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# An enabling framework for carbon capture and storage (CCS) in Europe: An overview of key issues

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There are few credible scenarios for reaching the EU's long-term climate policy objectives, such as net-zero by 2050, without the large-scale deployment of CCS technology. Carbon capture and storage technology is a pre-requisite for the decarbonisation of energy-intensive industries, which in the EU are responsible for about a fifth of all greenhouse gas emissions. At the same time, carbon capture technologies have only been tested at smaller scales and are not yet available at scale for the multiple energy-intensive industries that need them. To prepare for larger-scale CCS deployment in the period after 2030, steps should be taken today to address economic as well as political barriers, and thereby support development of key infrastructure and technology. In doing so, policy should focus on improving the investment case for both CCS as well as low-carbon industrial products that carbon capture makes possible. This includes specific financing models that account for the high capital intensity of CCS, regional variation in industrial clusters, infrastructure and storage availability as well as the need to combine both private and public money.

## Recommendations:

- Plans for CCS deployment should be developed in parallel with analysis on the expected demand for negative emissions, as well as how to deliver these negative emissions. Imperfect capture rates and bio-energy with CCS (BECCS) use will impact this demand.
- Policy support should target the improvement of capture rates in major energy-intensive industries so that theoretical potentials can be demonstrated.
- To support scale-up, initial focus should be on industrial clusters where various sources of $CO_2$ can be combined into larger volumes.
- EU state aid rules (e.g. environmental state aid guidelines) should facilitate member state spending to support CCS infrastructure development.
- Political choices should be made as to the market and financing models that will apply to CCS development, both on the capital investment side as well as on the operational financing side.

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With the release of the European Commission's long-term climate strategy, the question of how to reach net-zero greenhouse gas emissions is crucial for EU climate policy development. Carbon capture technology, as well as transport and storage infrastructure, is seen as indispensable to address emissions from energy-intensive industries that are otherwise hard to abate. Without carbon capture and storage (CCS), zero-carbon products in some industries (e.g. basic materials such as steel and cement) are not feasible.[1] This makes CCS a transformational technology on the path towards a net-zero economy. As a result, the role of carbon capture features prominently in the long-term strategy, with potential reductions of 52 $MtCO_2$ to 606 $MtCO_2$ depending on the different scenarios.[2] The upper range represents about a third of total EU ETS emissions in 2018.

CCS technology is similar to other low-carbon technologies in that government policy is a necessary part of market creation. Without policy, there will be no market. Without a market, there will be no investment case. CCS is one element of the general long-term climate policy challenge of creating a market for zero-carbon industrial products.[3]

Nevertheless, CCS is not the only relevant technology for achieving deep decarbonisation in industry: electrification can also significantly contribute to decarbonisation of industry. In trying to electrify major industrial processes, however, low-carbon electricity demand could increase precipitously. The European Commission roadmap scenario, which maximises electrification, leads to a doubling if not tripling of EU electricity demand.[4] Hydrogen can likewise be important as a feedstock in industry. The production of low-carbon hydrogen, however, either greatly increases electricity demand further (electrolysis) or requires methane reforming with carbon capture as well, thereby reinforcing the case for CCS.

Besides storing $CO_2$, utilising it (i.e. Carbon Capture and Use - CCU) is also an option. The most important constraint is the limited demand for processes where $CO_2$ is used, while not being released into the atmosphere at a later stage.[5] Without such permanence, CCU is not a good alternative to CCS but rather a means to incrementally reduce emissions and create an additional revenue stream for CCS projects. Additionally, the process of transforming $CO_2$ into

[1] See also: Wyns et al, (2019). Industrial Transformation 2050 *Towards an Industrial Strategy for a Climate Neutral Europe*, IES VUB.

[2] See European Commission (2018), "In-Depth Analysis In Support Of The Commission Communication COM(2018) 773", p. 198.

[3] This can include contracts for differences, public procurement standards etc. See Elkerbout, M. and Egenhofer, C, (2018), Tools to boost investment in low-carbon technologies, CEPS Policy Insight, (http://ceps-ech.eu/publication/tools-boost-investment-low-carbon-technologies) where the issue is further explored.

[4] The EC roadmap scenario, which maximises electrification, leads to an increase in EU electricity demand from 22% in 2015 to 58% of final demand in 2050. See European Commission (2018), In-depth analysis in support of the Commission Communication COM(2018) 773: A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, p. 72.

[5] CCU is discussed more in detail in the CEPS Policy Insight "Sinking to Zero: the role of carbon capture and negative emissions in EU climate policy" by Milan Elkerbout and Julie Bryhn; January 2019.

an input or product that can be utilised elsewhere is energy-intensive. This comes on top of the capture stage which is already inherently energy-intensive.

## Ready to go? The technological readiness and deployment of CCS

As of summer 2019, there are four particularly promising projects that could push CCS further: the Porthos Project in the Port of Rotterdam which targets a major industrial cluster; the Northern Lights project in Norway, which aims to be an open-access hub where companies can deliver captured $CO_2$ for storage; the Acorn project in Scotland, which promulgates close public-private cooperation, and the Teesside region, where process industry and a gas power plant are jointly working on CCS infrastructure. After 2030, the lessons from such projects should facilitate further deployment of CCS at scale, thereby making industrial decarbonisation and net-zero climate targets more feasible.

The attraction of carbon capture is partly based on the assumption that it can address emissions that are otherwise hard to avoid, particularly in energy-intensive industries. This presumes high capture rates for the capture technology applied to industrial processes. The viability of CCS to deliver net-zero depends on capture rates being sufficiently high, i.e. up to 90%. In principle, there are no technological reasons why they cannot reach close to 100%, but a capture rate in excess of 90% significantly escalates costs. For some industrial processes, however, experience with capture has been insufficient so far as to establish even 90% capture rates. In the absence of sufficiently high capture rates, CCS usage will increase the demand for negative emissions technology. To manage this, it could be desirable to consider limits for $CO_2$ capture from processes where capture rates are not sufficiently high so that the impact on negative emissions demand can be managed.

As the costs of capture represent about two thirds of the total costs of CCS according to some industrial stakeholders, further improvements in capture technology could be a major contributor to increasing the cost competitiveness of CCS. This points towards the need for continued investment in R&D (e.g. through the EU's Horizon Europe programme) for capture technology, in addition to later stage innovation and infrastructure investments.

Ideally, initial CCS projects will be focused on industrial clusters where the supply and concentration of $CO_2$ to be captured is sufficiently high. In these cases, an infrastructure of pipelines would be the most efficient way of transporting $CO_2$ in large quantities. As many CCS projects will likely receive initial public support, such pipelines will likely be open to all operators wishing to store captured $CO_2$. Such open-access infrastructure can help with scaling up use of CCS, thereby lowering costs.

In other cases, installations seeking to capture $CO_2$ will not have pipelines at their disposal. Transportation via inland waterways or trucks is then an alternative. This may increase operational costs, but on the other hand may be less risky investments, as there are no lock-in effects associated with the infrastructure. Transportation via ships or trucks could also work for installations only wanting to capture smaller volumes and can be scaled up more rapidly than fixed networks that may require permits.

Land-based $CO_2$ storage may be less suitable for permanent storage due to the difficulty of ensuring safe storage. There is a minor risk[6] of earth tremors when storing $CO_2$ on land, as well as the hazard of ground water acidification should any $CO_2$ escape. More generally, storage on land risks public opprobrium in countries where there is public scepticism towards $CO_2$ storage. For temporary storage, however, as part of a larger carbon capture supply chain, storage on land could be an option. Assessing the continued integrity of storage sites to ensure permanence requires continuous monitoring and expenditure and therefore raises operational costs.

## Financing the future: the investment case for CCS

The upfront capital investments required in capture, transport and storage infrastructure prompt the question of the relative shares of private and public finance.

Given that CCS would be implemented mostly[7] for sectors covered by the EU emissions trading system (ETS), the first question is what the contribution of a carbon price signal can be. Up to now, even following the higher carbon prices seen in the wake of the reforms completed between 2015 and 2018, the ETS price of around €25 is well below the price needed to make the investment case for CCS. Even if the ETS price continues to rise, investment in CCS infrastructure is needed in the short-term if emissions are to be captured at scale in the medium and long-term. Instead, a higher carbon price will rather support investment cases in CCS by making continued investment in and operation of more carbon-intensive assets less attractive. The carbon price will have a greater impact in later stages of technology deployment once costs come down thanks to process improvements and scale.

Much like limiting the concentration of greenhouse gases in the atmosphere which CCS contributes to, CCS infrastructure itself could also be construed as a public good.[8] Being a public good, however, implies that there would be underinvestment due to free-riding concerns, i.e. all companies wanting to capture emissions would benefit from already existing CCS infrastructure. This creates an additional rationale for public intervention.

CCS is not extraordinarily expensive compared to other low-carbon technologies that have received public support. The implicit carbon price associated with renewables support[9] has in some cases been well over €100 per tonne.

[6] See also: https://www.chalmers.se/en/areas-of-advance/energy/Documents/Chalmers%20Energy%20Conference%202011/argumenten%20kaart%20CCS%20engels.pdf

[7] The waste treatment sector is an exception.

[8] A public good is non-excludable and non-rivalrous. I.e. the use of CCS infrastructure by one part would not impede another party doing so as well. In principle, infrastructure can be exclusive, but it can also be set up in such a way that other parties can have equal access, as is common with public infrastructure.

[9] E.g. the case of solar support in Germany under the EEG. See also: http://cadmus.eui.eu/bitstream/handle/1814/30200/RSCAS_2014_28_REV.pdf?sequence=3

## Where should funding come from?

One instrument created with the express purpose of supporting, *inter alia*, CCS in industry, is the EU ETS Innovation Fund. This fund will disburse money generated by the sale of some 450 million allowances over the 10-year trading period of the ETS starting in 2021. At current carbon prices, this amounts to just over a billion euros a year in funding. However, it has been set up to fund more than just CCS, including other industrial decarbonisation and renewable energy projects. Another European instrument is the Connecting Europe Facility (CEF), which targets infrastructure investment, and which has already supported CCS projects.

While the transportation infrastructure of CCS could be funded this way, the storage of $CO_2$ itself is not eligible, thereby limiting the potential of the Connecting Europe Facility for CCS. Furthermore, the EIT Climate-KIC on sustainable finance could support the development of CCS at the European level through its capacity for demonstration, scaling of financing and de-risking. This makes the instruments of the next Multiannual Financial Framework (MFF) of the EU budget especially pertinent. While they can provide important sources of funding for CCS, they are unlikely to cover all the funding needs. Funding will need to be provided by EU and EEA member states as well, some of which may contribute significant funds. Through the Northern Lights project, Norway is in fact one of the biggest proponents of advancing CCS. By promising storage availability, it aims to support the investment case. Beyond Europe, the US 45Q tax credit[10] is an example of a fiscal measure that supports CCS development while differentiating the support between different CCS applications.

Whatever investments are made in CCS infrastructure, expectations for the long-term demand for CCS as well as negative emissions and bio-energy with CCS (BECCS)[11] use should be considered. Significant use of bio-energy with CCS in the second half of the century to deliver negative emissions can further increase demand for storage sites. Particularly for early projects, the business case for operating $CO_2$ transportation and storage infrastructure could be undermined if operators cannot acquire, and be remunerated, for sufficient amounts of captured $CO_2$.

## CCS: not the most regulated space

Up until now, CCS has not received much dedicated regulatory attention. This creates some uncertainty for market actors that often need to operate across multiple countries and with extended time horizons. The EU's CCS Directive is without a provision for continuous review, and as such, may not necessarily be updated in time to reflect new realities, including the

[10] See https://uscode.house.gov/view.xhtml?req=(title:26%20section:45Q%20edition:prelim)

[11] With bio-energy and carbon capture and storage (BECCS), $CO_2$ is first absorbed by trees or other biomass, thereby lowering the concentration of $CO_2$ in the atmosphere. This biomass is subsequently combusted to produce energy, e.g. electricity or heat. The $CO_2$ released upon combustion is then captured and stored, leading to 'net-negative emissions'. See also the CEPS Policy Insight "Sinking to Zero", 22 Jan 2019, https://www.ceps.eu/ceps-publications/sinking-zero-role-carbon-capture-and-negative-emissions-eu-climate-policy/

required scale in light of net-zero GHG targets.[12] Currently, for example, the definition of a transport network under the Directive only concerns $CO_2$ transported through pipelines, as opposed to that transported by ships or trucks.

The London Protocol [on marine pollution],[13] which covers dumping of waste in the sea, restricts $CO_2$ trade across borders. An amendment to this protocol, currently pending ratification,[14] would allow for cross-border transport of $CO_2$ between countries to develop, and thereby facilitate the creation of a European market for CCS. Nevertheless, willing states should not be hindered from engaging in bilateral agreements bypassing the limitations set out in the London Protocol.

Clarity on issues such as the safety, monitoring and verification, liability, permits, intellectual property rights, trade of $CO_2$ and infrastructure between countries, and accounting for $CO_2$ capture and use is a precondition for the investment case. Various pieces of EU legislation already apply, including directives on environmental liability and industrial emissions. However, given the cross-border impacts, consistent transposition at member state level is important, as are domestic regulations in case the EU has not acted.

## What type of market?

The positioning of competition authorities will influence the investment landscape for CCS infrastructure. With dense infrastructure requirements and network externalities, CCS infrastructure may be a natural monopoly. This requires adequate regulation.

The issue of monopoly is also relevant from the perspective of countries wanting to make use of storage infrastructure in other countries. The market power accruing to monopolistic $CO_2$ storage (or transportation) operators may be a deterrent for those parties considering long-term commitments to capturing $CO_2$. This compounds the need for multiple regions to develop CCS infrastructure, ideally with different models, such as pipelines and open-access transportation through ships (or trucks).

The choice between two common models of private participation in public infrastructure financing is relevant for CCS infrastructure. These models are the Regulatory Asset Base (RAB) model and project financing through Public-Private Partnerships (PPP).[15] A benefit of the RAB model is that it is able to accommodate changes in policy more easily, which may be desirable given the complexity of long-term climate governance. A downside is that the RAB model tends to lead to excessive capital expenditure. This capital bias is the result of regulated party preferring capital over operational expenditure, as the former earns a rate of return. The PPP

[12] The Directive was reviewed in 2015, but the Directive does not contain a provision for continuous reviews. However, no future reviews are planned yet.

[13] See page of 10 of https://www.iea.org/publications/freepublications/publication/CCS_London_Protocol.pdf

[14] See e.g. https://hub.globalccsinstitute.com/publications/temp/ratify-or-not-ratify-2009-london-protocol-amendment.

[15] See also the discussion in this OECD paper: https://www.oecd-ilibrary.org/docserver/5jrw13st0z37-en.pdf?expires=1556204485&id=id&accname=guest&checksum=5702723216B6DAA3E1A8CD734E10B4C3

model scores better when it comes to timely and cost-effective delivery, which in the case of CCS is beneficial given the steep pathways to 2050 targets. It focuses more strongly on returns on capital, but this also makes the approach more complicated. Even if the PPP model is structured to boost competition, it may not always result in the financing of societally desirable projects, given concerns on the returns. The choice between these models should also be informed by the need to achieve cost reductions so that further economies of scale are facilitated.

## Open questions on financing and the business case

Both companies wanting to capture $CO_2$ emissions as well as those wanting to invest in transportation and storage of $CO_2$ need each other equally. Without the necessary infrastructure being available, a company cannot go ahead with capture. At the same time, those providing transportation and storage infrastructure need to be ensured that there is enough supply of captured $CO_2$. This points to a need for partnerships that can bring stability for investments and get projects up and running, including by limiting cross-chain risk, where failure of one element leads to risks to the larger CCS value chain.[16]

Policy support may need to differentiate between capital investments and operational expenditure. At every stage of the CCS value chain, whether in capture, transport or storage, significant capital expenditure will be required to fit installations and build infrastructure. It may be necessary in some cases to provide public support for operational expenditures, such as ongoing energy use when capturing $CO_2$ or when transporting it. This would have implications from a state aid perspective, as operational state aid is subject to more stringent conditions in order to be compatible with the internal market. Currently, environmental state aid guidelines do allow for operating aid for the promotion of renewables.[17] Nevertheless, the choice of what products or technologies to promote remains a political one.

If operational financing is provided this could take the form of a given amount of funding per tonne of $CO_2$ stored. The EU ETS price will be an important point of reference here. For every tonne of $CO_2$ that is no longer emitted due to the use of carbon capture technology, an operator no longer needs to surrender an allowance for those emissions. If the subsidy provided exceeds the carbon price, the question arises of what happens to this 'upside', i.e. whether there should be conditionality on how this additional money is spent.

On the side of capture, investments will also be relatively capital-intensive to adapt industrial processes in such a way as to enable the capture of $CO_2$ that is sufficiently clean and concentrated.

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[16] See also p. 17 of the report to the thirty second meeting of the european gas regulatory forum 5-6 june 2019: https://ec.europa.eu/info/sites/info/files/iogp_-_report_-_ccs_ccu.pdf

[17] The Commission Regulation EU 2017/1084 revising the General Block Exemption Regulation makes further reference to instances where operational aid is deemed compatible with the internal market. See also the Annex containing these instances, including for renewables support

Equally important as what type of funding is provided is the question of who will provide the financing in practice. For earlier stages (which should focus on replicability), mixed financing of both public and private sources will be more important, with more market-based mechanisms being suitable for later stages. In the case of public financing, the idea of green bonds being issued by a public operator of $CO_2$ infrastructure has been proposed in the context of the Acorn project.[18] The issue of who operates (and develops) $CO_2$ infrastructure also raises the question of whether this could be done by a private entity, in light of the public good characteristics of CCS. Conversely, for private entities, in the absence of higher carbon prices, a business case may be lacking until carbon capture technologies are scaled up. With regard to the financial sector, their close involvement in projects in early stages in crucial, due to the long lead times (of 5 years or more).

## Outlook

While carbon capture technology and $CO_2$ transportation and storage infrastructure remains essential for deep decarbonisation in industry, barriers remain to its deployment at scale. For now, CCS technology and infrastructure has not reached levels of technological maturity that allow for capturing significant shares of industrial GHG emissions.

However, policy needs to start addressing existing economic, regulatory and political barriers. These barriers are manageable, although they require close coordination between different industries and EU and EEA member states and in some cases, other countries.

A complication is that capture on the one hand and transport, storage, or use on the other need to be developed in parallel: industry needs to capture emissions so that there can be something to store (or use). Countries need to commit to transportation and storage infrastructure so that companies can commit to capturing emissions, and vice versa. The parallel involvement of multiple member states and regions is also desirable from a competition point of view, and to gain experience with different models for developing CCS infrastructure. The example of the Porthos project in the Port of Rotterdam is a good example of an entire region and industrial cluster being involved in a CCS project, with potential pipelines to Germany further extending its scope.

While some of the issues discussed here are specific to CCS, many are inherent to any capital-intensive breakthrough low-carbon technology. Moreover, carbon capture – as a technological process – is ultimately a means to an end. The end is to allow for the production of low-carbon industrial products. CCS may not always be necessary for delivering such products. In some cases, material/product substitution can even reduce the demand for current carbon-intensive products. In many cases, carbon capture could however prove to be a good option to combine

[18] See also the discussion of this idea in a CEPS Commentary by Heleen de Coninck: https://www.ceps.eu/publications/what-can-ipcc-special-report-global-warming-15°c-tell-us-about-ccs-and-ccu-agenda.

industrial production in sectors in which Europe has long been competitive with the demands of a net-zero climate strategy.

Therefore, in supporting the market – specifically also on the demand-side[19] – for these low-carbon materials and industrial products more broadly, CCS can emerge and develop as one building block of such a market. One of the common challenges facing most industry sectors for which CCS is an option – and for whom low-carbon markets are still missing – is that of international competition. With the main barriers being economic, and the sectors for which CCS would be an option being trade-intensive, addressing the issue of embedded carbon traded in international goods is likewise important if CCS is to emerge at scale.[20]

[19] Cf http://ceps-ech.eu/publication/tools-boost-investment-low-carbon-technologies.

[20] See also the discussion in this SWP Research Paper by S. Droege et al (2018). https://www.swp-berlin.org/en/publication/mobilising-trade-policy-for-climate-action-under-the-paris-agreement/.

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