSLF members are focusing on strategies to "move beyond the first wave of CCS demonstrations" and meet current challenges, including capacity-building for CCS in developing countries and methods for financing CCS projects. The CSLF also launched a new initiative, the "Large-Scale Saline Storage Project Network", to facilitate collaborative testing of advanced CCS technologies at real-world, saline storage sites.[9]

Technologies required to capture and transport CO_2 are generally well understood and, in some cases, technologically mature.[10] High costs and high energy penalties of CO_2 capture and uncertainties surrounding the storage phase (especially the identification of proper storage sites) are among the major concerns for CCS deployment (as discussed below).

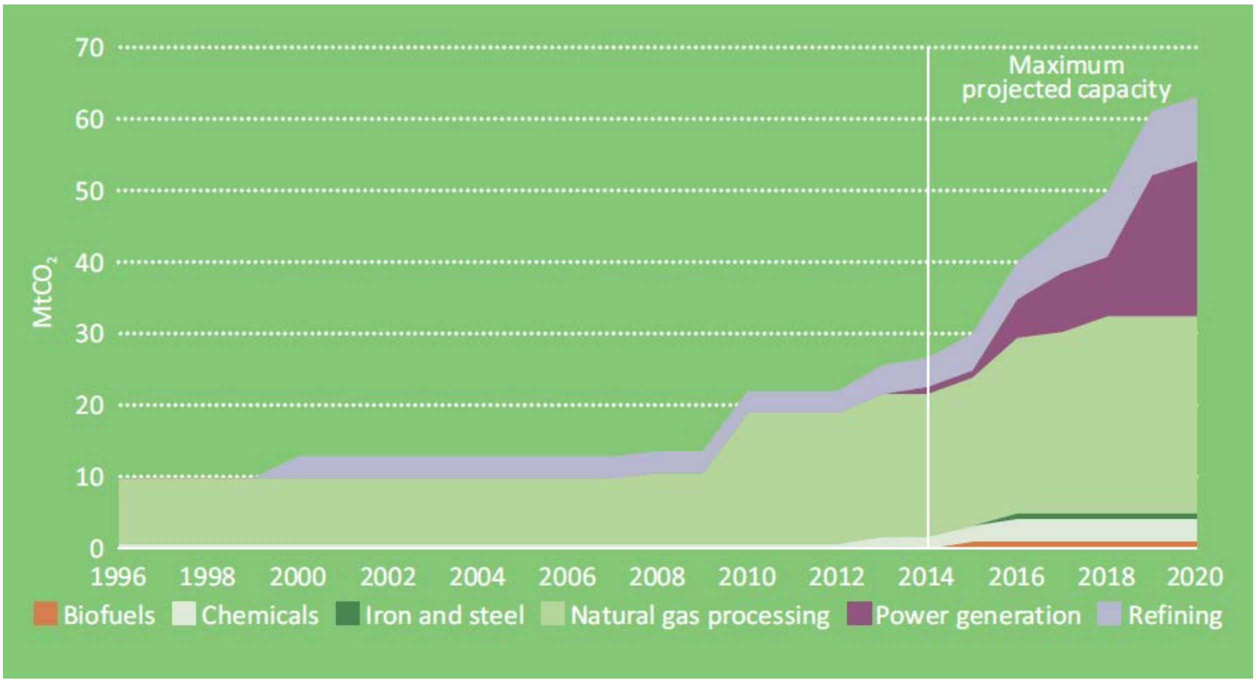
According to experts from several research fields, **technical and operational progress** has been made in the last decade concerning CO_2 capture, transport, storage efficiency, and methods to assess leakage impacts and risks of induced seismicity.[11]

Overall, individual components and phases (separation, capture, transport and storage of CO_2) have been studied and upgraded, but they need to be tested and evaluated on the ground, at integrated levels, in far more cases in order to provide better knowledge and substantially move to a more efficient, cost-effective and better designed next generation of CCS systems.

In its latest assessment of low-carbon technologies, the IEA recognized that CCS has seen some positive developments ("a slow but steady increase in the number of CCS projects under construction"), but not enough to be on track with the levels required. IEA estimates CCS could deliver around 13% of the emissions reductions needed by 2050 to limit the temperature increase to 2°C, with the removal of around 6 billion tonnes of CO_2 per year in 2050.[12] In order to achieve such levels by 2020, the capture of CO_2 should be successfully demonstrated in at least 30 projects across many sectors, with over 50 $MtCO_2$ safely and effectively stored per year. By 2030, CCS should be routinely used in power generation and industry, with the storage of over 2,000 $MtCO_2$ per year. In the period 2015-2050 approximately 120 $GtCO_2$ would need to be captured and stored across all regions of the globe.[13]

Even though the potential **capacity** of current projects in operation, under construction, or in advanced stages of planning has been estimated at 63 $MtCO_2$/y by 2025 (thus roughly in line with the IEA roadmap), shortcomings and deadlocks cast doubts on the development of additional projects in the coming years.[14]

[8] CSLF, final communiqué of the 6th Carbon Sequestration Leadership Forum Ministerial Meeting: "Moving Beyond the First Wave of CCS Demonstrations" (November 4, 2015)
[9] U.S. Department of Energy, Media release: Secretary Moniz Announces New CO_2 Storage Network at Multinational Carbon Sequestration Forum (November 4, 2015)
[10] H. C. de Coninck and S. M. Benson, : Carbon Dioxide Capture and Storage: Issues and Prospects, in Annual Review of Environment and Resources 2014. 39, pp. 243–270
[11] International Journal of Greenhouse Gas Control Volume 40, September 2015: Special Issue commemorating the 10th year anniversary of the publication of the Intergovernmental Panel on Climate Change Special Report on CO_2 Capture and Storage
[12] IEA, Carbon Capture and Storage: The solution for deep emissions reductions, (2015)
[13] IEA, Technology Roadmap: Carbon Capture and Storage (2013)
[14] IEA, IEA Tracking Clean Energy Progress (2015)



IEA Tracking Clean Energy Progress 2015 report, Fig. 1.17

Projections of future capacity have to be handled with due caution. For instance, the Boundary Dam system in Canada captured 400,000 tonnes of CO_2 in its first year of operation, falling short of the announced design capacity of one million tonnes per year. The adjusted, scaled-down target is to capture 800,000 tonnes in 2016. Moreover, some planned projects may not be completed due to changes in the political or economic context, as is the case for two planned projects in UK, the Peterhead Project by Shell in Scotland and the White Rose site in North Yorkshire, whose fates are on hold after the UK government in November 2015 withdrew its £1bn CCS Commercialisation Programme as part of a spending review. Dozens of CCS projects across the world have been dismissed or postponed due to investment shortages and government U-turns, such as the FutureGen CCS-equipped coal plant in Illinois, from which the US government pulled out in early 2015.

The **economic case** is the Achilles' heel of CCS. Without predictable government support, emission limits or a strong carbon price, private investors and utilities are reluctant to build new CCS-equipped plants or retrofit the existing ones. At the same time, governments cannot entirely finance projects whose financial viability, especially in the power sector (where the majority of GHGs are produced), is unclear. But without new investment, deployment and testing, it is unlikely to achieve the progress needed to reduce costs and increase efficiency.

Bringing CCS in line with a 2°C scenario would require a total undiscounted investment of USD 3.6 trillion until 2050.[15] Current cumulative investment in large-scale CCS has amounted to USD 12 billion since 2005.[16]

[15] IEA, Technology Roadmap (2013)
[16] IEA Tracking Clean Energy Progress (2015)

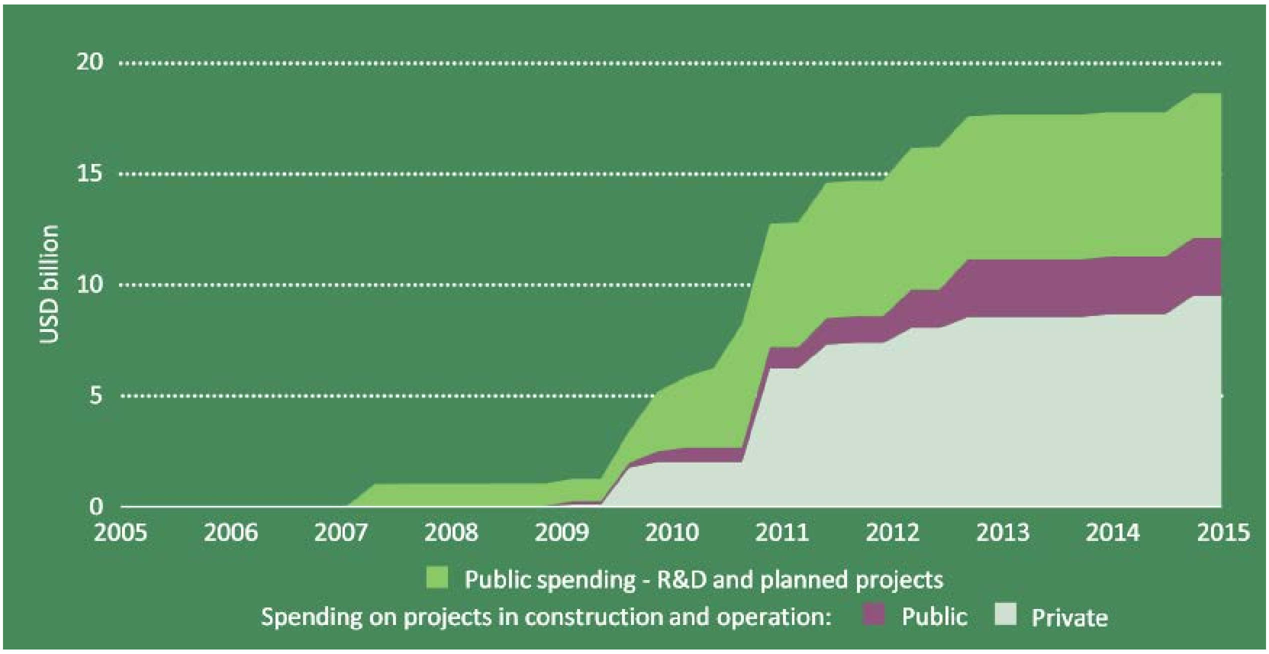


Image: Cumulative spending on CCS projects, IEA Tracking Clean Energy Progress 2015 report

The cost of producing electricity with CCS has been estimated at 60–100 USD/tonne CO_2, of which 70–80% is made up by the CO_2 capture phase burdened by high energy penalties.[17] In an efficient CCS-equipped power facility the energy used for CO_2 capture should be 2-3% of the output of the power plant, but in the real world this figure is 5 to 10 times higher, and additional energy is required to compress the CO_2 in order to transport and store it.[18]

Waiting for R&D and demonstration projects to reduce cost and increase efficiency, enhanced oil recovery (EOR, the injection of CO_2 into depleting oil fields to increase the pressure and drive the oil towards the production wells) remains the main commercial rationale for deploying CCS. In fact, more than half of the CCS power plants currently under construction and planning are EOR-oriented. But CO_2-EOR projects are not generally required to undertake monitoring, measurement and verification that injected CO_2 is permanently stored. In the long term it would be essential to make CO_2-EOR plants comply with the same performance standards as those applied to projects storing CO_2 purely to prevent the release into the atmosphere.[19]

With the exception of Norway, whose CO_2 tax introduced in 1991 created the incentives to start the Sleipner and Snøhvit CCS projects in 1996 and 2008 respectively, attempts to link CCS deployment to carbon pricing systems have delivered poor results to date, due to low carbon prices. The prime example is the NER300 programme experience within the European Emissions Trading Scheme. Launched in 2011 to provide funds for renewable energy and CCS projects in EU member states by setting aside 300 million allowances (EUAs) in the period 2013-2020, it was expected to earn around €6-9 billion. The collapse in EU carbon prices resulted in a significant reduction of expected returns, resulting in €2.1 billion for 38 projects.[20]

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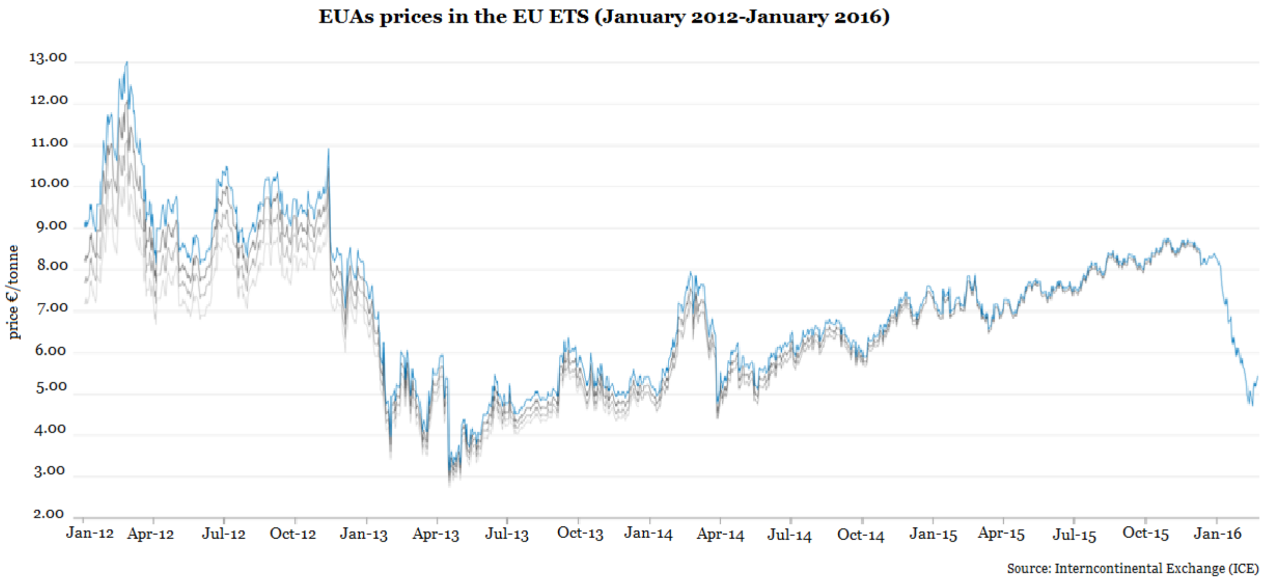
[17] D. Y.C. Leung, G.Caramanna, M. Mercedes Maroto-Valer, An overview of current status of carbon dioxide capture and storage technologies, in Renewable and Sustainable Energy Reviews, Volume 39, November 2014, Pages 426–443

[18] H. C. de Coninck and S. M. Benson, : Carbon Dioxide Capture and Storage: Issues and Prospects, in Annual Review of Environment and Resources 2014. 39, pp. 243–270

[19] IEA Tracking Clean Energy Progress (2015)

[20] EU Commission, NER 300 programme, online: http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm



A legislative proposal for reforming the EU ETS includes a similar program for the period 2021-2030, covering returns from the sale of 400 million EUAs. The EU Commission estimated the new "NER400" program would raise around €10 billion assuming a €22 average EUA price.[21] Even in the case that this assumption proves to be correct, the assumed price will be inadequate to develop CCS at the level required by the EU's long-term goals. According to a study from the UK's Grantham Research Institute, EUA prices need to be around €35-60 for coal-fired power stations and €90-105 for gas-fired plants to make CCS competitive with unabated thermal power generation.[22]

Besides the provision of funding and economic incentives, the key role of governments in CCS deployment is to provide the adequate **legal and regulatory frameworks**.

However this aspect is far from being well established at the international level. Policy frameworks covering R&D support, regulation and (where suitable) incentives to CCS are concentrated in the richest and long-established industrialized nations: the United States, Canada, Australia, the United Kingdom and the European Union. Sub-national governments are playing a key role, with Canadian provinces and Australian states leading the developments of specific regulatory frameworks.

In emerging and developing countries (where the majority of future emissions are projected to occur) the process is almost nonexistent, with the notable exception of China. In recent years governments and stakeholders in Indonesia, Malaysia, South Africa and Turkey have started discussing options and potential for CCS.[23]

Even where the overarching rules are in place, they may lack the on-the-ground testing and feedbacks necessary to consolidate a sound CCS regulatory framework tailored on the specific national and local conditions, especially concerning **CO_2 storage** permits and long-term liability.

For instance, in the European Union the transposition of the 'EU Directive on the geological storage of carbon dioxide' of June 2009 in the 28 countries' national jurisdictions is almost complete. It covers CO_2 capture, transport and storage and guarantees flexibility for EU member states on storage regulation (leading to very different choices from EU countries of allowing, limiting or prohibiting storage operation on their territories[24]). Despite the theoretical completeness, the EU Directive is still lacking the practical experience to assess its performance as normative tool,

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[21] Carbon Pulse, EU ETS Innovation Fund could raise €10.7 bln to clean up industry, online: http://carbon-pulse.com/7369/
[22] S. Bassi et al., Bridging the gap: improving the economic and policy framework for carbon capture and storage in the European Union (2015)
[23] IEA, Carbon Capture and Storage: Legal and Regulatory Review, Edition 4 (2014)
[24] Finland, Luxembourg and Belgium did not allow CO_2 storage on their territory or part of it due to unsuitability of their geology. Some other Member States have also not allowed geological storage of CO_2 (Austria, Estonia, Ireland, Latvia, Slovenia, Sweden) or restricted it (Czech Republic, Germany).

because the number of CCS systems installed has been much lower than expected when the law was passed in 2009.[25] Another example is the case of the Canadian province of Alberta that in 2012 concluded a review of its regulatory framework that resulted in 71 recommendations for improvement across 21 issues, showing that after the key regulatory elements are in place additional work is required to finalize the legislation.[26]

Also the rules concerning the long-term liability associated with a storage sites are not well established. Trends in the most advanced CCS regulations are oriented towards liability transfer. Australia, the European Union and some Australian, Canadian and US states and provinces set out that governments should take on the responsibility of the storage sites provided for operators to respect certain requirements, such as the absence of significant leakage risk and a financial contribution to the long-term stewardship of sites. However, some jurisdictions do not cover all the elements of long-term liability and the interpretation of the requirements operator should comply with varies significantly.[27]

Worldwide, the technical potential of storage capacity has been estimated at about 2,000 $GtCO_2$. However, this figure can be limited by specific constraints at the local level, such as shortcomings in geological knowledge, restrictions related to injection technologies, costs, regulatory limitations and public opinion opposition. National and regional assessments are uncertain due to lack of information and of formally recognized international methodology and standards. For instance, storage capacity in European Union has been estimated in 117 Gt of CO_2 (of which approximately 25% is offshore Norway),[28] while in the United States recent assessments found a potential of 3,000 Gt.[29]

While the characterization of depleted oil and gas fields for CO_2 storage is a relatively accessible process, the identification of a storage site in an underground geological formation (onshore or offshore) can take decades from exploration to operation. Without a sound strategy and information about where and how to store the captured CO_2, it is even less likely for a CCS initiative to attract the investment needed.

To allow CCS to be developed at scale, experts are calling on governments to invest quickly in characterizing actual storage capacity and ensuring appropriate monitoring and verifying rules for future storage sites.[30]

Conclusion

Weighting the slow progress and the significant barriers that CCS is facing, a realistic approach should suggest downsizing the original expectations of CCS being a “silver bullet” for climate change. Above all, it cannot be considered a convincing reason to delay the emissions cuts urgently needed in order to keep the global temperature increase at the safest possible level. Recent studies founded a relative small contribution of CCS in prolonging the currently intense use of fossil fuels, given the technology’s costs, its relatively late date of introduction and a reasonable rate at which it can be built.[31] Other studies have raised the attention on the uncertain (but potentially significant) consequences a widespread application of CCS and other “negative emissions” technologies may have on natural resources, social and ecological systems.[32] Policy makers and specialists should take these concerns into careful consideration.

On the other hand, despite hurdles and delays, CCS should not (and will not) be dismissed for

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[25] European Commission, Report on review of Directive 2009/31/EC on the geological storage of carbon dioxide (2015)
[26] IEA, Carbon Capture and Storage: Legal and Regulatory Review, Edition 4 (2014)
[27] IEA, Carbon Capture and Storage: Legal and Regulatory Review Edition 2 (2011)
[28] Rütters, H. and the CGS Europe partners (2013) - State of play on CO_2 geological storage in 28 European countries. CGS Europe report No. D2.10, June 2013, 89 p.
[29] U.S. Geological Survey (USGS), National Assessment of Geologic Carbon Dioxide Storage Resources, 2013.
[30] IEA, Tracking Clean Energy Progress (2015)
[31] C. McGlade and P. Ekins, The geographical distribution of fossil fuels unused when limiting global warming to 2 °C, in Nature 517, 187–190
[32] Pete Smith, Steven J. Davis, Felix Creutzig et al. : Biophysical and economic limits to negative CO_2 emissions in Nature Climate Change (2015)

different good reasons. First, it is so far the only technological breakthrough, together with efficiency improvements, that may significantly reduce emissions in the industrial sector. Second, fossil fuels are projected to remain abundantly available and relatively economical in the foreseeable future, and it is reasonable to think that they will be used at a significant level despite the increasingly important role of renewable sources. Third, CCS has been indicated as an integration element to involve fossil fuel-rich countries in climate mitigation efforts, reducing the risks of carbon leakage via trade and intensified extraction in anticipation of stringent climate legislation.[33]

Recent developments in the international context may influence the technology's outlook. Weak international climate action has been considered one of the key reasons behind the slow pace of CCS deployment. In this sense, the Paris outcomes may represent a turning point, even if CCS is explicitly mentioned in only three of the approximately 120 climate pledges, or INDCs, submitted by countries before COP21: Canada, Norway and China. Moreover, lower fossil fuel prices are seen as an opportunity to introduce carbon pricing mechanisms or emission standards to support CCS without impacting excessively on consumers.[34]

In any case, the next, critical phase of CCS deployment will see an increasingly important role played by public opinion and the media, often neglected elements among decision-makers, investors and traditional stakeholders. The role of the public opinion is linked both to the financing issues and to the storage challenges. Given that government support is needed to bring CCS systems from the pilot testing to the commercial scale, decisions on where to allocate public investments will be taken according to economical and social priority order that public opinion help define. At the same time, a well-informed public opinion is crucial at local level, when new CO_2 transport routes and storage sites are to be planned and implemented. Clarity and transparency on a CCS project's operations, risks and safety requirements will become increasingly important to gain public acceptance, as the number of CO_2 transport and storage infrastructures is supposed to increase in the next years. Public perception has proven to be critical in the decision to cancel a CCS project, as with the Barendrecht project in the Netherlands and the Janschwalde project in Germany.[35]

It will take a few years to understand if the Paris Agreement and the evolving energy prices will become the game changers in the next phase of CCS deployment. On the other hand, the pathway for CCS to become a solid climate mitigation strategy will take longer as it involves several complex and interconnected questions to which most answers are still uncertain.

[33] Massimo Tavoni: Carbon capture and storage: Promise or delusion? In Barrett, Scott and Carraro, Carlo and de Melo, Jaime, 2015: Towards a Workable and Effective Climate Regime, pp. 343-351
[34] IEA, Energy Technology Perspectives (2015)
[35] H. C. de Coninck and S. M. Benson, : Carbon Dioxide Capture and Storage: Issues and Prospects, in Annual Review of Environment and Resources 2014. 39, pp. 243–270

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