CCS chapter – draft

Carbon dioxide Capture and Storage

Nils Markusson

What is CCS?

Carbon dioxide Capture and Storage (CCS) is a technology with components that capture carbon dioxide (CO2) from a source, transport it to a suitable site and sequester the CO2, typically underground (IPCC 2005). The origins of the idea can be traced back to the 1970s (Marchetti 1977), and many of the different component technologies have long histories too.

History

The interest in CCS in climate policy, and underpinning modelling, grew in the 1990s and early 2000s, focussing on applying CCS as a way to decarbonise fossil fuelled power plants, and especially coal-fired ones, but also some other heavy industries that rely on fossil inputs, e.g. cement production. We may call these applications 'fossil CCS'. The promise of fossil CCS also brought hope of sustained use of coal and gas for power production, in a context of increased concerns about climate change, and so helped bring some previously recalcitrant actors into the climate policy fold (Narita 2012). However, progress deploying fossil CCS turned out to be slow. Lacking revenue from implementing fossil CCS, industry was not volunteering to foot the bill, and governments neither paid nor forced industry to do so. There were also problems with publics protesting against planned deployments.

As the early hope vaned, industry and government hope turned in the late 2000s towards utilisation of the captured CO2 for profitable enhanced oil and gas recovery (EOR/EGR). Here the captured CO2 would injected in oil and gas fields to help extract more fossil fuels. The climate benefits of this were debatable, but the main hope was that the revenue would help fund development of capture technology, and help bring down its costs, for later commercially viable application in CCS systems that sequester CO2. The label given to the broadened scope of application was Carbon Capture Utilisation and Storage (CCUS) (Endres 2016).

As climate mitigation progress continued to be slow, across the board and including CCUS, climate policy turned to so called negative emissions technologies (NETs). These are technological systems that are meant to capture CO2 from the atmosphere and sequester it, thus creating an artificial sink. In modelling and policy circles, a lot of hope has been placed in a NET that combines biomass-fired power stations and CCS (BioEnergy CCS, or BECCS). There is also scope to build dedicated plants that just filter CO2 out of the air (Direct Air Capture, DAC). Since the Paris Agreement was adopted in 2015, 'net zero' has been a dominating framing of climate policy, and it presupposes that we decarbonise as much as we can (including using fossil CCS), but that some hard to abate emissions will be compensated for by negative emissions. NETs are also expected to be needed in case we miss net zero targets by some limited margin, to clean up the atmosphere afterwards.

The actors

Realising CCS systems relies on expertise from existing industries. Power companies and other heavy industries are relevant as potential sites of carbon capture. The oil and gas industry has much of the expertise required for transporting and storing CO2. In the case of enhanced oil and gas recovery they would instead be users of the CO2. Less directly, coal as well and oil and gas companies have an interest in the promise of CCS offering a more secure future for their product. In the case of BECCS, the upstream sourcing of biomass brings in a whole range of new actors. There are of course also companies specialising on developing technologies, products and services for the (still limited) CCS market.

The technology

Technologically, there are many different ways to realise CCS systems. As discussed, the CO2 can be sourced from fossil-fuelled power plants or other large, industrial, fossil-derived point sources, from biomass processing, or from the air.

The carbon capture component is about separating the CO2 from industrial flue gases (or further upstream in the industrial process) or air, can be realised using different chemical, physical or biological techniques. Chemical and physical capture techniques tend to require large amounts of energy (electricity, waste heat) input, and much more so if capturing dilute CO2 from the air than from high concentration industrial sources. Biological capture of CO2 from the air includes growing new biomass, for example through afforestation. But after the biomass is burnt or otherwise processed, the CO2 needs to be re-captured, using the chemical or physical capture techniques. Because of the energy input required, capture tends to be the most expensive part of CCS systems.

CO2 transport would likely be dominated by pipelines, and there is long-term experience of transporting CO2 in onshore pipelines from primarily US EOR operations. CO2 can also be transported by ships or even lorries, where circumstance so require. CO2 is not very compressible, making large-scale temporary storage very energy intensive and expensive, and CCS systems need to be designed to allow continuous operation. This is one of several reasons for why it may make sense to develop geographically concentrated clusters of CO2 capture facilities sharing joint transport and storage infrastructure.

The main options for CO2 storage are in subsurface rock formations, where the CO2 is sequestered mainly in liquids that fill small pores and cracks in the rock, and trapped underground by a range of geological mechanisms. The relevant subsurface formations are either depleted oil and gas fields, or saline aquifers. Saline aquifers potentially hold out a larger storage potential globally, but depleted oil and gas fields are attractive for being well mapped and understood (Woods et al 2022).

Issues

CCS has promised to square the circle of our fossil addiction with the decarbonisation imperative. By the same token, it has long been criticised for legitimising sustained use of fossil fuels, and letting fossil interests off the hook. Environmental NGOs have been divided in their stances on CCS, with some embracing it whilst others have dismissed it as greenwashing (Corry and Riesch 2012). Some academics have argued that the prospect of only talking about deploying CCS in the future, but not spending any serious money on investing in it, or in other decarbonisation options in the short term, is what has been attractive to fossil interests and governments alike (Markusson et al 2017).

Deployment of fossil CCS has been slow globally. The main policy response to this has been to move on to the next set of technology promises: NETs (which in turn has given CCS in the guise of

BECCS and DAC some new momentum). For some, this has merely meant a new generation of empty promises of future technology. And it should be noted that fossil CCS expectations are still as high as they ever were in policy-oriented modelling work. Currently, fossil CCS, BECCS and DAC are all required at large scale in the pathways that mainstream climate policy sets out to meet its targets. In that sense, adding NETs to the mix has not solved the problem of slow fossil CCS progress.

Arguably the main policy conundrum is a lacking source of revenue and/or willingness to pay. Adding CO2 capture to an industrial plant adds an energy penalty, and hence a cost. But industry has shown itself unlikely to accept that extra cost without government pressure and/or assistance, which has also in the main been lacking. As costs of other ways of producing low-carbon power have shrunk in recent years, the relative economic competitiveness of fossil CCS has also weakened. The case appears stronger for other heavy industries, where there are fewer lower-cost alternatives. Biomass CCS suffers from the same energy penalty as fossil CCS, but its prospects are currently buoyed up by high levels of policy attention.

The CO2 price in regulated emissions trading schemes has so far not proven sufficiently high or reliable to drive CCS deployment. There is however a currently rapidly growing set of unregulated offsetting schemes that provide some investment for negative emissions technologies, including Direct Air Capture projects. Whether these really offer reliable negative emissions, and how important this funding stream will turn out to be for CCS development is so far unknown.

Part of the challenge of making CCS happen is the scale and speed of the industrial development required. Even if the willingness to pay problem were solved, there is still the matter of how to develop large new industries in the matter of a few decades. There is some scope for re-use of existing oil and gas related infrastructure, but there is still a huge need for hardware construction, development of business models, training of staff etc.

In the past, public acceptance has also sometimes been a hinder, with some CCS projects being abandoned as a result. Local publics have been concerned with, among other things, the safety of living on top of CO2 storage, and worried about impacts on house prices. In some places, policy makers and developers have in response turned to offshore storage.

There are also potentially a range of environmental impacts of CCS. The energy input required for CO2 capture comes with its own environmental footprint. CO2 capture operations can also be a load on local water resources, which is problematic where water is scarce (Rosa et al. 2020). If CO2 were to leak from CCS systems, several kinds of impacts are possible. If it is released into the air, then it will contribute to the climate crisis. There have also been concerns about large localised leaks into the air causing the formation of heavy CO2 clouds and risk of suffocation for humans and animals. If the CO2 is released into water, it would turn that water more acidic, which would impact on plants and animals.

There are also environmental, health and safety and social justice impacts from upstream CO2 sources. For example, the burning of coal has large particulate air pollution effects with large negative impacts on human health. Switching to biomass is not unproblematic either. Concerns include the climate impact if the harvested burnt biomass is in the end not replaced by new growth, or if the biomass growing cause land use changes with negative climate impacts (Hanssen et al 2020), but also the impact on biodiversity of forestry operations, and on local health impacts of biomass processing.

Research needs

There are full scale CCS capture facilities in operation, but there is also need for ongoing R&D about these to improve reliability and drive down costs. Capture operations come with considerable costs, both up front when constructing a new facility, and from operations. A lot of research work is being done to find cheaper capture options. Ultimately, the cost of CCS is a problem of political will, but making CCS cheaper would certainly also help. Further work on breakthrough capture technologies is needed, alongside incremental improvements from studying demonstration plants.

In terms of storage, there is a large need for improved knowledge about saline aquifers, which involved both routine mapping work and dedicated research about unique geological formations (Woods et al. 2022). It may be the case that their potential has been over-estimated (Lane et al. 2021)

There has been quite a bit of research on public understanding of and engagement with CCS, but there is an ongoing need for such work. The public understanding research agenda could usefully include looking at CCS as part of just transitions, and exploring how public engagement can be done globally (Buck 2021).

It would also be worthwhile exploring the potential to develop policy that allows CCS deployment without deterring and delaying emission reduction overall (McLaren 2020). Suggestions include adopting separate targets for NETs and emissions reductions, but the debate is going strong on what might work (see e.g. Smith 2021).

In the current climate policy regime, based on the Paris Agreement’s focus on net zero, there is a need to do critical research about estimates of future residual emissions from different sectors of society, and claims about what is to count as hard to abate. The need for BECCS, DAC and other negative emissions technologies relies on our understanding of residual emissions, and so they warrant scrutiny.

References

Buck, H. 2021. Social science for the next decade of carbon capture and storage. *The Electricity Journal* 34(7).

Corry, O. and H. Riesch, “BEYOND ‘FOR OR AGAINST’: Environmental NGO-evaluations of CCS as a climate change solution”, in Markusson, N., S. Shackley and B. Evar (eds) *The Social Dynamics of Carbon Dioxide and Capture: Understanding CCS Representations, Governance and Innovation*, Abingdon : Earthscan.

Endres, D. et al. 2016. “Putting the U in carbon capture and storage: rhetorical boundary negotiation within the CCS/CCUS scientific community.” *Journal of Applied Communication Research* 44 (4): 362–380.

Hanssen, S.V et al. 2020. “The climate change mitigation potential of bioenergy with carbon capture and storage.” *Nature Climate Change* 10: 1023-1029.

IPCC. 2005. *IPCC Special Report on Carbon Dioxide Capture and Storage*, Intergovernmental Panel on Climate Change, Working Group III, Geneva.

Lane, Joe, Chris Greig and Andrew Garnett, A. 2021. "Uncertain storage prospects create a conundrum for capture and storage ambitions." *Nature Climate Change* 11: 925-936.

Marchetti C. 1977. "On geoengineering and the CO_2 problem." *Climatic Change* 1 (1): 59–68.

Markusson, N., M. Dahl Gjefsen, J. Stephens and D. Tyfield. 2017. "The political economy of technical fixes: the (mis)alignment of clean fossil and political regimes." *Energy Research and Social Science* 23: 1-10.

McLaren, D. 2020. "Quantifying the potential scale of mitigation deterrence from greenhouse gas removal techniques." *Climatic Change* 162: 2411–2428.

Narita, D. 2012. Managing uncertainties: the making of the IPPC's special report on carbon dioxide capture and storage, *Public Understanding of Science* 21 (1): 84–100.

Rosa, Lorenzo, Jeffrey A. Reimer, Marjorie S. Went and Paolo D'Odorico. 2020. Hydrological limits to carbon capture and storage. *Nature Sustainability* 3: 658-666.

Woods, Andy. et al. 2022. *Locked away – geological carbon storage*. Policy Briefing. Royal Society: London, UK.

Smith, Stephen M. 2021. A case for transparent net-zero carbon targets. *Communications Earth & Environment*. 2(24).1-4.