Closing the gap on climate – Why CCS is a vital part of the solution

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About the international ENGO network on CCS:

Created in 2011, the ENGO Network on CCS comprises organizations coming together around the safe and effective deployment of Carbon Capture and Storage (CCS) as a timely mitigation tool for combating climate change. Because urgent reductions in greenhouse gas emissions are needed to prevent dangerous climate change, a variety of innovative solutions is necessary. Given the world's current and projected reliance on fossil fuels, CCS should be considered a critical mitigation technology that will provide faster and deeper emission reductions. The mission of the International ENGO Network on CCS is to pursue domestic and international policies, regulations and initiatives that enable CCS to deliver on its emissions reduction potential safely and effectively.

Our shared goals include the following:

Ensure that CCS is performed and regulated safely, effectively and according to best practices, in a manner that protects our climate, human health and the environment

Disseminate scientifically sound and objective information on CCS technology

Work toward common positions and responses to international developments in the CCS arena

Work to phase out the construction of new unabated, conventional coal-fired power stations as soon as possible, with CCS playing a part of the solution. In developed countries, no new, conventional coal-fired generation should be constructed without CCS

Work to incorporate CCS in other types of fossil-fired power generation, industrial sectors, and in combination with sustainable biomass.

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Introduction

Climate change is a pressing problem that demands urgent action. It is now widely recognized as being far more than just an "environmental" issue, and is now understood to threaten human security, health, wellbeing and prosperity. If left unchecked, climate change will negatively impact human civilization and the natural world.

As the global economy continues to burn fossil fuels at an alarming rate, each passing year makes it more likely that humanity will surpass its "carbon budget," the amount of additional carbon pollution that the planet can tolerate without changing its climate to a dangerous degree.[1] Evidence that the climate is changing fast, and that humans are responsible, is overwhelming. With each iteration of its Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) – the independent international body tasked with studying climate change science – paints a starker picture and in ever more definitive terms.[2] It is already clear that current and future generations will be called upon to deal with a changed climate.[3] However, there is still time to limit environmental, social and economic disruption and to reduce the risks of catastrophe.

For that to happen, decisive action is imperative. Action by governments, corporations and citizens on the policy, economic and technological fronts will be essential. Ambitious targets will have to be set and policies implemented to achieve them. No silver bullet solution exists. Instead, many measures and technologies must contribute to this effort, including increasing efficiency and reducing demand in all energy-consuming sectors, switching to renewable and lower carbon energy sources and increasing carbon uptake in forests and soils.

Our organizations actively advocate for policies that will lead to the rapid uptake of many of these technologies and mitigation strategies, some as a matter of priority. However, five years ago, we came together to collectively pursue the safe and effective adoption of Carbon Capture and Storage (CCS) as an important part of this action portfolio. We are united by the common belief that the technology can make a significant contribution toward reducing carbon emissions from the extremely widespread use of fossil fuels today and can play an integral role in achieving the international goal of avoiding global warming of two degrees Celsius above pre-industrial temperatures.

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[1] For more information see: "The Carbon Budget", World Resources Institute, available here: http://www.wri.org/sites/default/files/WRI13-IPCCinfographic-FINAL_web.png and Meinshausen, Malte, et al. "Greenhouse-gas emission targets for limiting global warming to 2 C." *Nature* 458.7242 (2009): 1158-1162.

[2] In its latest (Fifth) Assessment Report (Summary for Policy Makers), the IPCC noted that: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased," "Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes […]. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." Available here: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

[3] According to the IPCC, "Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2." Intergovernmental Panel on Climate Change, "Climate Change 2013, The Physical Science Basis," Summary for Policy Makers. Available here: https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WGIAR5_SPM_brochure_en.pdf

CCS can lower the overall cost of climate mitigation, provide emission reduction opportunities for sectors that do not have many, or scalable, alternatives, and expedite the pace of action to reduce emissions and assist in removing carbon dioxide from the atmosphere.

Discussions and international negotiations focused on mitigating climate change are several decades old now. Despite that, a substantial gap remains between what science prescribes as essential if dangerous anthropogenic climate change is to be avoided, and what nations have committed to in terms of emission reductions, let alone have achieved. With each year that passes, the burden increases on all climate mitigation solutions to deliver the necessary reductions in time.

The IPCC reports that fewer than half of its climate models were able to reconcile an atmospheric stabilization at 450ppm CO_2eq[4] without CCS, and that without it, modelled mitigation costs rose by 138 percent on average. The IPCC also summarizes what models predict if some low-carbon technologies are curtailed.[5] Compared with phasing out nuclear power generation, limiting solar and wind energy, and limiting the available bioenergy, eliminating CCS from the mitigation portfolio posed the greatest difficulties in terms of actually reaching the desired stabilization level of CO_2 in the atmosphere, and resulted in by far the largest cost.[6] This underlines the value of pursuing CCS as part of the overall effort to deeply decarbonize society, to achieve net zero emissions and below, and thereby to curb climate change.

Our organizations are conscious that, all-too-often, CCS is perceived to be a continuation of business-as-usual practices by fossil fuel interests. CCS has often been judged to be guilty by association, sometimes justifiably so. CCS, however, is a broad category of technologies that can be applied across multiple processes and fuels, with many different uses and values as the world pursues deep decarbonization over the coming decades.

In our 2012 paper, "Environmental Non-Government Organisation (ENGO) Perspectives on Carbon Capture and Storage (CCS),"[7] we detailed the rationale for pursuing CCS as part of the climate mitigation portfolio. We presented the case for CCS as a technology that is sufficiently proven and developed to be deployed at scale safely and effectively today. In the present paper, we reinforce this case by taking stock of broad technological developments over the past decade and progress in deploying large-scale projects.

We re-examine the role of CCS as a technology traditionally perceived as specific to coal-fired power generation, but whose value is now widely recognized as much broader: in the decarbonization of power generation fuelled by natural gas, in the industrial sector, and in the increased focus on removing carbon from the atmosphere through Bio-CCS.

[4] Which was thought to be the maximum allowed concentration to limit warming to 2 degrees Celsius, but that level is now considered to be closer to 350ppm CO_2eq.
[5] Either due to express policy decisions, or to real-world shortfalls, for example.
[6] Other analyses come to different conclusions but there is no basis to conclude we know enough know to guarantee we can protect the climate without CCS as part of the toolbox. Due to lead times to improve and deploy CCS systems, we need to expand efforts now to pursue them.
[7] Available here: http://www.engonetwork.org/engo_perspectives_on_ccs_digital_version.pdf

We also assess the extent to which governments have made progress in instituting laws, regulations and policies that can lead to the meaningful deployment of CCS technology, presenting detailed regional and country perspectives for the European Union, Norway, Canada, the U.S., Australia and China.

We conclude that, globally, the pace of CCS deployment has proved slower than anticipated, but significant technological and technical progress has been made in recent years, as witnessed by the numerous large demonstration projects now in operation. These are likely to triple by 2017 compared to the beginning of the decade. Government action and supporting policies remain the missing ingredient, and the key to unlocking more substantial and faster adoption of CCS technology. Concerted policy efforts will be needed at the regional, national and international levels to overcome this.

CCS in 2015 – taking stock 10 years after the "SRCCS"

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The IPCC published its Special Report on Carbon Dioxide Capture & Storage (SRCCS)[8] in 2005 – 10 years ago. The report represented the most comprehensive collection of scholarly knowledge on the technology at the time, and confirmed the significant maturity of the technology. Today, the report remains the definitive treatise of the subject, but a lot of water has since flowed under the bridge. Notable technological and operational advances have been made on the capture and storage fronts, and mature product and service offerings with full commercial guarantees are now available from a number of vendors. The costs of the technology are much better understood. The body of statutes and regulations that govern storage, in particular, but also elements of capture and transport, has been greatly expanded in several jurisdictions. Meanwhile, policy proposals have come and gone, some leaving behind them cancelled projects, dashed hopes of broad-scale deployment and disillusionment, while others have, in fact, resulted in the planning, construction and operation of a substantial number of large-scale integrated projects that give solid reason for hope. Below, we examine the developments synoptically in each of these areas over the last decade.

[8] 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, 442 pp.

Applications and the Role of CCS

CCS has commonly been regarded over the past decade as a technology that is almost entirely applicable to the use of coal, and for coal-fired power generation in particular. This narrow focus stemmed in large part from concerns about the continued increase in coal use during the last decade: coal-fired power generation represents the biggest grouping of large stationary source CO_2 emissions globally. As such, coal was identified as a high priority candidate for decarbonization and CCS application. However, this paradigm has begun to shift substantially to include a broader set of CCS applications and fuels, with CCS increasingly regarded as a tool with many more uses, and of prime importance and value far more broadly in deep decarbonization efforts.

A number of reasons have contributed to this shift. First, key countries such as China and the U.S. have witnessed a reduction in the use of coal for power generation in recent years, while natural gas has become the fuel of choice for investments in new capacity in many countries.[9] Second, the need to deeply decarbonize all sectors of the economy and not only electricity generation has become increasingly apparent. The industrial sector[10] in particular has few decarbonization options aside from CCS. Finally, it appears increasingly likely that the world may have to resort to one or more means of "rewinding" and removing CO_2 from the atmosphere if it is to contain climate change within "safe"[11] bounds, in the case of an emissions overshoot or if our current allowed carbon budget estimates keep being revised downward.

Together, these reasons make a compelling case for CCS not as a coal-only technology or as a lifeline for fossil fuels, but as a decarbonization tool with broad applicability and of greater importance in the decades to come. Below, we examine the rationale in more detail.

From Coal to Natural Gas

As mentioned above, some parts of the world are currently witnessing a structural shift in power generation from coal to natural gas, due to an abundance and low prices for the latter as well as other economic and regulatory factors.[12] Significant new gas generation capacity may be built that, despite being less carbon intensive than coal, still carries with it a significant carbon footprint. With coal capacity diminishing, the role for CCS in the medium and long term lies in

[9] This is due to a combination of economic and regulatory factors; primarily cheaper and more abundant natural gas supply, but also stricter pollution controls on coal-fired power generation in the U.S. and. For more details see, for example: U.S. Department of Energy, Energy Information Administration, "Short-Term Energy And Winter Fuels Outlook", October 6, 2015, and "China fossil fuel emissions down as coal use drops," Econews, 3 Mar 2015, http://econews.com.au/45729/china-fossil-fuel-emissions-down-as-coal-use-drops/

[10] This includes iron and steel, cement, chemicals and refining.

[11] "Safe" is a misnomer, even if warming is limited to two degrees Celsius, and is a very subjective term. For many displaced islanders or victims of extensive, warming-induced flooding, for example, such a term would be unacceptable. We use this term here reflecting its common use in the context of the IPCC reports over the years, and established scientific literature, but note our discomfort.

[12] This has resulted in a near-complete end to new coal investments as well as retirements to existing coal-fired power plants. See: G7 Coal Scorecard: Benchmarking Coal Phase Out Actions, E3G, October 2015, available here: http://www.e3g.org/news/media-room/japan-isolated-as-usa-leads-the-way-in-g7-move-beyond-coal

decarbonizing this gas use, while coal decarbonization becomes a shorter term prospect for those plants that are young enough and efficient enough to be retrofitted with CCS.

Decarbonizing Industry

Industrial emissions make up roughly one fifth of global emissions.[13] The sector's carbon footprint is derived from the combustion of fossil fuels, indirect emissions from electricity consumption, and process emissions.[14] A few subsectors make up the bulk of industrial emissions. Iron and steel production make up about four to seven percent of CO_2 emissions globally[15] and their emissions are due to the high energy intensity of steel production and the chemical reactions involved, its reliance on carbon-based raw materials and fuels, and the large volumes of steel produced. Cement production is responsible for five to seven percent of global emissions.[16] The majority (60 percent) of the industry's CO_2 emissions do not originate from energy use, but from the very manufacture of cement from limestone.[17] Chemical production and petroleum refining make up the bulk of the industrial sector's remaining emissions. Capturing and storing this CO_2 is one of the main options for decarbonizing this industry.

Reducing emissions from industrial processes poses unique challenges. First, many industrial products do not have direct substitutes today. Second, many industrial processes are highly optimized leaving limited room for deep emissions reductions through efficiency measures alone.[18] Third, many industrial processes such as steel and cement production, petroleum refining and production of chemicals generate significant CO_2 emissions not only from energy consumption or direct combustion, but also as an inevitable by-product of the chemical reactions inherent in the process.[19] Finally, many industrial products are competitively traded across the globe. If emissions limits on those are imposed locally, the industry may perceive its competitiveness to be harmed globally if low-carbon products are not required or rewarded by the market in other countries too.[20]

[13] "Industrial applications of CCS", International Energy Agency: https://www.iea.org/topics/ccs/subtopics/industrialapplicationsofccs/ Accessed October, 2015.
[14] I.e., emissions inherent to the processes and chemical reactions.
[15] "Energy Efficiency and CO_2 Reduction in the Iron and Steel Industry," European Commission. Available here: https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Energy_Efficiency_and_CO2_Reduction_in_the_Iron_and_Steel_Industry.pdf
[16] Benhelal, Emad, et al. "Global strategies and potentials to curb CO 2 emissions in cement industry." *Journal of Cleaner Production* 51 (2013): 142-161.
[17] In very simple terms, clinker, a major constituent of cement is manufactured by breaking down limestone into calcium and CO_2. The calcium is subsequently used and the CO_2 emitted to the atmosphere.
[18] UK Department of Energy and Climate Change (DECC)'s recent study, "Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050," recognizes that the steady increase of emissions in recent years reflects the limits to technological opportunities that can further improve energy efficiency in the industrial sector, with only relatively small incremental improvements in energy consumption.
[19] *CO_2 Capture and Storage (CCS) in energy-intensive industries, An indispensable route to an EU low-carbon economy.* Zero Emissions Platform 2012, Brussels. http://www.zeroemissionsplatform.eu/news/news/1601-zep-publishes-key-report-on-ccs-in-eu-energy-intensive-industries.html
[20] Ultimately, of course, first movers who reduce their CO_2 footprints now stand to increase their competitive advantage when climate policies take effect, but not all corporations are of this mindset.

CCS is technologically available to reduce emissions substantially from all these sectors. Refineries[21] and chemical plants[22] often have high purity sources of CO_2 that are vented and are therefore relatively cheap and straightforward to capture. Capturing CO_2 from a direct-reduced iron process is set to be demonstrated at large scale in the UAE as of 2016.[23]

Removing CO_2 from the atmosphere ("Negative Emissions")

A clear message delivered by the IPCC's 5th Assessment Report is that reaching the 450 ppm CO_2eq concentration by 2100 becomes much harder under delayed or limited availability of key technologies, such as bioenergy, CCS, and their combination (BECCS). In fact, almost all models that manage to limit warming to two degrees Celsius rely on some means of atmospheric carbon removal.[24] The IPCC estimates that the requirements for CO_2 removal from the atmosphere would peak at between 10 – 35 Gt of biogenic CO_2 to be stored globally.[25] This is an alarming reliance in many ways, given that few, if any, technologies except BECCS are available or economic today to achieve this.

When combined with the use of biomass at large point sources, CCS has a large potential for delivering net negative CO_2 emissions. As biomass grows, it absorbs and binds atmospheric CO_2. When the CO_2 from biomass combustion or conversion is captured and permanently stored, the value-chain becomes carbon negative, which means that more CO_2 is taken out of the atmosphere than is released into it. Thus, a service that would have otherwise likely relied on a fossil fuel is obtained with the net result of atmospheric carbon being injected underground. BECCS applications are already operational and have shown that simple and relatively cheap carbon negative solutions can be put into place today.[26]

The prospect of atmospheric removal of CO_2 through BECCS does not mean that we can afford to delay other mitigation efforts. In addition, achieving substantial carbon negative emissions through BECCS requires increasing the sustainable supply of biomass substantially. This clearly requires new pathways to biomass supply, along with strict accounting and enforcement to ensure

[21] Refinery emissions come from numerous point sources that include steam methane reformers, crackers, process heaters, burners. Capturing the entirety of a refinery's CO_2 entails going after many sources, at an increasing cost but diminishing emission savings. The biggest savings, and at the lowest cost, usually come from the hydrogen production facility, usually followed by the crackers. See for example: https://www.concawe.eu/uploads/Modules/MCMedias/141441856957/cs_09_t3-4_maas-carbon_capture_and_storage_in_the_refinery_context-2011-00703-01-e.pdf

[22] One example of CO_2 capture in the chemical industry is the ammonia plant of Yara in Prosgrunn, Norway, where CO_2 with such high purity levels is produced, that it can be sold to the beverage industry across Europe.

[23] The Abu Dhabi CCS Project involves CO_2 capture from the direct reduced iron process used at the Emirates Steel plant. See: https://sequestration.mit.edu/tools/projects/esi_ccs.html

[24] See for example: http://www.centerforcarbonremoval.org/what-is-carbon-removal/#CDRContext

[25] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

[26] Since 2009, Archer Daniels Midland's Agricultural Processing and Biofuels Plant located in Decatur, Illinois has been demonstrating an integrated system of CO_2 capture in an industrial setting and geologic sequestration in a deep sandstone formation. By the beginning of 2015, the project had stored one million tons of CO_2, illustrating the great potential of deploying BECCS to remove CO_2 from the atmosphere. See: http://netl.doe.gov/research/proj?k=FE0001547 and http://herald-review.com/news/local/adm-carbon-capture-reaches-million-metric-tons/article_0b2711c9-d969-5f1b-a83c-e3787763bc59.html

the sustainability and beneficial carbon balance of the source and supply chain.[27] It remains to be seen whether, in practice, large biomass-based energy systems can be managed sustainably.

Technology and Know How[28]

Considerable ground has been covered since the 2005 SRCCS on the technological front, both on the capture and the storage of CO_2.[29] Perhaps the biggest advances were made in the field of post-combustion capture and oxy-combustion. Pre-combustion capture appeared as the most mature option a decade ago, based on its use in various industries and projects around the world. However, since then, a number of solvents were tested at ever-increasing scales in test projects around the world, and several vendors now have full-scale, post-combustion commercial offerings with performance guarantees for removing CO_2 both from coal-fired and natural gas-fired combustion. Oxy-combustion has also undergone a transformation from a bench-scale proposition to a technology that has been tested at the pilot scale, and is sufficiently mature for large-scale project investment decisions.

On the storage side, several injection wells have been drilled and operated since 2005. Many of these provided invaluable insights into the behavior of CO_2 in different environments, as well as the structure and other properties of the storage sites. A large array of monitoring methods has now been tested in the field, and best practice manuals have been published relating to the use of such methods. For those operators without the skill set needed to design, build and operate a storage operation, several oilfield services or science-based companies now undertake such projects. Storage capacity assessments have been completed in various parts of the world, painting a much more comprehensive picture about the potential technical and economic feasibility of storing CO_2 in the subsurface.[30]

Taken together, the last decade represents a significant step forward in "first generation CCS technologies" to the point of unquestionable commercial availability of several capture options. It also represents a very large expansion in the knowledge and technical know-how from operating storage projects. What remains to be achieved is significant cost reductions in those first-generation technologies, which will come only after a greater number of projects have been

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[27] Not all biomass is created equal, and some sources or practices are actually carbon positive. Achieving a net-negative carbon balance over the entire lifecycle can be achieved only if practices are screened and selected accordingly. This will require accounting and oversight. See for example: "Think Wood Pellets Are Green? Think Again," Natural Resources Defense Council, Issue Brief 15-05-A, available here: http://www.nrdc.org/land/files/bioenergy-modelling-IB.pdf; or "Palm Oil and Global Warming," Union of Concerned Scientists, available here: http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/palm-oil-and-global-warming.pdf

[28] For more details see: J. Gale, J.C. Abanades, S. Bachu, C. Jenkins, 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, *International Journal of Greenhouse Gas Control*, Volume 40, September 2015, Pages 1-5, ISSN 1750-5836, http://dx.doi.org/10.1016/j.ijggc.2015.06.019. (http://www.sciencedirect.com/science/article/pii/S1750583615002728)

[29] Transport of CO_2 using pipelines has been a mature technology for decades now. Although it would be helpful for compression costs to drop further and pipeline safety can always benefit from advances, pipeline transport has never been considered a technological roadblock for CCS.

[30] However it should be noted that the level at which these assessments are typically conducted falls far short of proving accessible CO_2 storage options in specific locations for use by specific plants.

commissioned and operated.[31,32] Better yet, far more efficient second generation technologies will eventually replace existing ones. Even though this does not appear to be an immediate prospect, constant progress is being made on the R&D front.

Projects

In 2005 when the SRCCS was published, it identified three operating Large Scale Integrated Projects (LSIPs):[33] In Salah, Sleipner and Weyburn-Midale. There were three more LSIPs already operating in the U.S. for decades at that time,[34] but these were all enhanced oil recovery (EOR) projects without an express purpose to store CO_2 and without any monitoring dedicated for that purpose.

Since that time, the list has grown considerably to include the following projects:

- Uthmaniyah, Saudi Arabia (natural gas processing, 2015)
- Quest, AB, Canada (bitumen upgrading, 2015)
- Boundary Dam, SK, Canada (coal-fired power generation, 2014)
- Shenhua Ordos Coal-to-Gases Project (gas production, 2011-2014)
- Port Arthur, TX, United States (petroleum refining, 2013)
- Coffeyville, KS, United States (fertilizer production, 2013)
- Lula, Brazil (natural gas processing, 2013)
- Lost Cabin WY, United States (natural gas processing, 2013)
- Illinois Basin Decatur Project, IL, United States (ethanol production, 2011)
- Century, TX, United States (fertilizer production, natural gas processing, 2010)
- Snøhvit, Norway (liquefied natural gas processing, 2008)

The launch of these projects represents a substantial increase in the installed base of operating projects. Even though the list includes easier[35] capture targets, such as natural gas processing and fertilizer or ethanol production, it also notably includes the first coal-fired power plant, and the first foray in the refining sector. Also, although EOR features more heavily, pure storage projects are strongly represented.

The existence of these projects puts any discussions of readiness and commercial maturity of CCS in a vastly different context compared to 2005. The results and technical learnings from all of

[31] Whether a project comes in over or under budget is a function of many variables and not always indicative of cost reductions for a technology, but the learning process from the design and construction of large projects has begun by operators, vendors and service providers alike, as is illustrated in the case of the Quest project: http://www.albertaconstructionmagazine.com/index.php/issues/59-fall-2015/768-the-quest-ccs-project-looked-at-constructability-to-keep-costs-under-control

[32] SaskPower has stated that a capital cost reduction of up to 30 percent is readily achievable if a project similar to its Boundary Dam effort is undertaken in the future. See: https://www.globalccsinstitute.com/insights/authors/RonMunson/2014/11/05/future-carbon-capture-will-focus-cost-reduction

[33] The Global Carbon Capture and Storage Institute (GCCSI) defines a Large Scale Integrated Project as one that involves "the capture, transport, and storage of CO_2 at a scale of: at least 800,000 tonnes of CO_2 annually for a coal–based power plant, or at least 400,000 tonnes of CO_2 annually for other emissions–intensive industrial facilities (including natural gas-based power generation)." See: http://www.globalccsinstitute.com/projects/large-scale-ccs-projects-definitions

[34] The Val Verde natural gas processing plants in Texas since 1972, the Enid Fertilizer plant in Oklahoma since 1982, and the Shute Creek natural gas processing plant in Wyoming since 1986.

[35] Meaning capture of relatively pure CO_2 streams that need to be separated as part of the industrial process anyway.

these projects all point to the same direction: the evidence is now overwhelming that there is no scientific or technological reason not to pursue more of these. In addition, several more LSIPs in many different countries are under current construction and include: Alberta Trunkline, Abu Dhabi, Gorgon, Illinois Industrial CCS Project, Kemper and Petra Nova. Yet more are in the planning phase.

In addition to these large-scale projects, many smaller, or non-integrated projects (that, for example, capture CO_2 but do not sequester, or that use naturally occurring CO_2 for a test injection) have been commissioned around the world.

Overall, the picture that emerges today is overwhelmingly different from that of 2005, with a host of operating projects as living proof that CCS technology is a reality, right here, right now, and not a theoretical future prospect. The wave of projects under construction and in the planning stages will only reinforce this.

Statutes and Regulations

In 2005, there were two commonly voiced questions by CCS project developers regarding their projects: who would pay for them, and how (and if) they could be constructed under existing legal and regulatory frameworks. The former is a question of policy and is examined later in this paper. The latter, however, is a question that many regional and national governments have addressed comprehensively since that time, to the point that today we can say that in many – if not most – jurisdictions where CCS projects are a near-term possibility, a legal and regulatory (permitting) framework for them is clearly defined.

Since 2005, a concerted effort by national and regional governments across many continents has addressed regulatory and legal gaps for CCS. The vast majority of the unanswered questions at the time concerned the injection and storage portion of CCS, with capture and transport generally requiring minor clarifications, if any. In particular, the most commonly encountered questions included (but were not limited to):

- What type of permit does an operator need to obtain to inject CO_2, and from whom?
- What information must be presented to obtain such a permit?
- What are the operational and technical construction requirements for injection wells and projects?
- What type of monitoring of the injected CO_2 (or otherwise) needs to take place, and for how long?
- Who ensures integrity of injection sites decades into the future, and who pays for ongoing stewardship?
- Who is liable if something goes wrong?
- Who owns the pore space where CO_2 is injected underground?
- Is it legal to transport CO_2 for storage across national borders?

A flurry of regulatory but also, in some cases, legislative activity resulted in comprehensive regulatory and statutory frameworks in several key regions. Australia,[36] most EU member states,[37] Canada[38] and the U.S.,[39] promulgated new regulations, passed new statutes or amended existing ones, putting into place clear rules for CCS projects. In addition, CCS was admitted as a project activity under the UNFCCC's Clean Development Mechanism (CDM),[40] and the Canadian Standards Association adopted a new standard for CCS.[41] Parties to the London Convention/Protocol also amended treaty language to allow for transboundary transfer of CO_2 for disposal.[42]

Taken together, these developments mean that the regulatory and permitting pathway for a CCS project in several prime host countries of the world is clear.[43] This will now need to be replicated in yet more host countries, primarily developing ones.[44] The pace with which new frameworks were developed or existing ones amended also demonstrates what can be done when the will is there. We consider this one of the positive CCS success stories of the past decade, and call for the current deficiencies in the policy arena to be resolved with similar decisiveness.

The Policy Rollercoaster

Summary of Developments Since 2005

A decade ago, governments had not yet seriously considered policies to promote the deployment of CCS. To their credit, governments in key countries did consider such policies for a period, and

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[36] Key developments include the passage by the Australian Commonwealth Government of the Offshore Petroleum Amendment (Greenhouse Gas Storage) Act of 2008, which provides a regulatory framework for carbon dioxide storage in federal offshore water, and The Victorian Greenhouse Gas Geological Sequestration Act 2008, which received Royal Assent in November, 2008 and which provides a dedicated legal framework enabling the onshore injection and permanent storage of greenhouse gas substances. For further details see: http://hub.globalccsinstitute.com/publications/onshore-CO_2-storage-legal-resources/australian-onshore-regulation, and http://hub.globalccsinstitute.com/publications/offshore-CO_2-storage-legal-resources/australian-offshore-CO_2-storage-legislation
[37] Report From The Commission To The European Parliament And The Council On The Implementation Of Directive 2009/31/Ec On The Geological Storage Of Carbon Dioxide, COM/2014/099 final. Available here: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52014DC0099&from=EN
[38] In Alberta, the Carbon Capture and Storage (CCS) Regulatory Framework Assessment issued its final report, which recommended regulatory changes related to the technical, environmental, safety, and monitoring requirements for the safe deployment of CCS as well as other actions to increase the body of knowledge on CCS-related topics. See: http://www.energy.alberta.ca/CCS/pdfs/CCSrfaNoAppD.pdf
[39] In the U.S., the Environmental Protection Agency finalized a new rule for permitting injection wells for geologic storage of CO_2, as well as greenhouse gas reporting requirements for such wells. See: http://water.epa.gov/type/groundwater/uic/class6/gsclass6wells.cfm and http://www2.epa.gov/ghgreporting/subpart-rr-geologic-sequestration-carbon-dioxide. In addition, a number of states adopted legislation that relates to property rights or incentives. For more details see: http://www.ccsreg.org/bills.php
[40] See: http://unfccc.int/resource/docs/2011/cmp7/eng/10a02.pdf#page=13
[41] See: http://shop.csa.ca/en/canada/design-for-the-environment/z741-12/invt/27034612012 and https://www.iea.org/media/workshops/2014/ccsregnet/6.4_McCoy.pdf
[42] See: http://www.ieaghg.org/docs/General_Docs/IEAGHG_Presentations/London_Protocol_CCS_and_Geo_update_v1SEC.pdf. Note that the changes had not been ratified at the time of writing.
[43] Even though unaddressed issues may remain, these are not significant impediments for CCS projects, as witnessed by the operation of several large-scale integrated projects across several of these regions.
[44] For an assessment of legal and regulatory progress around the world, see: "Global CCS Institute CCS Legal and Regulatory Indicator – A Global Assessment Of National Legal And Regulatory Regimes For Carbon Capture And Storage", Global CCS Institute, September 2015, available here: http://hub.globalccsinstitute.com/sites/default/files/publications/196443/global-ccs-institute-ccs-legal-regulatory-indicator.pdf

the future looked bright for CCS. Perhaps the biggest incentive package for promoting CCS deployment was included in the U.S. climate bills of 2009-2010, and was estimated to be worth in the region of $150-200 billion and several tens of gigawatts of new power plant (and some industrial) capacity. The EU set aside a sizeable chunk of EU Emissions Trading System (ETS) allowances to fund CCS projects.[45] Norway was considering its own investments in two natural gas combined cycle power plants and a refinery (Kårstø and Mongstad); the UK had its own incentive program; and Australia seemed set to fund a portfolio of projects. The CCS "community" was booming with activity and optimism, and the scene seemed set for the technology to begin broad deployment.

Unfortunately, this did not materialize. Due to persistent industry opposition in many cases, policies to limit carbon emissions and even incentivize CCS have stalled. Ironically, sometimes the same corporations that tout the benefits of CCS are the ones most strongly opposed to the adoption of carbon policies that would result in its deployment. Thus, for a variety of reasons, which we examine in more detail in the country sections below, the policies fizzled out and alongside them a good deal of planned projects: critical pieces of legislation failed to be enacted (U.S.), EU ETS allowance values plummeted draining the total amount available (EU), disbursement of funds proved slow and problematic (UK), negative public reaction proved detrimental (Germany), and governments did not honor their funding commitments (Norway). What followed was a severe loss of momentum, with a number or projects being cancelled or put on hold, and a significant "defunding" of activities related to those projects (including academic research funds, studies, contract work) and beyond. CCS had suffered a strong blow, and did not seem poised to survive as a viable near-term climate mitigation strategy.

However, too much time, expertise, knowledge and effort has been spent on CCS for it to disappear from the scene. A few demonstration projects that were committed went ahead during the hiatus period of 2010-2012 approximately. In the meantime, and even though broad-scale deployment prospects remained elusive, some governments were able to maintain and even strengthen their targeted funding for demonstration projects (while others were not). As a result of sustained national and regional incentives that were targeted at a small number of plants, the U.S. and Canada, first and foremost, were able to see those projects through to completion. As we describe above, this resulted in an expansion of the existing array of demonstration projects. Their numbers may pale in comparison with the tens or hundreds of projects that could have resulted from the enactment of the grand policies contemplated at the end of the last decade, but they are a testament to a strengthened CCS arsenal and the readiness to proceed with broader deployment.

The question remains, of course, how we will be able to translate existing progress on demonstration projects into a meaningful dent in worldwide emissions. This is a question that is

[45] Under the "NER300 Programme." See: http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm

best considered at a national level, but here we offer some general thoughts, as well as a discussion of what could be agreed upon collectively among nations at the international level.

CCS in the International Arena

The Role of CCS Internationally

CCS has a particularly important role to play in some emerging economies, simply because a number of large developing nations are major carbon emitters, control vast fossil fuel reserves, and adhere to policies that virtually ensure the continued emission of carbon dioxide well into the future. In many cases – e.g., China and India – the large size and young age of the fossil fuel power plant fleet means that without CCS, they risk locking the world into several more decades of heavy emissions or facing the impacts of stranded assets.[46] Although there are encouraging signs of slowing the growth of new construction, carbon emissions are likely to escalate for at least several more decades.[47]

At present, China is the CCS leader among developing nations. Given its size, coal and gas reserves, growing reliance on carbon-based fuels, and scope of economic development, China is in a category by itself. It also is at the forefront of CCS research and demonstration, having fielded a broad portfolio of initiatives. In 2015, for the first time, China was host to more CCS projects (9) than Europe (8). Unfortunately, those projects – compared with those in the U.S. (13), Canada (6), and Europe – are not as far along in the development chain and none were operational. In contrast, of the 15 operational projects worldwide, 12 projects were collectively located in the U.S. (7), Canada (3), and Europe (2).[48] Still, Chinese commitment to CCS is considerable, and has been strengthened recently by the cooperative efforts of the U.S.-China Climate Change Working Group. It is estimated that, under an aggressive scenario, China could commercialize more than 20 CCS technologies by 2020, while capturing up to 250 million tonnes of CO_2 per year, with the program expanding to encompass nearly all CCS technologies by 2030, diverting nearly 900 million tonnes of CO_2 per year.[49]

Other promising emerging economies include Brazil, which is home to one operating project.[50] It is the only offshore enhanced oil recovery facility in the world and it boasts the deepest injection wells. A strong possibility exists that by 2020, the Brazilian state oil company will install other floating oil and gas extraction systems with EOR capacity, storing CO_2 from the solution gas under a massive offshore salt dome. Mexico and Indonesia – even more heavily fossil-fuel reliant

[46] "CCS and Carbon Budgets," David Hawkins. Available here: http://www.globalccsinstitute.com/insights/authors/engonetwork/2013/01/21/ccs-and-carbon-budgets
[47] IPCC, 2014.
[48] For project numbers and status, refer to Global CCS Institute, "The Global Status of CCS, 2015, Summary Report," available here: http://hub.globalccsinstitute.com/sites/default/files/publications/196843/global-status-ccs-2015-summary.pdf
[49] "The Administrative Center for China's Agenda 21. (2014). *China's National Assessment on CO_2 Utilization Technologies*. Beijing: Science Publication (in Chinese)."
[50] The Lula project by Petrobras is capable of capturing 0.7 $MtCO_2$/yr from an offshore gas processing facility over the Lula oil and gas field, with the captured CO_2 re-injected into the field for use in EOR operations.

than Brazil – have made initial strides as well, adopting national climate change blueprints and identifying potential CCS opportunities.

Collectively home to nearly two billion people – more than a quarter of the world – these large, emerging economies possess centuries-long fossil fuel reserves and their citizens are rapidly achieving middle-class affluence. Implementation of advanced CCS programs in these nations could meaningfully assist global decarbonization efforts.

International Support Mechanisms

Despite the need to pursue the adoption of CCS in a variety of nations, some of which do not have the technical or financial resources to do so alone, progress has been slow.

Currently, only one formalized international market mechanism exists that could provide financial support from developed to developing countries to deploy CCS: the Clean Development Mechanism (CDM) under the UNFCCC. Despite its designation at the end of 2011 as an eligible CDM activity (subject to certain modalities), this mechanism has had no real impact on projects. The traded value of CDM credits (Certified Emission Reductions, or "CERs") has plummeted by several factors of magnitude[51] since its peak to mere cents per tonne of CO_2. This is nowhere near the tens of dollars or Euros per tonne that most CCS projects require. Uncertainty surrounding the future of the CDM itself has compounded the "uselessness" of this mechanism for CCS.

The World Bank has also undertaken efforts to promote CCS, as has the Asian Development Bank and the Carbon Sequestration Leadership Forum. These have been in the form of high-level familiarity exercises focusing primarily on "capacity building."[52] Although useful and even necessary at a preliminary level, they have not involved substantive exchanges of expertise that can have a direct impact on projects in the short term.

Perhaps of greatest value have been bilateral agreements, such as those between China and the UK or the U.S. These have succeeded in initiating and expanding contact between experts from both parties and in facilitating exchanges at a deeper and more detailed level. In some cases, collaboration between private corporations has assisted the development of pilot projects.[53] However, the agreements have not yet advanced large-scale integrated projects, and so far do not approach the levels of ambition or funding needed to achieve meaningful emissions reduction in developing countries.

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[51] At the time of writing, CER futures prices were trading approximately at around €0.6/tonne, which is approximately 1/20th of their 2011 high value (just over €13/tonne) and almost 1/40th of their 2009 high value (near €23/tonne).
[52] See for example: http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTENERGY2/0,,contentMDK:22926556~pagePK:210058~piPK:210062~theSitePK:4114200,00.html and http://www.zeroCO₂.no/projects/world-bank-ccs-trust-fund
[53] For example, Peabody is the only non-Chinese equity partner in GreenGen, China's signature carbon initiative, a 250MW integrated gasification combined cycle plant, which ultimately would capture carbon for enhanced oil recovery.

Conclusions and recommendations

CCS Today

The need for CCS today is even more compelling than it was 10 years ago. The pace of climate mitigation is still worryingly slower than what is dictated by science, and many climate models now rely on CO_2 removal not just from point sources, but from the atmosphere itself in the second half of this century. CCS is the leading technology candidate to perform this task today through the use of biomass, and without it, mitigation costs could be significantly higher. Atmospheric removal is only one example of the expanded role and significance of CCS today as a climate mitigation tool. Originally perceived as a pollution control technology for coal-fired power generation, the useful applicability of CCS today has been greatly expanded to include natural gas-fired power generation and the industrial sector.

A few years ago, CCS seemed poised for significant deployment at scale in many key areas and countries around the globe. This grand vision did not materialize as countries and their policies largely failed to set meaningful carbon limits, price signals and complementary policies that would push or pull CCS into the marketplace, bridge the economic gap for early projects, and drive costs down for subsequent plants. However, sporadic but crucial government support in select regions around the world has resulted in a substantial increase in number of operational (and soon-to-be operational) large-scale integrated projects. By 2020, a global portfolio of around 30 operating large-scale CCS projects is projected. This increase is critically important, and reflects the significant technological improvements that have taken place over the past ten years. Moreover, the experiences from these projects are already pointing toward material ways to lower costs and improve design and operational protocols for subsequent projects.

The experience of the past decade has proven beyond any doubt that the technology is available today, and that it can be deployed safely and effectively. In the recent words of some of the world's leading geoscientists and engineers to the UNFCCC Secretary, "Extensive research gives us very high confidence that CO_2 storage in appropriately selected sites is secure over geological timescales and leakage is very unlikely. […] Full-chain CCS, which integrates CO_2 capture, transport and storage technologies, is already being demonstrated at a growing number of facilities. The security of properly selected and regulated storage sites presents no barrier to its further deployment and enables its important contribution to climate change mitigation."[54]

Despite these significant steps and marked technological progress, however, the prospects for CCS deployment at a scale that will make a dent in global CO_2 emissions remain in serious doubt today. This is a failure on the part of policy makers to provide robust frameworks for deployment, and reflects how supposed "supporters" of CCS have sought to delay action.

[54] "Open letter to Christiana Figueres, Executive Secretary of the United Nations Framework Convention on Climate Change", 08 October, 2015. Available here: http://www.sccs.org.uk/news/227-open-letter-to-christiana-figures-executive-secretary-of-the-united-nations-framework-convention-on-climate-change

BOX 1: Excerpt from open letter to UNFCCC Executive Secretary, Christiana Figueres

On 8 October, 2015, the world's leading geoscientists and engineers sent an open letter to the United Nations Framework Convention on Climate Change Secretary, Christiana Figueres. The signatories include several authors and lead authors of the 2005 IPCC Special Report on CCS. In the letter, these experts re-iterated the physical basis for geological CO_2 storage:

"The knowledge and techniques required to select secure storage sites are well established, being built upon decades of experience in hydrocarbon exploration and production. A global capacity of suitable CO_2 storage sites has been estimated at several trillion tonnes. There is also extensive experience of CO_2 injection and storage in a variety of situations and locations around the world.

We can state the following with very high confidence:

> **Natural CO_2 reservoirs have securely held billions of tonnes of CO_2 underground for millions of years.** These provide an understanding of CO_2 storage processes and inform the selection of rock formations for secure storage as part of full-chain CCS.
>
> **Stored CO_2 is securely contained by physical and chemical processes that increase storage security with time.** Injected CO_2, held within the storage site by multiple layers of impermeable rocks, is trapped in isolated pockets, dissolves in fluids in the rock and may eventually react with the rock to make new minerals.
>
> **Millions of tonnes of CO_2 have been injected and stored since 1972 in storage pilots and demonstrations, enhanced oil recovery and other industry practices.** Accumulated experience of CO_2 injection worldwide has led to the development of routine best practices for the operation and closure of CO_2 storage sites, and provides direct evidence of engineered storage security.
>
> **CO_2 injected into underground rocks can be monitored to confirm its containment.** A variety of monitoring methods has been developed and demonstrated. In the very unlikely event of poor site selection, these techniques are able to identify unexpected CO_2 migration before leakage to the surface can occur.
>
> **Leakage of CO_2 from geological storage presents a very low risk to climate, environment and human health.** Research results show that the impacts of any CO_2 leakage on land or at the seabed will be localised and very unlikely to cause significant harm to ecosystems and communities. Should CO_2 move towards the surface, interventions can be made to control, minimise and prevent leakage.

Tackling CO_2 emissions from power generation and key industries is critical to delivering climate change mitigation in line with the UNFCCC's objectives. The IPCC finds, with high confidence, that attempting to limit global warming to below two degree Celsius without CCS is unachievable."

The Path Forward Nationally

For CCS to deliver on its significant potential, concerted government action at the regional, national and international levels is needed. This is, without question, the missing ingredient today, and the key to unlocking more substantial and faster adoption of CCS technology. More large-scale integrated projects need to be deployed to a degree that will enable movement beyond the initial high-cost phase inherent to any technology that has not yet achieved widespread use.

A combination of policy instruments and actions are needed in order to achieve this. Carbon limits themselves are the foundations of any mitigation strategy. Price signals are also needed in order to drive investment toward this and other low-carbon technologies. Performance and/or portfolio standards have proven highly successful in driving deployment of other critical technologies. Some government support for early projects may be necessary until the market conditions support the costs of CCS. Government support can take many forms, such as direct subsidies, feed-in tariffs, tax credits, or set-aside revenues or allowances from various programs. In order for these measures to be effective however, they need to be reliable and workable, and not subject to the uncertainties that have plagued many previous attempts.

In general, we view domestic, national actions as the key catalyst for CCS deployment. It is national and regional governments that will be able to most efficiently and expeditiously put into place and sustain the needed policy ingredients. This does not mean that transnational cooperation should not be pursued, but experience has shown that the combination of national and regional action has been most effective in deploying early projects.

The Path Forward Internationally

While national action by key industrialized nations is critical to CCS deployment, there remains a need for action at the international level as well. Large, emerging economies possess centuries-long fossil fuel reserves and their citizens are rapidly achieving middle-class affluence. Implementation of CCS programs in these nations could meaningfully assist global decarbonization efforts. International agreements should not only focus on economic assistance, but also on the transfer of knowledge and know-how. Engineering and geological expertise in particular are paramount to operate a sound CCS project, and it is imperative that the excellent track record of CCS not be tarnished by suboptimal location choices or projects. To that effect, academic institutions and industry in industrialized countries must be leveraged in order to transfer their expertise internationally.

An international mechanism for facilitating financial support to developing countries will be necessary, either specifically for CCS or as part of a larger portfolio. Such a mechanism should not crowd out other mitigation efforts such as efficiency or renewable energy. The optimum nature and context for this mechanism remain undefined at this point, but we consider it worth pursuing under the auspices of the UNFCCC or outside. Bilateral or multilateral (with few parties) agreements may also be effective. Such agreements do have precedent today, and have been quite successful on the knowledge transfer front, but these would need to be expanded significantly if they are to result in the deployment of a material number of projects.

Additionally, to drive CCS forward internationally, there is a clear need for leading countries to share expertise and resources to accelerate investments across the different CCS applications that can add most value to deep decarbonization pathways, and beyond coal-fired power generation. As the imperative shifts toward reducing emissions from natural gas, industrial processes, and biomass applications, there would be significant benefits from targeted investments to deliver lighthouse projects that can illuminate the path forward for different sectors.

Conclusion

CCS is available as a safe and effective climate mitigation tool that is of primary significance in many sectors. Its success and ultimate fate in terms of delivering on its potential are in the hands of governments. Despite recent setbacks, significant progress has been made over the past decade, and the scene is set for further expansion, if governments are willing to grasp the nettle of deep decarbonization.

Australia

Chapter Author:

Olivia Kember (The Climate Institute)

Introduction/Overview

Australia still lacks a widespread pathway to commercial-scale CCS deployment. Although government support remains in place for specific initiatives, and key research projects have made progress, CCS-related policies have stagnated, and the broader climate and energy policy environment has degraded in recent years.

This policy failure undermines Australia's interests in achievement of the internationally agreed goal of limiting climate change to less than two degrees and a reduction of domestic emissions in line with the two-degree goal.

Regional CCS Status/Issues

Recent analysis has shown several options for CCS use in Australia. Modelling for The Climate Institute suggests that bio-energy with CCS could remove and displace 63 million tonnes annually by 2050 (approximately 12 percent of total domestic emissions in 2013-14). Analysis by ClimateWorks for the multi-country Deep Decarbonisation Pathways Project finds opportunities for CCS application to fossil-fuelled electricity emissions, and could capture non-electricity sector emissions from industrial processes of about 38 million tonnes annually by 2050.

The federal government's 2015 Energy White Paper[55] claims that "Australia is set to be largely an early adopter of carbon capture technology." However, it is difficult to see how this will happen without significant changes in the current policy environment. The government has itself made the task harder by repealing legislation that priced and limited 60 per cent of domestic emissions.

Although the price and limit on carbon were expected not to facilitate CCS deployment until the mid-2030s, they made emitting companies financially responsible for their pollution and created an adjustable mechanism that could have been used to bring deployment forward.

The repeal of this legislation has left Australia without any means of achieving its proposed post-2020 emission reductions or of enabling the country to be "an early adopter" of CCS. It has also added significant uncertainty and risk to energy investments. This uncertainty has not been resolved by the government's replacement policies, which are still in development. These policies center on taxpayer-funded abatement purchases and a still nascent system of company and

[55]Australian Government, *2015 Energy White Paper* (2015). http://www.industry.gov.au/EnergyWhitePaperApril2015/index.html

sector-level “baselines.” As currently proposed, these are estimated to result in national emissions rising rather than falling.[56][57] The government has committed to review its policies in 2017.

In 2014, the government, like the previous government the previous year, also cut around half a billion dollars from the centerpiece of government support for CCS projects, the CCS Flagships Program.

There was some opposition to the cuts from CCS supporters, but neither Australia’s fossil fuel producers nor its major green groups are strong advocates for CCS deployment. Key coal and gas industry bodies have been more focused on ensuring the repeal of the carbon laws and the winding back of other clean energy initiatives. The Coal21 Fund, originally established to fund research into low-emission coal technologies, primarily CCS, ceased collecting funds from companies in 2013, stopped investing in new CCS research projects and altered the constitution of its administering body to include the objective of “[p]romoting the use of coal both within Australia and overseas and promoting the economic and social benefits of the coal industry”.”[58] The gas industry, with the exception of Chevron’s Gorgon project, appears content to leave the running of CCS efforts to others. Environmental organisations have prioritised support mechanisms for renewable energy.

Significant regional CCS projects

Callide Oxyfuel Project, Queensland. An existing 30MW unit was retrofitted with oxyfuel combustion technology to produce a concentrated stream of CO_2, which was captured at a rate of 75 tonnes per day. Approximately 30 tonnes of CO_2 were then transported by road to Victoria and used in an injection trial for the CO_2CRC Otway Project (see next project). The operational phase of this demonstration project concluded in March 2015; data analysis is ongoing, with detailed findings expected to be released in early 2016.

CO_2CRC Otway Project, Victoria. Australia’s only operational storage demonstration project has injected and monitored 65,000 tons of CO_2-rich gas in a depleted gas field. Stage two, injection and monitoring of 15,000 tonnes of CO_2 into saline formations is expected to begin before the end of the year. Monitoring will continue to 2019.

Gorgon CO_2 Injection Project, Western Australia. Chevron’s Gorgon project will extract and process gas from the Gorgon and Jansz-Io fields under the ocean off northwestern Australia. Reservoir CO_2 will be stripped from the gas from the Gorgon field and injected into a reservoir more than 2km below nearby Barrow Island. This is projected to reduce the project’s emissions by 40 percent. The Gorgon Project commenced construction in 2009 with commissioning and start-up activities occurring during the period from 2015 to 2018. The injection of reservoir CO_2 is

[56] Climate Action Tracker, ‘Australia set to overshoot its 2030 target by large margin’ (20 August 2015). http://climateactiontracker.org/assets/publications/briefing_papers/082015_Australia.pdf
[57] Reputex. Safeguard leniency to dilute ACCU demand’ (3 September 2015) http://www.reputex.com/publications/analyst-update-safeguard-leniency-to-dilute-accu-compliance-demand/
[58] ‘”Clean coal” money used to promote coal use,’ *Lateline*, ABC 21 June 2013. http://www.abc.net.au/lateline/content/2013/s3787338.htm

anticipated to commence mid-way through this period. *The South West Hub Project, Western Australia and CarbonNet Project, Victoria*. Both hub projects funded through the CCS Flagships Program remain in the feasibility research stage. The South West Hub, originally intended to store industrial emissions from a range of sources, lost funding for its private sector partners Alcoa, Perdaman, Synergy and Premier Coal, which have now left the project.

Moving forward

The policy review in 2017 offers an opportunity to strengthen Australia's approach to climate change and clean energy development. However, given the urgent need for greater predictability in the energy sector, not to mention national emission reduction, this should be brought forward. The current government's resistance to carbon pricing is not necessarily an obstacle to effective policy, but it means that regulatory tools such as emission performance standards (EPS) on electricity generation become essential. The Climate Institute continues to recommend an EPS for coal plant of 0.5 t CO_2e/MWh, dropping to 0.2 t CO_2e/MWh after 2020. Non-peaking gas plants should also be required to meet the 0.2 tCO_2e/MWh standard 15 years after their commissioning. The mandate of the Clean Energy Finance Corporation should be extended to allow financing of technologies that have negative net emissions, such as CCS with bio-energy.

Canada

Chapter Author:

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Introduction/Overview

Canada has been an early mover on carbon capture and storage with the completion of full-scale commercial CCS projects and the completion in Alberta of the provincial Carbon Capture and Storage Regulatory Assessment Framework. This framework identifies regulatory changes related to the technical, environmental, safety, and monitoring requirements for the safe deployment of CCS.[59] With CA$1.7 billion of public funding for CCS, three significant projects are currently operating, while one project is in the planning stages. (See Significant Regional CCS Projects.)

Canada and some leading provinces have recognised the importance of a transition out of unabated coal. The Federal government enacted an Emissions Performance Standard for coal that doesn't allow any new coal unless it can use CCS to emit no more CO_2 than a gas power plant, and introduced a 50 year end, end-of-life limit for existing coal plants. Ontario completed a phase out of unabated coal in 2014, having retired 9GW of coal power plants over the preceding 10 years. Ontario realized significant improvements in air quality as well as reducing CO_2 emissions. Alberta remains the last province with significant coal electricity production, burning more coal for electricity than all other provinces combined.[60] The new Alberta government has stated that it intends to reduce emissions from coal, and is currently considering how it might deliver this including phasing out coal more quickly than under the existing federal coal regulations. Independent analyses show that a cost-effective transition away from coal can be achieved in Alberta by around 2030.[61]

Regional CCS Status/Issues

In spite of these successes, the Government of Canada and Canadian provinces have failed to implement comprehensive climate policies that will help drive the adoption of CCS by Canadian industry in the future.[62] As well, the general public has not been engaged in a meaningful dialogue about how CCS and other climate change mitigation solutions can help Canada achieve deep decarbonization.

[59] Alberta's CCS Regulatory Framework. http://www.energy.alberta.ca/CCS/3843.asp
[60] 18 coal fired generating units at 6 power plants emitting roughly 46.7 MT or 17% of the province's overall emissions.
[61] Power to Change: How Alberta can green its grid and embrace clean energy. http://www.pembina.org/pub/power-to-change
[62] The federal government announced Canada's withdrawal from the Kyoto Accord in 2011 and has taken only limited action on climate change through two sectoral policies, while the Province of British Columbia is the only province with a meaningful climate change policy and price.

The large-scale commitment of public funding that originally totalled CA$3 billion[63] has been pared down to almost CA$1.7 billion.[64] The Province of Saskatchewan still supports the technology as a solution,[65] but opposition to public funding of CCS projects continues to grow.[66]

Significant regional CCS projects

SaskPower Boundary Dam

In October 2014, SaskPower started operating the CCS unit on unit #3 of its Boundary Dam Generating Station. The project retrofitted an existing coal-fired generation unit with a post-combustion carbon capture system.[67] The project will ultimately capture approximately 1 MT/annually using the Cansolv system that utilizes rechargeable amines to capture CO_2 and SO_2. The project's final cost was CA$1.5 billion with the Government of Canada contributing CA$240 million.[68] Captured CO_2 will be almost completely used for EOR in the Weyburn project, with some of the CO_2 stored in the Aquistore storage project.[69]

Shell Quest

In early November 2015, Shell and its partners in the Athabasca Oil Sands Project (Chevron Canada and Marathon Oil Canada) officially launched the Quest project near Edmonton Alberta. The project will be capturing over 1 megatons of CO_2 from the Scotford Upgrader, a facility that converts bitumen into synthetic crude oil. The existing concentrated CO_2 stream is captured from the upgrader's steam methane reformer unit. It is transported in liquid form 80 km by underground pipeline and injected into a saline porous rock formation approximately two km below the surface. The Alberta Government has committed CA$745 million to the project and the Government of Canada has invested CA$120 million. The project will also receive two-for-one credits for 10

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[63] Sum of all government contributions (Government of Canada and the governments of Alberta, Saskatchewan, and British Columbia.)

[64] Natural Resources Canada, "Large Scale CCS Demonstration Projects." http://www.nrcan.gc.ca/energy/funding/current-funding-programs/4951; Alberta Energy, "Alberta's Carbon Capture and Storage projects." http://www.energy.alberta.ca/CCS/3822.asp (September 21, 2015)

[65] Max Fawcett, "The Full Alberta Oil Interview with Saskatchewan Premier Brad Wall," *Alberta Oil*, September 2, 2015. http://www.albertaoilmagazine.com/2015/09/saskatchewan-premier-brad-wall/ (September 21, 2015)

[66] As reflected in media: Questions over 'spin' of SaskPower's early carbon capture failures. http://globalnews.ca/news/2304736/questions-over-spin-of-saskpowers-early-carbon-capture-failures/.
Activist friends set up anti-Boundary Dam website
http://www.thestarphoenix.com/technology/activist+friends+anti+boundary+website/11516669/story.html
Saskatchewan Should Repay CO_2 Project Costs, Wind Group Says
http://www.bloomberg.com/news/articles/2015-03-26/saskatchewan-should-repay-costs-of-CO_2-project-wind-group-says
SaskPower's Carbon Capture Project. What Risk? What Reward?
https://www.policyalternatives.ca/publications/reports/saskpowers-carbon-capture-project

[67] SaskPower, "Capturing Carbon and the World's Attention," *Innovating Today to Power Tomorrow* (2015). http://www.saskpower.com/our-power-future/innovating-today-to-power-tomorrow/capturing-carbon-and-the-worlds-attention/ (September 21, 2015)

[68] The final CA$150-200 budget overrun was a result of challenges with the installation of the new generating unit. Canadian Centre for Policy Alternatives
https://www.policyalternatives.ca/sites/default/files/uploads/publications/Saskatchewan%20Office/2015/02/Saskpowers_Carbon_Capture_Project.pdf

[69] Aquistore. http://aquistore.ca/ (September 21, 2015)

years from the Alberta government under the Alberta Government Specified Gas Emitters Regulation (credits are currently valued at CA$15/tonne, increasing to $30/tonne by 2017).[70]

Weyburn

Canada is also home to the International Energy Agency Greenhouse Gas Weyburn–Midale CO_2 Monitoring and Storage Project, one of the world's most intensively researched CO_2 EOR projects. The goal of the project is to understand the behaviour and fate of injected carbon in the Weyburn-Midale oil formation and to guide future CO_2 storage projects.[71] Operated by Cenovus Energy, the Weyburn operation has been injecting CO_2 since 2000. Cenovus estimates that, to date, it has stored more than 24 million tons of CO_2 in the formation. Cenovus currently purchases CO_2 from Dakota Gasification's Great Plain Synfuels Plant in Beulah, North Dakota as well as the SaskPower Boundary Dam project.

Alberta Carbon Trunk Line

Enhance Energy continues to work on the Alberta Carbon Trunk Line Project which will be a 240 kilometre pipeline that will transport CO_2 from industrial emitters in and around Central Alberta to EOR operations. Currently, Agrium (fertilizer facility)[72] and Northwest Upgrading Project (oilsands bitumen refinery) have both agreed to supply CO_2 to the pipeline when it is completed. The project will receive just over CA$0.5 billion in public funding from the Government of Alberta and Government of Canada.

Moving forward

The next phase of development of CCS in Canada remains uncertain, as it is clear Canada's CCS ambitions were significantly overstated. The presentation of CCS as a "silver bullet" solution for greenhouse gas emissions from the largest emitters may have damaged the public's perception of CCS as a credible climate change solution.

The challenge is that Canada currently has a heavy economic reliance on carbon-intensive sectors, and for deep carbonization to occur in Canada, CCS will still need to be part of the package of solutions. The right conditions will need to be established to incentivize companies to adopt CCS, and/or Canadian regulators will need to be ready to make CCS mandatory for carbon-intensive sectors. Canada needs to put a price on carbon (such as a carbon tax/levy or cap-and-trade policy) to start guiding investment decisions and reducing emissions.

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[70] Alberta Environment and Parks, "Industrial Emissions Management." http://esrd.alberta.ca/climate-change/programs-and-services/industrial-emissions-management.aspx (Sept 22, 2015)
[71] Cenovus Energy, "Operations: Weyburn." http://www.cenovus.com/operations/oil/weyburn.html (Sept 22, 2015)
[72] Agrium, "Enhance Energy and Agrium Sign CO_2 Agreement," news release, May 27, 2008. http://www.agrium.com/en/investors/news-releases/2008/enhance-energy-and-agrium-sign-CO_2-agreement (Sept 22, 2015)

As it is unlikely that the price on carbon will be high enough to incentivize investment in CCS,[73] Canadian governments will need to continue to provide public support for CCS through direct and indirect investment — capital grants, investment tax credits, credit guarantees and insurance for the early stages of deployment of the CCS technology.

[73] The Pembina Institute has concluded that CCS in the oilsands sector will occur only if federal and provincial governments establish a price on carbon in the range of CA$95-255 per ton. Bramley, Matthew, Marc Huot, Simon Dyer and Matt Horne "Responsible Action? An assessment of Alberta's greenhouse gas policies" http://www.pembina.org/pub/2295

China

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Introduction/Overview

China has incorporated CCUS development into its national climate mitigation and energy security strategy. Since 2006, China's top policy-making bodies, including State Council, Ministry of Science and Technology, National Development and Reform Commission, have issued a series of policy guidelines on CCUS (See Table 1). With strong government support, state-owned energy giants, top universities, and national labs are conducting CCUS RD&D activities at all levels and stages. Government-supported programs have resulted in better technical understanding, pilot and demonstration projects.

Year	Policy Guideline
2006	National Mid- and Long- Term Science and Technology Development Plan
2011	National 12th-Five Year Plan on Science and Technology
2011	CCUS Roadmap Study
2013	National 12th-Five Year Plan on Carbon Capture and Storage
2013	National Notice to Promote CCUS Demonstration projects
2014	China's Policies and Actions for Addressing Climate Change

Table 1: Some leading government documents to guide CCUS development

Regional CCS Status/Issues

Research Program

The National Basic Research Program (973 Program), National High-Technology Program (863 Program), and National Key Technology R&DD program are the three main drivers behind the CCUS RD&D. Within these programs, state-owned enterprises, various institutes at Chinese Academy of Sciences, and top universities, are undertaking a broad portfolio of research projects from basic to demonstration stage. Research areas include post-combustion capture, pre-combustion capture, oxy-fuel combustion, CO_2 utilization and storage, etc.

Project Name	Program	Main Institute
CO_2 Enhanced-Oil-Recovery	973 program	China National Petroleum Corporation, Huazhong University of Science and Technology
CO_2 Capture and Storage Technologies	863 Program	Tsinghua University, China Academy of Sciences-Geology and Earth Institute
Oxy-Fuel Combustion Research	863 Program	Huazhong University of Science and Technology
CO_2-Algae-Biofuel Technology	863 Program	ENN, Qinan University
IGCC+CCS Research	863 Program	Huaneng Group
CO_2 Capture from coal-to-liquids plant and CO_2 storage research	National Key Technology R&D Program	Shenhua, Academy of Sciences-Wuhan Institute of Soil and Rock Mechanics

Table 2: Some notable government supported RD&D programs for CCUS development

Significant regional CCS projects

Demonstration Projects

To date, China's portfolio of demonstration projects includes the construction and operation of GreenGen (owned by Huaneng), an IGCC with CCS planned in its third phase, a test injection and storage (owned by Shenhua) at a direct coal liquefaction plant in Inner Mongolia, and an operational post-combustion CO_2 capture (owned by Huaneng) on a supercritical coal plant near Shanghai, and a recent 35MW oxy-fuel combustion demonstration project (owned by HUST) in Hubei province.

The 2014 National Assessment on CO_2 utilization technology

Over the last few years, China's policymakers have turned to CO_2 utilization technologies for solutions, even though some major multinational agencies downplay the role of CO_2 utilization technology in the CCUS chain. China's energy and climate change pundits believe that CO_2 utilization technologies can offset the high cost of carbon capture; by integrating low-cost CO_2 capture sources, the CCUS chain might make extra profits and eventually, help the country more easily implement the technology. Based on this rationale, the Administrative Center of China's Agenda 21, an agency of the Ministry of Science and Technology, published *China's First National CO_2 Utilization Technology Assessment Report* in April 2014, as the Third National Climate Change Assessment Report's Special Issue. Around 30 experts joined in this one-year study examining more than 25 CO_2 utilization technologies (see Table 3) through its technological development stage, CO_2 reduction potential, and economic feasibility.

Geological Utilization	Chemical Utilization	Biological Utilization
Enhanced Oil Recovery	Biodegradable Polymer	Algae to Biofuel or Chemicals
Enhanced Coal Bed Methane Production	Isocyanate/polyurethane	Algae to Fertilizer
Enhanced Gas Recovery	Polycarbonate/Polyester	Food/Feed Additives
Enhanced Share Gas Recovery	Vinyl Polyester	Gas Fertilizer
Enhanced Geothermal Systems	Poly Butyl Diacid Glycol Ester	
Enhanced Uranium Leaching	CO_2 to Liquids	
Enhanced Water	Methanol through Hydrogenation	
	Dimethyl Carbonate	
	Formic Acid	

Table 3: CO_2 Utilization Technologies

Under the scenario of strengthened governmental policy and strong private investment, by 2020, 20 CO_2 utilization technologies will be able to achieve commercialization with a CO_2 emissions reduction of 250 million tons/year (4 percent of the 2011 total CO_2 emissions). By 2030, almost all CCU technologies will be commercialized, with an expected CO_2 emissions reduction of 880 million tons/year (13 percent of the 2011 total CO_2 emissions) with the same scenario.

International Cooperation

There has been significant international cooperation on CCS research in China, including engagement in the Carbon Sequestration Leadership Forum and the Global CCS Institute, as well as focused cooperative research efforts, such as the EU-UK CCS Cooperative Action within China, or COACH program, the U.S.-China Clean Energy Research Center (CERC), the China-EU Cooperation on Near Zero Emissions Coal (NZEC) and the Asia-Pacific Partnership on Clean Development and Climate. In particular, on November 12, 2014, the U.S. and China made a historical agreement to enhance cooperation on climate change and clean energy. President Obama pledged to cut U.S. greenhouse gas emissions 26-28 percent below 2005 levels by 2025. President Xi announced targets to peak carbon emissions around 2030. As part of this announcement, both countries agreed to expand joint clean energy R&D and advance major carbon capture, utilization and storage demonstrations through the US-China Climate Change Working Group and the CERC.

Cooperative efforts under these programs have spanned basic and applied research and have also included efforts designed to inform policy and regulatory developments that would enable CCS in China, reinforcing the value of continued international collaboration.

Moving forward

Continuous investment in CCS RD&D indicates China's determination to low-carbonize its fossil-based energy and industrial structure. China's central government has been pushing on both technology and policy fronts, and is demonstrating its willingness to continue doing so in its thirteenth five-year economic development period. It is expected that China will have commercial-scale integrated CCS demonstration projects around 2020, which is envisioned in the U.S.-China Joint Climate Agreement in 2014. The biggest challenge to enable further development of CCS at this moment lies in the lack of market incentives for emissions-reduction technologies. China has promised to establish its national carbon market around 2017. Along with other policy and financial incentives, CCS might receive more and more market interests. At the same time, China's central government needs to build its national environmental and safety framework for CCS. The technical guidance of environmental assessment of CCS demonstration project issued in 2014 is a good start; however, the guidance needs to be detailed for implementation. CCS can only be successful in China if there is a comprehensive and effective economic and environmental regulatory framework in place.

European Union

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Introduction/Overview

CCS in Europe showed strong promise nearly a decade ago, only to have government and industry pull away from planned research and demonstration efforts. Initially, CCS received strong support from political leaders following the impetus given by the UK Presidencies of the G8 and EU during 2005. As a result, the EU agreed to:

- co-fund development of a 'Near Zero Emissions Coal' plant in China (2005);
- deliver a domestic 'demonstration' programme of 12 CCS projects by 2015 (2007);
- create a funding mechanism (NER300) linked to auction revenues from the EU ETS (2008);
- create a regulatory framework for geological storage of CO_2 (2008); and provide economic stimulus support for 6 leading projects (2009).

However, the policy approach taken was almost entirely focused on the 'demonstration' of CCS for coal power generation as part of a 'cleaner fossil fuels' agenda. Deployment incentives were limited to the inclusion of CCS under the EU Emissions Trading System (ETS). Regulatory measures such as Emissions Performance Standards were not supported by the European Commission and Member States, despite support from NGOs and the European Parliament. This approach was in line with the international prioritization of the time, which foresaw the deployment of CCS on (and via) new coal plants and/or future retrofits. However, it had a number of shortcomings:

- It excluded broader conceptions of CCS on industry, gas power generation and for carbon reduction / negative emissions. Not only do these options all receive higher public support than CCS on coal and lignite, but they can also provide cheaper CCS deployment opportunities. By limiting its initial efforts to coal, the EU trapped itself in an unpopular and high-cost approach to CCS.
- It assumed that utilities would be delivery agents for end-to-end CCS projects, creating a market for technology suppliers, and engaging the oil and gas sector for CO_2 storage. But utilities and the coal sector have consistently retreated from action on climate change and delayed efforts on CCS.
- It provoked backlash in Germany and other member states, where campaign groups attacked CCS as a fig leaf for continued coal and lignite extraction without clear climate benefits. This poisoned the debate about CCS in Germany and undermined previous

political support as well as limiting the scope of national CO_2 storage legislation, resulting in the cancellation of demonstration projects.

It is important to note that this approach was largely delivered by policymakers with a predominant focus on fossil fuel development rather than climate change. By prioritizing coal and engagement with a few powerful utilities it failed to make a clear public interest case for CCS. Additionally, policymakers leading on climate change sought to reduce the scope for technology-specific policies and regulatory measures, preferring to use only the ETS. Even the creation of NER300 was a struggle against policymaker resistance. Advocacy efforts in this period were led by a small group of NGOs and companies – even at this early stage the utilities and coal sectors were reluctant participants rather than cheerleaders.

Regional CCS Status

The subsequent experience of CCS in Europe since 2010 has been one of stasis. The economic crash and collapse of the carbon price destroyed the putative business case for CCS and radically reduced the level of financial support for demonstration projects via the NER300.

During this period, CCS disappeared from the list of political priorities, even within the climate change arena. Most member states were seen as having a lack of interest or a negative view of CCS – viewing it as an expensive distraction from efforts to tackle the economic crisis, and preferring to wait to see the outcome of the demonstration programme. Further, the continued growth of renewables meant that there has been a near total collapse of the proposed pipeline of new coal plants in Europe.[74] Only a few 'new' coal plants are proposed in Poland, which is more generally unwilling to make significant efforts to address CO_2 emissions, and is, therefore, not persuaded of the merits of investing in CCS.

At the EU level, the European Commission began to recognise in its analyses that CCS could play a valuable role for industrial processes and even saw a greater role for gas CCS in power generation than that for coal. However, when it came to policy action, the Commission remained wedded to an ETS-driven policy framework, meaning that it did not foresee substantial deployment of CCS until after 2030. Additionally, the Commission has also recognised the importance of access to CO_2 Transport and Storage infrastructures as an enabler of CCS deployment. However, the Commission has yet to drive the development of cross-border CO_2 transportation projects, instead prioritising efforts on gas and electricity interconnections.

This combination of political disinterest and policy inertia resulted in CCS receiving only passing reference in the EU 2030 climate and energy package agreed upon in October 2014 – and this was only possible due to proactive UK engagement to ensure it was included. The EU 2030 deal

[74] Note: recent media coverage of 'new coal' in Germany and The Netherlands refers to plants that were permitted in 2007-08 but have been delayed in construction. Latest analysis shows that these plants will struggle to ever recover their investment costs. The case for CCS retrofit on these plants is currently implausible from a financial perspective, even though these plants are among the few which might have sufficiently high efficiencies to justify CCS retrofit on a technical basis. It should also be noted that these plants were not constructed as 'capture ready'. A notable exception could be plants located in Rotterdam, which have the prospect of close access to CO_2 storage and CO_2 infrastructure being developed by the ROAD project.

did, however, include the continuation of funding for CCS under a new Innovation fund that will extend the current NER300 approach. This firmly placed CCS in the ‘too difficult’ box labelled ‘innovation’.

It should be noted that throughout this period, the utilities and coal sector firmly retreated from CCS. The economic crisis and continued deployment of renewables have combined to challenge their business models, with their response being to prioritise pursuit of capacity payments for existing fossil fuel power plants. Their approach also undermined support for CCS from equipment suppliers, and blocked attempts to develop alternative policy options via the CCS technology platform ZEP.

The sudden ending of the UK CCS Programme

Throughout this period, the UK alone had a proactive CCS development programme, prior to its shock cancellation in November 2015.[75] UK government efforts to bring forward demonstration projects had however been hampered by poor project management and uncertainty over funding availability.[76] Renewed commitment to CCS under the Coalition Government of 2010-15 saw the creation of a new Commercialisation Programme project selection process. This was supposed to lead to the provision of funding under electricity market reforms that made available comparable incentives to renewables, nuclear and CCS. This policy framework had been widely praised for its combination of capital support for early CCS projects as a means of opening the door to wider deployment. The policy intention was for follow on projects to share CO_2 transport and storage infrastructures as a means of driving cost reduction.

Unfortunately, the UK Treasury made an unexpected decision to withdraw the capital funding for the programme at the Comprehensive Spending Review in late November 2015, just four weeks before Commercialisation Programme bids were due to be submitted for government evaluation. At the time of publication, this decision is still being digested and full details are yet to be announced. However the early indications are that the UK government does not intend to deliver on its previous commitments to integrate CCS into the electricity market. With no capital allocation for CCS for the coming five years it also has no means of taking forward significant development of CO_2 infrastructures or industrial CCS projects. The funding cut therefore has far more significance than just the impact on the two bidding projects, and represents a threat to the deployability of CCS in the UK in the period to 2030 and beyond. The expected outcome is that Phase 2 CCS projects will also cease development work, while industrial CCS initiatives will struggle to proceed without the rapid development of a forward policy framework.

The decision to cut CCS funding will have significant domestic implications for the UK government, as it looks at how it will take forward decarbonisation efforts in line with the carbon budgets set under the Climate Change Act of 2008. By mid-2016 the UK government must

[75] The Netherlands had a proactive CCS research programme, but just one large scale CCS project.
[76] See National Audit Office report into cancellation of the UK’s first CCS competition in 2011: https://www.nao.org.uk/report/carbon-capture-and-storage-lessons-from-the-competition-for-the-first-uk-demonstration/

confirm how it intends to meet emissions reductions in the period to 2032 (the 5th carbon budget). The absence of CCS in this time period will require significant additional efforts and expense via the deployment of alternative technologies and efforts by other sectors beyond power generation.

Politically, the UK's apparent withdrawal from CCS for the foreseeable future is likely to remove its sole remaining proactive political champion within the EU. A handful of other member states had been willing to see continued efforts on CCS, particularly for industrial sectors, but had left the UK to push for the inclusion of CCS within EU policy processes.

Significant Regional CCS Projects

Despite the absence of a central role for CCS within the EU2030 package, there had been a number of encouraging developments in the broader CCS landscape over the past 18 months prior to the UK announcement. These offered an opportunity to rebuild advocacy networks on the basis of positive intent from participants, and would have enabled the communication of a public interest case to policymakers, politicians and citizens. Such an approach could also have formed the basis for improved engagement from previously antagonistic NGOs.

Recent developments of note include:

- In early 2015, utility members decided to leave ZEP (the EU technology platform on CCS). They instead retreated to a non-functioning taskforce within their existing industry association. This is excellent news, as they had been barriers to collective agreement within ZEP, particularly in respect to policy options that could drive CCS deployment. (Notably this extended to financing options as well as regulatory measures).
- There are positive signs that key industry sectors are beginning to engage more proactively on CCS. The '2050 Roadmap' exercises undertaken by the trade associations for iron and steel, cement, and chemicals have all identified CCS availability as a key enabler of their ability to meet deep decarbonisation objectives out to 2050. While there are still significant differences of opinion within industrial sectors, the positive engagement of progressive companies is a major shift from the blocking approach taken by utilities.
- This industrial engagement is also being taken forward on a collaborative regional basis, providing a positive reference point for policymakers and politicians. Most notably, the Teesside Collective in North East England is bringing together local governments and industrial players to develop an engineering master plan for a CO_2 network that can enable cost-effective decarbonisation of multiple industrial emitters. The core project participants come from the steel, hydrogen, chemicals and plastics sectors. Importantly, the project is also undertaking analysis of potential financial incentives that could drive deployment of CCS on industry.

- Similar practical collaborations are underway in the Ports of Antwerp and Rotterdam, while Scotland is taking the lead in developing options for CO_2 storage (notably including some of the few European opportunities in CO_2-EOR).
- Nordic and Baltic countries and industrial emitters are cooperating on assessments of CO_2 storage opportunities and the development of combined pipeline/shipping networks for CO_2 transport, as CCS is increasingly recognized as a key enabler of deep decarbonization for their industrial and biomass sectors. The CCS roadmap project for Portugal similarly identified the need for CCS for cement production over the coming decades.

A common theme emerging across sectors and locations had been a recognition that CO_2 transport and storage infrastructures should be provided in advance (ideally by publically owned infrastructure providers or via a contractor-to-the-state business model), and that they should be overseen by regulators to enable equitable access to emitters. The UK Commercialisation Programme had also been seen as a means of kick-starting this approach, so its sudden end is a significant blow to CCS prospects elsewhere in Europe too.

Box 2.1: Status report

Original EU aim – fund CCS demonstration project in China.

Status: not delivered. Initial phases completed, but large-scale funding not provided. Some bilateral engagement with China continues at academic level, but limited government support. U.S.-China cooperation now well advanced. European international engagement would be better targeted at countries with particular interests in CCS for gas power generation and industrial sources, negative emission / carbon reduction options and offshore CO_2 storage.

Box 2.2: Status report

Original EU aim – deliver 12 CCS demonstration projects in Europe by 2015.

Status: not delivered. The prospects for the last three large-scale projects remaining are now slim. The aim was for them to be operational by 2020, but none have yet taken a final investment decision:

- ROAD (post-combustion coal, Netherlands – EEPR recipient). The project is being reconfigured to become a smaller scale pilot project and receive R&D support. With pressure growing for a coal phase out in The Netherlands the project must address additional commercial and political hurdles if it is to proceed.
- White Rose (Oxy-combustion coal, UK – NER300 recipient and UK programme). The White Rose project had seen the withdrawal of original utility partner Drax during 2015 as a result of UK government cuts to biomass subsidies that impacted company financial standing. The remaining members of the consortium were set to announce a partnership with a Chinese utility in December 2015 prior to the cancellation of the UK commercialization programme. Without government support the project is unable to proceed.
- Peterhead (post-combustion gas, Scotland, UK – UK programme). This project had the greatest chances of progressing commercially prior to the cancellation of the UK commercialization programme, as it would have combined Shell Cansolv capture technology with re-use of an existing offshore pipeline and injection platform at the Shell Goldeneye depleted gas field. Shell has announced that there is no future for the project following the UK funding cut. This puts at risk the availability of the CO_2 storage resource of Goldeneye and the surrounding saline formations.

Prior to the UK announcement, there were a handful of 'second phase' UK projects that might have been able to come forward in the early 2020s, subject to the intended provision of access to the UK's new system of 'Contracts for Difference' Feed In Tariffs for CCS.[77] In both the EU and UK, competitive procurement processes have killed off CCS projects rather than expanding industry interest and engagement. Refreshed efforts should therefore focus on building the opportunity space for multiple projects via a focus on the enabling infrastructures required for cluster and hub development.

[77] Summit Power's proposed Caledonia Clean Energy Project had received support from UK and Scottish governments in early 2015 in order to undertake further design work. Their intention was to co-locate an IGCC alongside the Grangemouth refinery complex. The Don Valley Power Project had previously been awarded EU funding under the EEPR programme, but had not been selected in the UK competition. Earlier in 2015 the project was taken over by Sargas, who intended to reconfigure it as a natural gas CCGT with CO_2 capture, rather than the original plan for a coal-fired IGCC. The final tranche of EU funding was still to be provided, subject to UK government clarification of potential future access to funding arrangements.

Box 2.3: Status report

Original EU aim – create regulatory framework for CO_2 storage.

Status: EU legislation enacted in 2009. Slow transposition into national laws since then, with some countries (e.g., Germany, Austria) incorporating more restrictive provisions. Recent evaluation of EU directive found no need to re-open legislation, but recommended improvements to guidance on liability issues and implementation of currently loose 'capture readiness' requirements.

Practically, however, just one CO_2 storage site has a valid permit at present (for the ROAD project). Permitting processes were finally beginning for Peterhead and White Rose. But Europe has suffered from a chronic underinvestment in storage characterization which will require targeted action to correct over the coming decade. This further reinforces the importance of maximizing the value of CO_2 stored, rather than seeking to maximize CO_2 volumes from coal and lignite (as would typically be the case for CO_2 -EOR projects elsewhere).

Moving forward

A new set of European Commissioners entered office in late 2014, following agreement on the EU2030 framework. A new post of commissioner for Energy and Climate Change was taken on by Spanish politician Miguel Arias Cañete. He has expressed support for CCS and has visited the Emirates steel project in Abu Dhabi. Similarly, the new Vice President of the Commission for Energy Union, Maroš Šefčovič, has made positive statements on CCS.

At a practical level, an extensive evaluation of the existing CO_2 storage directive was undertaken during 2014 with positive industry and stakeholder engagement. This concluded that the directive itself did not need to be amended, but that there was a need for further enabling policies for CCS. Recommendations from the evaluation process included the need for CCS to feature within the 2030 action plans to be developed by each member state and for there to be a supporting CCS strategy at EU level. It also proposed that the EU could undertake targeted action on CO_2 transport infrastructure development, storage characterization and incentive measures, as well as considering additional regulatory interventions such as Emissions Performance Standards or even mandatory CCS requirements.

In late November 2015 the European Commission finally released its review of the CO_2 storage directive.[78] Disappointingly, the review says very little in respect to future enabling policies. The

[78] http://ec.europa.eu/clima/policies/strategies/progress/docs/com_2015_576_annex_2_en.pdf

EU ETS remains the central focus of policy, and is used as a justification for not taking forward further consideration of Emissions Performance Standards. This is a missed opportunity to consider complementary policy approaches that could enable the accelerated retirement of ageing and inefficient coal power plants.

A little more positively, the Commission acknowledged the importance of CCS featuring within the 2050 governance process and member state plans, together with the importance of CO_2 transport and storage infrastructures to reduce costs. But beyond referencing existing funding instruments the Commission has failed to set out any proposals to accelerate action on CCS. Instead, the North Sea Basin Taskforce was due to take on the task of defining the outline of a CO_2 strategy for the North Sea to guide the development of Projects of Common Interest and CO_2 infrastructure. Without proactive UK engagement, this approach will likely struggle for political traction.

Overall, the combination of the UK's shock cancellation of CCS funding and the lack of any substantial initiatives in the Commission's review paper poses a serious challenge to the credibility of European action on CCS. It was already abundantly clear that CCS deployment in Europe will not be led its application to coal-fired power generation, as was assumed by policy makers. With the UK's recent about-turn the prospects for CCS on gas have also been significantly set back. Similarly, big questions must now be answered in respect to the deliverability of CCS for industrial emitters given the absence of an enabling financial and regulatory framework and insufficient efforts at EU and member state level to bring forward CO_2 transport and storage infrastructures.

This now poses a stark challenge to the European Commission. If CCS is not a deployable solution at scale, then the Commission must reflect this by removing CCS from its analysis of European decarbonisation pathways. It must highlight the different costs of decarbonization pathways with and without CCS, and consider the implications for industrial sectors and employment if CCS is not available. But it cannot continue to pretend that CCS is an option if its own policies and the inaction of member states are failing to bring CCS forward.

Europe's supposed political commitments to deep decarbonisation will likely require refreshed attention to CCS as member states consider their potential pathways to 2050. But there needs to be some serious reconsideration of the simplistic policy assumptions and industrial opposition that have left CCS hanging by a thread at precisely the time it could start to offer a valuable way forward.

Norway

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Introduction/Overview

Norway has been conducting research on CCS for more than two decades. The first report for a CCS project in Norway was published in 1987. The main focus until recently was gas power plants, but now the country is undertaking feasibility studies mainly on industrial CCS projects.

With research and development, the Norwegian environment has produced significant results and built several pilots, including the BIGCCS and SUCCESS research centres. The first government policy for CCS in Norwegian power plants dates back to 1997 when the pollution authorities gave permission to build a new gas-fired power plant at Kårstø, with an obligation to build and use CCS from day one. In 2000, a Parliament conflict over this permit was thought to be due to the opposition allowing startup of the gas power plant without a CCS obligation, leading to the resignation of the Bondevik government, which would not accept such a solution.

It was followed by the Stoltenberg (I) government, which changed the CCS obligation connected to the startup of Kårstø and Mongstad. In 2005 the new Stoltenberg (II) coalition government promised in its government declaration that from that date, no new gas-fired power plants would be built in Norway without carbon capture, and the government would contribute toward the building of a full-scale capture plant at Kårstø and Mongstad as soon as possible. The planned date of the investment decision was postponed several times, and finally, the late coalition government shelved the full-scale plant at Mongstad in autumn of 2013.

The Mongstad hearing and the report from that hearing released in March 2014 revealed fundamental issues that should be taken into consideration when launching another full-scale CCS project in Norway. The main learning point for further projects was to ensure cost efficiency and tight project management.

Regional CCS Status/Issues

The present government, elected in 2013, has promised that despite the cancellation of Mongstad, it will support the promise of a Norwegian CCS project by 2020. Since then, several studies have been undertaken.

In May 2015, the Department of Oil and Energy published the Gassnova report on potential full-scale CCS projects in Norway – a pre-feasibility study. The study shows that several industrial companies are willing to consider CO_2 capture and storage, but this is – not surprisingly – dependent upon the framework established by the state. The study concludes that a basis for investment decisions for a CO_2 capture project can be presented at the earliest in autumn 2018, which might push the politically set time frame.

Gassnova, based on the study, is now conducting further feasibility studies specifically on three highlighted projects: at the Norcem cement factory in Brevik; at the Yara mineral fertilizer plant in Porsgrunn; and at the waste management plant at Klemetsrud in Oslo. The fact that these three industrial projects have been chosen for further study is good news for the potential learning and technical transfer worldwide.

Norway has the ability to initiate measures for expediting the process toward realization of a full-scale project, however there is a need to move forward in terms of Norwegian CCS policy. The goal in the Parliamentary Climate Settlement in 2008 (and the updated version from 2012) – to establish a Norwegian full-scale CCS project by 2020 – is an achievable goal. However, the national budget thus far, and the included CCS strategy do not contain concrete plans for how to fund and realize such a project, leaving significant doubt for how such action could realistically take place within the next five to 10 years.

Still, the feasibility studies of the three highlighted projects can, and should be, expanded and restructured to be part of a process that, after the investment decision continues, leads toward a building phase, ending in the realization of full-scale CCS project(s).

Without specific goals and an action plan for implementation, it becomes more difficult for potential CCS projects to set aside time for yet more evaluation processes and to make the financial decisions necessary to gather momentum. The industry needs certainty that there will be sufficient money on the table before it is able to invest. The funds are accessible now in this development/study period, but with a planned investment decision for 2018, a decision entirely dependent on the future of political will and thus uncertain, the industry cannot obtain the required, long-term certainty needed.

Significant regional CCS projects

Sleipner/Snøhvit

The world's largest and perhaps best-known storage projects are the capturing of CO_2 from natural gas production at Sleipner in the North Sea and Snøhvit, close to Hammerfest in Northern Norway. These two projects were initiated by the Norwegian government's introduction of an offshore CO_2 tax in 1991 that made it commercially preferable to capture and store the CO_2 from the natural gas, rather than emitting it to the atmosphere. In the Sleipner project, approximately 1 Mt of CO_2 has been injected every year into a saline aquifer in the Utsira formation since 1996. Significant knowledge about CO_2 injection technology, monitoring and storage safety has been gained from this project. Snøhvit is a very similar project that started its injection in 2008. Quite different geological properties of the storage formation have introduced some challenges to the project, but approximately 3Mt have been injected the last five years.

Test Center Mongstad (TCM)

The Technology Centre Mongstad (TCM) with a capacity of 100,000 ton/y, was officially opened in May 2012, and contains two capture facilities that can switch between two different flue gases. One source of emissions is the existing catalytic cracker facility at the Mongstad Refinery, and the other is emissions from the gas-fired combined heat and power plant. In its first two years of operation, TCM was performing tests for Alstom and Aker. After a comprehensive evaluation, TCM selected two processes, a chilled ammonia process from Alstom and an amine process from Aker Clean Carbon (ACC).

The size of the facility, the flexibility and features implemented in the specifications and design opened the door for extensive test options. These tests generated a significant amount of results. The size of TCM means from the results, relevant information can be extrapolated for eventual full-scale implementation elsewhere in the world.

In late 2012/early 2013, TCM launched an international test facility network, in order to exchange information and experience that seeks to promote the deployment of CCS worldwide.

Shell Cansolv started in November 2014 the testing of its CO_2 capture process at TCM. The testing is confirming Shell Cansolv's processes and emission controls using exhaust gas from the Combined Heat and Power (CHP) Plant at Mongstad. The test phase will reinforce the CANSOLV CO_2 Capture technology, and validate its readiness for deployment at industrial-scale projects.

In September 2015, TCM signed a test agreement with Carbon Clean Solutions Limited (CCSL) to test its solvent technology starting in mid-November. GE, Alstom, and the University of Kentucky (UoK) may be on their way to TCM to test their CO_2 technologies with funding from U.S. Department of Energy. (TCM is a joint venture which consists of Gassnova, on behalf of the Norwegian state, Statoil, Shell, and Sasol.)

Norcem

One of the projects in the "Gassnova report on potential full-scale CCS projects in Norway – a pre-feasibility study"79 described as among the more relevant is Norcem's cement plant in Brevik in Porsgrunn. There, Norcem has tested various CCS technologies successfully since 2013, and most importantly, appear agreeable for upscaling the project to a larger scale. Norcem has even said that it would aim to be emission-free by 2030. As part of the European Heidelberg, it will do this on behalf of the cement industry in Europe.

If Norcem succeeds in its ambitions to capture and store CO_2 from cement production in Brevik, there will be significant technological advances of an international character. The world needs proven climate solutions for industry if we are to avoid dangerous global warming. Norcem has

[79] See: https://www.regjeringen.no/contentassets/3652c303169e46e7815617adab685710/gassnovas-pre-feasibility-study.pdf

tested and developed purification technology for cement since May 2013 and is now in the process of completing this with early noteworthy results.

Production of cement in 2012 stood at around four percent of global greenhouse gas emissions, meaning such proven solutions would be deemed quite significant. For several industries, there are no other technologies to handle CO_2 emissions from production and thus, it is essential that we develop similar spearheading types of projects for eventual large scale implementation.

Yara

Yara is considering its ammonia plant in Porsgrunn as relevant for further studies in CO_2 capture and is now in the same feed study process as Norcem. Yara's overall emissions are about 1.2 million tonnes of CO_2 annually at full ammonia production, and it sells some of this to the food industry. Approximately 0,8 Mt is captured a year, 0,2-0,3 of this is sold and the rest is emitted.

Yara, Ineos and Norcem have managed to reduce emissions. These firms may be appropriate candidates for concrete cooperation on CO_2 sequestration, also because of their geographic proximity. The challenge remains to develop better frameworks for the processing industry to invest in environmental technologies.

The benefits of capturing CO_2 from industrial processes potentially include lower capture costs; excess energy that can be used for CO_2 capture; stable CO_2 sources; and lower transport costs since many industrial facilities are located along coastal regions. As for Yara, it has industrial experience from commercial use. Now, Norwegian authorities must facilitate coordination for the pursuit of industries such as Norcem and possibly Yara, which appear willing to upscale their projects and subsequently, increase industrial development and job growth. The area of Grenland has 100 jobs related to CO_2 management. We believe it is possible to secure many more jobs in addition.

Klemetsrud

Oslo Municipality has a stated philosophy that aims to contribute to a CO_2 sequestration project at the waste management and energy recovery plant at Klemetsrud. The total emissions from Klemetsrud system represent in excess of 20 percent of the municipality's total greenhouse gas emissions. This is comparable to the annual emissions from about 120,000 cars.

The reporting regime for greenhouse gas emissions is such that CO_2 emissions associated with biomass is not counted on an equal footing with fossil CO_2 emissions. Nevertheless, all reductions in greenhouse gas emissions are equally valuable for the world's climate. Capture of CO_2 emissions partly biological in origin means that CO_2 is taken out of circulation and the atmosphere, making it so-called carbon negative. There is broad consensus that carbon negative technology must be developed and used in this century to avoid dangerous climate change.

If CO_2 emissions from the Klemetsrud plant can be reduced by 2020, this will be a significant contribution to Oslo's climate targets for 2030 and 2050. Also, it will be a significant contribution to the commitment of the Parliamentary climate agreement on a full scale plant for CO_2 capture by 2020. It can also be the world's first full-scale CO_2 capture associated with energy recovery. Oslo City Council has signalled commitment to this project. National authorities must also commit in order to ensure realization.

Moving forward

The lack of instruments and regulations is the biggest barrier for CCS today, both in Norway and internationally. Experience from Norway shows that it does not work with direct public support – at least not alone, or in the long term. CO_2 tax offshore, however, worked triggering offshore Sleipner and Snøhvit. Experience from elsewhere shows that it is possible to trigger CCS through political means, such as strict pollution standards, tax exemptions, regional cooperation and various types of funds and subsidies.

CCS in Norway is now funded by grants from the state budget. CCS projects may also be financed in the same way, but it may also be possible and desirable to obtain financing in other ways, as for example what is done with renewable energy initiatives, with earmarked levies on the distribution tariff for Enova and the green certificate system.

The policy of obligatory CCS in permits from the pollution authority for any new gas-fired power, must be continued and extended to existing plants. The Norwegian Government must fulfil its promise to build full-scale CCS projects, while also establishing infrastructure for transport and storage. Further, a new political framework must be put into place to make CCS economically feasible for industry. As well, the CO_2 tax on offshore plants should be increased and earmarked for a fund dedicated to climate change technological solutions, including CCS.

Different views exist for the most appropriate forms of financing. What is important is that there is a sufficiently large, long-term and predictable financing mechanism to achieve the implementation objectives of several CCS projects. Conditions must be established by the state to drive forward and allocate funds for viable CCS projects.

A national fund/state driven process

Based on international experience with implementation of full-scale CCS facilities, it is possible to cut the outlined plan period from the national CCS strategy by about one year and make an investment decision in 2017. With approximately a three-year construction period, the plant(s) might then be finished in 2020. Funds must also be granted in the budget for the entire planning period of the three projects included in the feasibility study, so that there will not be new periods of time lost due to anticipation of new political budgetary decisions.

In addition, Parliament must ask the government to clarify all the framework conditions needed for companies to be able to make investment decisions for realizing full-scale CCS. This should be finalized within the revised budget in 2016.

There is a need to cover operation costs after developing full-scale projects, to secure competitiveness for industries and energy projects with CCS. A certificate system is a good long-term solution; others could be strict EPS or tax incentives. There is also a need to find short-term solutions for projects built before the certificate system or before similar functioning policy-instruments are implemented. There are several methods to achieve this; one solution could be to hand out five-year guarantees by the Norwegian government to support operational costs.

In the years 2017-2020, designated CCS projects that have received funding should have a tight schedule with close follow-up, including facilitation of the project through the phases of organization, construction and commissioning of a Norwegian full-scale CCS project. The grant could, for example, follow the model of Alberta Energy (the Canadian province's energy department) with rate payments after certain milestones and results met. This is a way of sparking the first Norwegian full-scale projects, which also will need more built-in market mechanisms for operation in the long run.

Storage

The government should also take responsibility for developing storage sites, and the post-storage, long-term liability for CO_2, de-risking storage costs for all CCS projects. In the short term, special government involvement and funding focus is important to establish sufficient early stage storage capacity.

The CO_2 storage atlas created by the Norwegian Petroleum Directorate and the work done by the North Sea Basin Task Force, show that there are great opportunities for storage both on the Norwegian shelf and in the North Sea. Norway must continue its efforts to develop CO_2 storage in the North Sea to reduce the risk of future capture projects. Necessary frameworks must be in place so that storage sites and infrastructure are ready the day CO_2 is captured, or ensuring a site is under development while using ship transport of CO_2 for the first period.

Projects like the Norcem CCS plant, Yara and Klemetsrud, are dependent on the legislative process for storage being taken many steps farther in the coming years. It is especially important for industry and fossil fuel producers, to have clarity for who should be responsible for the long-term risk associated with storage. The fact that the Norwegian authorities are signalling a will to take this responsibility shows promise.

Norway can contribute in a joint European effort to lift CCS by providing storage for CO_2. Storage options in some countries on the continent seem limited both geologically and politically, as in Germany. Norway could contribute positively by facilitating storage of CO_2 from countries that need it.

On the way to a commercial storage business model, one solutions could be providing cash/feed-in tariff for storage. This could help trigger the construction of several capture projects in Europe, an establishment of a large pipeline infrastructure for transport of CO_2, as well as helping to lay the groundwork for business opportunities for Norwegian storage site owners in the long term.

When storage of CO_2 becomes a commercial business, the tariffs will reflect the acquisition of risk.

If Norwegian gas shall have a future role as a climate-friendly energy, the gas buyers need incentives to clean and store CO_2. Future fossil use, also gas, is inextricably linked to CCS. Norway can facilitate CCS of the fossil carbon it sells through establishing a recycling scheme for CO_2. The idea is for CO_2 to be turned back to where it came from – similar to the deposit system for bottles. The buyers are paying a mortgage fee when they buy gas, and get their deposit back when they return CO_2 to an established approved storage site.

Certificate system and other policy instruments

A mix of instruments to promote CCS is indispensable, and the industry needs long-term and predictable frameworks to be willing to invest in CCS. General CCS instruments are preferable to sector-specific instruments, covering emissions beyond power production to give competition for reduced CCS costs across all sectors. And policy instruments for the whole CCS chain are preferable to separate instruments for each part of the chain in the long-term perspective.

A mandatory certificate system

The basis of the certificate system is that if you make profit on taking carbon up, you have to make sure that the carbon is put back. This means that companies will have a legally binding obligation to buy – or "produce" – certificates as a share of their production/supply. The volume of CO_2 will be politically decided, and the market will set a price to fulfill the obligation. A certificate system is a cost-sharing instrument, distributing the extra cost to all fossil value chains, and creating a potentially minimal effect on carbon leakage issues. It is more likely to receive political acceptance when costs are covered by the industry and included in the product price for fossil fuels, rather than if the cost is passed on directly to consumers.

EPS

An output emissions performance standard (EPS) is a benchmark for production, which sets a restriction of maximum allowed emission per produced unit. EPS can be used for both power plants and other industry sectors, such as cement, steel, etc. EPS can also be set not on the specific plant, but on the total company portfolio or for a market portfolio.

Norway's role internationally

The Norwegian government, led by Prime Minister Erna Solberg, has discussed the option to finance CCS projects outside Norway. The only concrete suggestion for supporting and developing CCS with funds from Norway in the EU, is as mentioned, further contributing to ROAD through Horizon2020 funds. The added funds to the ROAD project are supposed to cover operation costs, and come with certain restrictions meaning they will not be made payable until 2017. In practice this means that there is no funding for large-scale CCS projects in Europe or internationally in the national budget for 2015.

The government has also suggested that some of the NOK 200 million funding through The Green Climate Fund (GFC) could be earmarked for CCS projects, and also to strengthen support to CCS projects through the World Bank and their CCS fund. These instruments are not securing any development of CCS today, but could be crucial for the development of CCS in developing and emerging economies in the future, as long as some of the funds are earmarked for CCS.

United States

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Introduction/Overview

The United States present both paradox and an opportunity to advance the status and availability of CCS as an essential decarbonization strategy. The paradox is that the major regional effort thus far has focused on EOR, an approach that harnesses economic drivers and proximate sequestration opportunities, but that, conversely, is imperfectly coordinated with major anthropogenic sources of CO_2 – primarily coal- and gas-fired electricity generators and heavy industry.

The opportunity lies in the fact that the potential for EOR to propel CCS in the near-term is quite large. Estimated potential demand for CO_2 from EOR in the U.S. is enough to drive roughly 80 GW of carbon capture on existing coal-fired power plants – about one-third of current U.S. coal plant capacity.[80] With sound policies, these diverging vectors can be brought into line efficiently by accelerating two evolving trends: nodal geographic organization and additional pipeline construction. By aligning these key elements, the U.S. could develop several hubs of CO_2 EOR that are sufficient to reduce technology costs substantially and pave the way for further CCS deployment in the mid and long term.

The U.S. experience with deployment of solar and wind technology shows that policies creating incentives (such as tax credits) or, in effect, imposing requirements (such as renewable portfolio standards) stimulate deployment and reduce technology costs. Sulfur dioxide scrubbers represent another example in which technology costs were higher when projects were first developed. Then, emission limits combined with R&D investment accelerated their deployment and significantly reduced costs. CCS as a "CO_2 scrubber" is at the beginning of that cost-reduction curve. With policies at the state and federal levels that promote further CCS deployment, the U.S. can realize the same benefit here, as it did with sulfur dioxide scrubbers.[81]

This summer, the U.S. took a major first step in this direction when it finalized carbon pollution rules that will limit power plant emissions. These new standards for new and existing sources, developed under the Clean Air Act, for the first time create a regulatory pathway that would

[80] Wallace, Matthew and Vello Kuuskraa (Advanced Resources International), "An In-Depth Look at 'Next Generation' CO_2 EOR Technology," US NETL, September 23, 2013. Available here: http://netl.doe.gov/research/energy-analysis/publications/details?pub=84d08acd-e46f-409a-8f87-521ca9544cae.
[81] See: "Reducing the Cost of CCS Through 'Learning by Doing,'" Edward S. Rubin, Presentation to the Clearwater Coal Conference, Clearwater, Florida, June 2, 2014. Available here: http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2014/Reducing%20the%20Cost%20of%20CCS%20through%20Learning%20by%20Doing.pdf

necessitate partial CCS on new coal-fired units and that allow them as a compliance option on existing units.[82]

Limited existing incentives in the U.S. have also laid the groundwork for initial CCS projects. By the latter part of the decade, the U.S. will be hosting a substantial share of the world's large-scale CCS projects. Of the 15 in operation globally, the U.S. is home to seven. Of the seven projects under construction, three are in the U.S.[83] But without a unified and firm commitment to stronger policies, it is hard to see how these initial projects will lead to wide-scale CCS deployment.

Regional CCS Status/Issues

The United States is the second-largest source of anthropogenic carbon emissions in the world, accounting for about 16 percent of all CO_2 from power plants and industry.[84] The IEA has projected that, under existing policies, global emissions from those sectors will nearly double by 2050.[85] Although the U.S. is unlikely to see a trend of that magnitude, its stationary source emissions – from power plants and industrial smokestacks – will likely remain significant for the next three to five decades, if not beyond.

In addition to the nation's rank among carbon emitters, other strong arguments compel the conclusion that a redoubled U.S. commitment to CCS can be expected to play a key role in global deployment of this essential climate change strategy.

First, even though the price of CCS may be higher in the West than in Asia, virtually all sequestration in the U.S. now takes place in oil and gas formations, a function of ongoing interest in enhanced oil recovery. In 2012, the U.S. was home to nearly 90 percent of the world's EOR efforts.[86] Because EOR delivers an economic benefit, its use is common, and in 2012, EOR accounted for almost six percent of national production, or 350,000 bpd.[87]

American leadership would have other positive consequences. These include the development and dissemination of complex technical and practical experience, as well as the international impact that U.S. engagement at times can exert. Moreover, the U.S. possesses a large share of the sequestration capacity that so far has been identified.[88] In the U.S., the federal Department of Energy (DOE) projects that available storage ranges from 2,182-20,961 Gt in saline formations,

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[82] See: http://www2.epa.gov/cleanpowerplan/regulatory-actions Accessed Oct, 2015.

[83] Global CCS Institute 2015, "The Global Status of CCS: 2015, Summary Report," Melbourne, Australia. Available here: http://hub.globalccsinstitute.com/sites/default/files/publications/196843/global-status-ccs-2015-summary.pdf.

[84] U.S. EIA, International Energy Statistics, 2012 (U.S. vs. world, 15.2 percent based on coal/natural gas use; 16.4 percent based on total energy use). Available here: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=44&aid=8.

[85] Energy Technology Perspectives 2010 – Scenarios and Strategies to 2050 (Paris: OECD/IEA, 2010), p. 161 (this does not include more recent national promises).

[86] Global CCS Institute 2014, *The Global Status of CCS: 2014*, Melbourne, Australia, p. 45 (89.44 percent of total EOR capture capacity is located in the Americas), pp. 15, 35 (available here: https://www.globalccsinstitute.com/publications/global-status-ccs-2014); Kuuskraa, Vello, Advanced Resources International, Inc., July 2, 2012 (available here: http://www.ogj.com/articles/print/vol-110/issue-07/drilling-production/qc-updates-carbon-dioxide-projects.html); *Oil & Gas Journal*, EOR Survey, April 2, 2012.

[87] *Oil & Gas Journal*, U.S. EOR Production, p. 56. April 2, 2012.

[88] de Coninck, Heleen and Sally M. Benson, "Carbon Dioxide Capture and Storage: Issues and Prospects," *Annual Review of Environment and Resources*, 39:243-70 (2014), p. 254 (aggregating recent regional estimates, from a low range of approximately 9,400 Gt to a high range of 47,000 Gt). Available here: http://www.annualreviews.org/doi/abs/10.1146/annurev-environ-032112-095222.

185-203 Gt in oil and natural gas reservoirs, and 34-113 Gt in unmineable coal beds – which add up to 26-45 percent of available global storage.[89] In theory, this is enough to sequester all U.S. CO_2 emissions from large stationary sources for more than six centuries.[90]

Significant regional CCS projects

Right now, North America is the leader in large-scale CCS projects, with most of them ancillary to EOR. In the U.S., one project – operated in Illinois by Archer Daniels Midland – will capture carbon dioxide from an ethanol plant and test the effect of injecting it into a nearby sandstone formation. Two others – one in Mississippi and one in Texas – could start up in 2016:

- Mississippi Power's Kemper County Energy Facility (Plant Ratcliffe), at 582 MW, is a coal-fired power plant that will draw on pre-combustion capture technology as part of an IGCC system that is expected to prevent around 3 million tonnes of carbon from reaching the atmosphere each year – approximately 65 percent of the plant's total emissions. Piped for nearly 100 km, the CO_2 will be sequestered in depleted oil fields as part of EOR operations. Though behind schedule, the project is now reported to be virtually complete, with operation set for the first half of 2016. The $5.6-billion facility received a $270 million U.S. Department of Energy grant under the second round of the Clean Coal Power Initiative, as well as federal investment tax credits worth more than $130 million. However, of far greater value was the Mississippi Public Service Commission's decision to allow major CCS costs to be recovered through increases in ratepayer bills in the state. A particular feature of the project is the plant's use of locally mined lignite, which is a low-rank coal that constitutes about half of the proven reserves in both the U.S. and globally. Mississippi Power is a subsidiary of the Southern Company, the fourth largest utility in the nation.
- The Petra Nova Carbon Capture Project in Texas is more than half completed and is expected to go online in 2016. This project is similar to SaskPower's in that its carbon dioxide stream is derived from a coal-fired power plant (240 MW) at NRG Energy's W.A. Parish station; it involves post-combustion capture of some 90 percent of the CO_2 emissions; and it will produce approximately 1.5 million tonnes of the gas each year for use in EOR, in this case after being transported about 130 km by pipeline. The project is a joint venture of NRG Energy and J.X. Nippon Oil & Gas Exploration; its partners include Mitsubishi Heavy Industries. The project is receiving partial funding of up to $167 million from the third round of U.S. Department of Energy's Clean Coal Power Initiative. A notable aspect of this project is that the power plant owner has also taken a stake in the oil field where the CO_2 will be injected.

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[89] U.S. National Energy Technology Laboratory and U.S. DOE, Carbon Storage Atlas, 5th ed., Aug. 20, 2015, pp. 110-111. Available here: http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/atlasv/ATLAS-V-2015.pdf. This compares low-low, high-high with data in fn. 9.
[90] U.S. EPA (3.47 Gt CO_2 equivalent annually from electricity and industrial sectors). See: http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html (accessed October 22, 2015).

The U.S. is also home to several other smaller or non-integrated projects that have been partly funded through government programs.[91]

Moving forward

To take advantage of the CCS resource, the U.S. faces a considerable challenge. It must find a way to mount and implement an effective deployment program that harnesses and builds on its strengths. This includes its expertise and experience with EOR, the further development of a pipeline network, and the advent of an efficient nodal ("hub-and-spoke") system to capture, transport, and sequester carbon dioxide. These features of the U.S. landscape – already either well understood or in advanced development – offer a roadmap for the design of a future CCS program.

- **Focus First on EOR:** By focusing first on EOR and leveraging the economic advantage afforded by the produced oil, EOR can help to drive the infrastructure that will expand CCS to all available CO_2 sources – that is, to all major stationary sources, particularly coal- and natural gas-fired electricity generation and heavy industry.
- **An Expanding Network:** An extensive network of pipelines has organically developed in the in the central part of the nation. There, several nodal systems serve the needs of EOR. A continuation of this approach makes sense, which means the continued growth of hub-and-spoke carbon dioxide use-and-sequestration systems.
- **Getting to Critical Mass:** In order to reach critical mass by mid-century, it will be necessary over the next 10 to 15 years for the U.S. to develop three to four new or greatly expanded carbon sequestration hubs. Initially, most or all of these will likely continue to rely on EOR. However, over time, an increasing number of CO_2 sources will be anthropogenic.[92] Future hubs will most likely be expanded versions of existing hubs (such as the network in the Permian Basin of west Texas and southeastern New Mexico), along new systems will be required as well. In achieving this "national impact scale" by 2050, carbon emissions from the nation's stationary sources would effectively be reduced to zero.

To move the debate and the on-the-ground situation forward, several regulatory improvements are extremely important:

- First, and most critically in the short run, Congress and the courts should support EPA's Carbon Pollution Standards, both for new and for existing plants. This essential regulatory backstop sets a level playing field for low-carbon power and sends a clear signal regarding the future direction of this sector. States should devote resources to the creation of their required implementation plans, paying close attention to the need for vigorous decarbonization targets over the next decade. States can and should consider

[91] Most of these have been under the umbrella of the Department of Energy's Regional Carbon Sequestration Partnership Program. For more details see: http://www.netl.doe.gov/research/coal/carbon-storage/carbon-storage-infrastructure/rcsp#.
[92] Right now, nearly three-quarters of the CO_2 used in EOR comes from natural sources, but affordable natural sources are running out.

the inclusion of CCS as a component in compliance plans, and should consider strengthening or instituting their own performance standards. Moreover, states that opt into a carbon allowance trading system could consider setting aside allowances for CCS incentives. Finally, both Congress and state legislatures should intensify efforts to set economy-wide limits on carbon pollution and put a price on those emissions.

- Second, the federal government must make a sustained commitment to CCS incentives. This could take many forms. One could be a reformed and much expanded version of the sequestration tax credits currently available under the tax code.[93] This would provide developers and lenders with the certainty they need to make projects economic. Other incentives that should be considered include allowing CCS to be financed under more favorable tax treatment, available, for example, through private activity bonds and master limited partnerships.
- Third, federal and state governments should consider policies that ratchet down the power sector's carbon intensity, as well as mandates to purchase low-carbon energy through such mechanisms such as portfolio standards.[94] Finally, states with state-based cap-and-trade programs could consider devoting a portion of their revenues or allowances to promising CCS projects, as well as supporting such projects in regulated electricity markets by spreading the associated costs among the entire rate-paying customer base.
- Fourth, increased and sustained research, development and demonstration funding should be directed at deploying second generation CCS technologies and beyond. This is critically important in order to dramatically decrease the cost of future capture, and further develop operational and monitoring techniques able to augment storage security and integrity. Additionally, monies should be directed at regions and projects that will support existing or nascent carbon capture hubs. Right now, government funding has been relatively slight, as well as opportunistic to a fault. A more orderly approach is required, aimed at building a strong and efficient national technological and scientific base.
- Fifth, particularly in the U.S., is the need for policymakers to articulate the utility of including CCS on the short list of climate change strategies.

[93] At the time of writing, three types of tax credits were available for capture and sequestration, named after the relevant sections in the tax code: 48A, 48B, and 45Q.

[94] This approach has proved very successful in many regions for the deployment of renewable energy, for example.