CCUS
SET-PLAN

KEY ENABLERS AND HURDLES IMPACTING CCUS DEPLOYMENT WITH AN ASSESSMENT OF CURRENT ACTIVITIES TO ADDRESS THESE ISSUES

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Contents

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Executive Summary

The new political momentum generated by the European Green Deal and the legally binding objective of climate neutrality by 2050 have given carbon capture and storage (CCS) and carbon capture and utilisation (CCU) strengthened and growing interest from policy makers and industrial stakeholders. CCS and CCU will support Europe's pathway to achieve climate neutrality, enabling a cost-efficient pathway for energy-intensive industries and power plants, safeguarding jobs in core sectors of the EU economy while creating others along the CCS/CCU value chain and preserving industrial competitiveness.

In the Impact Assessment on 'Stepping up Europe's 2030 climate ambition', the European Commission found that it is critical that CCS and CCU are deployed and tested at the industrial scale during this decade. Identifying key enablers and existing barriers for the scale up of CCS and CCU is thus important to create the right economic conditions and a favourable policy framework to enable investments in CCS and CCU.

This report identifies and discusses four categories of enablers and hurdles: technical, policy and regulatory, funding and business models and social acceptance, drawing from the expertise of the first commercial CCS and CCU projects that are currently being developed in Europe. These projects will provide a clear signal for industries to capture CO2 at industrial plants and the backbone infrastructure to which the next generation of CCS and CCU projects will be able to connect, creating Europe-wide CO2 transport and storage and giving access for CO2 emitters in industrial hubs to safe storage sites or utilisation networks.

As part of the European Green Deal workplan, the European Commission has announced new initiatives – such as the European Climate Law, the Hydrogen strategy, the Industrial strategy – and intends to revise existing pieces of legislation, such as the EU ETS directive and TEN-E regulation. All these initiatives are key to ensure that more CCS and CCU projects are deployed in Europe, overcoming current barriers and securing more announcements such as the Longship project and funding awarded through the Connecting Europe Facility for Energy (CEF) programme to European CCS and CCU projects (Porthos, Athos, Antwerp CO_2, Acorn Sapling, Ervia).

To support these recent positive developments and encourage more, R&I activities should be continued to address technical challenges along the value-chain, reduce the costs of the

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technologies and improve efficiency. Social acceptance challenges remain and will require the action of a wide group of societal stakeholders to be addressed. Local administrators, NGOs, academia, and other economic stakeholders play a central role in increasing the awareness around CCS and CCU and facilitating an informed debate around it.

To summarise, CCS and CCU can support the EU's decarbonisation pathway, delivering climate change mitigation and circularity, carbon dioxide removals and early, large-scale volumes of clean hydrogen for industry and homes. Testing and deploying these technologies at scale during the 2020s will be crucial to Europe's success in achieving net-zero by 2050.

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Introduction

The CCUS SET-Plan, IWG9

The European Strategic Energy Technology Plan (SET-Plan) aims to accelerate the deployment of low-carbon technologies, improve new technologies and bring down costs by coordinating national research efforts. The SET-Plan brings together EU countries, the European Commission, industries and research institutions.

The SET-Plan defined ten priority areas, covering a wide range of sectors including CCUS, wind, solar, geothermal, renewable heating and cooling, biofuels, etc. All priority areas have a dedicated working group.

The Implementation Working Group 9 (IWG 9) has been established to help the progress of Research and Innovation (R&I) activities required to achieve the 2020 targets for CCS and CCU agreed by the European Commission, SET-Plan countries and industry. R&I activities are outlined in the CCS and CCU Implementation Plan.

The IWG 9 consists of five thematic subgroups. Subgroups are currently in the process of being populated by experts in relevant areas.

The task at hand

The aim for this report is to:

- identify the key enablers and the common critical barriers impacting the development and deployment of large-scale CCS and CCU projects
- assess why the barriers appear and how they can be avoided
- highlight how the enablers can be strengthened and shared with the whole European CCS and CCU project community.

The enablers and barriers have been divided into the following categories:

- Technical
- Policy and regulation
- Funding and business models
- Public acceptance/perception

The work is carried out by CCSA in cooperation with CO2VE. The basis for the report is presentations and discussions at seminars between the IWG9 and CCUS Projects Network.

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This report has been discussed in the different IWG9 subgroups and circulated to the SET-Plan CCS and CCU community for comments.

The political context

The European Green Deal, Europe's new growth strategy, set the legally binding target of net-zero greenhouse gas emissions by 2050 in the European Climate Law. All economic sectors and member states will need to make strong efforts to reduce greenhouse gas emissions. This means that all low-carbon technologies with a scientifically proven role in achieving climate change mitigation should be developed and deployed. In this context, carbon capture technologies have been highlighted as necessary in order for Europe to reach climate-neutrality in all credible Integrated Assessment Models and scenarios (including the 1.5 degrees IPCC report and the European Commission Clean Planet for all, long-term strategy).

CCS/CCU status in Europe

In the mid-1990s, the Norwegian site of Sleipner – the world's first large-scale, dedicated CO_2 geological storage facility – began operation, storing CO_2 emissions from natural gas processing. According to a 2019 report on the global status of CCS, on the Norwegian continental shelf, Sleipner CO_2 storage and Snøhvit CO_2 storage facilities have cumulatively captured and stored around 22 million tonnes of CO_2[1].

Defined as a 'breakthrough technology' and identified as a priority area in the European Green Deal communication, the development of CCS and CCU gained positive political momentum at the end of 2019, which led to further developments and announcements in 2020.

In May 2020, the Northern Lights partners took their Final Investment Decision (FID) and received approval from the EFTA Surveillance Authority (ESA), with only a final investment decision pending from the Norwegian government. In October, the PORTHOS project in the Netherlands has been awarded CEF funding, which will contribute to the overall needed expenditure.

In other countries, around the North Sea Basin, large-scale CCS projects are also well underway. The 4th Projects of Common Interest list now has five CO_2 cross-border projects, with two projects, Athos and PORTHOS, in the Netherlands, Acorn Sapling in the UK, ERVIA in Ireland, and Northern Lights in Norway completing the list. The provisional

[1] https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf

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implementation of the amendment to Article 6 of the London Protocol of October 2019 removed the biggest legal barrier for these projects by allowing CO_2 to be exported for the purpose of offshore storage.

In Iceland, the Carbfix project has advanced carbon capture and mineralisation (CCM) to TRL9 where CO_2 from geothermal power plants is captured and permanently stored in basalts as solid minerals. Carbfix and Climeworks will start operating the first industrial scale direct air capture and storage (DACCS) chain in early 2021 and a new onshore storage site is in preparation that can receive CO_2 transported by ship.

Belgium and Sweden are also among the countries that have shown interest in the technology and have taken initial steps. Belgium's activity focuses in the area of the Port of Antwerp, where industries are coming together and evaluating the possibility to connect to the CO_2 transport and storage infrastructure in the Port of Rotterdam area and/or Northern Lights. Sweden, who has recently ratified the amendment to Article 6 of the London Protocol, has several interesting projects, including Bio-CCS by Stockholm Exergi and CCS Lysekil, both linked to the Norwegian Northern Lights project.

CCU is a new industry allowing the carbon cycle to be closed by reusing emissions for the production of fuels, chemicals, or materials. In recent years, several projects have demonstrated the technologies at high TRL levels (e.g. STORE&GO, MefCO2, Align-CCUS), and small commercial-scale plants already exist (George Olah Plant producing methanol from CO_2 in Iceland). Further commercial projects have been announced in the short term (e.g. Port of Antwerp, GreenLab, Norsk e-fuel) with the aim to achieve the commercialisation of tens of kilotonnes of product annually.

Preliminary analysis[2] of the national energy and climate plans (NECPs) suggests that other countries are leading R&I activities or assessing the feasibility of CCS and CCU for their countries. From an early assessment, the next developments in CCS and CCU can be expected in the Netherlands (Rotterdam and Amsterdam), Norway, the UK, Ireland, and Belgium – the area of Port of Antwerp, France (Dunkerque) and Italy (Ravenna).

[2] IOGP analysis: http://www.oilandgaseurope.org/wp-content/uploads/2020/04/NECPs-Factsheet-v2.pdf

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Key enablers and hurdles impacting CCS and CCU deployment

At present, four main areas have been identified as hurdles for CCS and CCU large-scale deployment. The following chapters aim to address the barriers and propose ways forward:

- Technical barriers
- Policy and regulation
- Business models and funding
- Public acceptance / perception

Technical barriers

While CCS and CCU are often described as low-carbon technologies with high potential for reducing GHG emissions in industrial and energy sectors, technical barriers for large-scale deployment still exist and are yet to be addressed. To better identify these barriers, there is a need to look at the different parts of the CCS and CCU value chain: CO_2 capture, transport, storage, and utilisation.

Continued R&I is crucial. The ongoing and soon to start CCS and CCU projects will identify new challenges/barriers that can be solved by undertaking R&I in parallel with large-scale activities. An iterative process is needed where R&I projects address specific challenges and barriers, with the results then implemented in large-scale projects.

CO_2 capture

Capture technologies can remove >95% of the CO_2 from flue gasses or industrial processes, and waste gas streams, which would otherwise be emitted to the atmosphere[3]. These technologies can decarbonise power generation, energy-intensive industries, and large-scale hydrogen production. Importantly, for sectors such as iron and steel, cement, and chemicals production, the manufacturing processes produce CO_2 as a by-product of chemical reactions (not combustion), and CCS is one of the very few solutions to cost effectively address these 'process emissions' and enable these industries to decarbonise.

The number of different capture technologies and suppliers that are available has increased steadily, which means that the general technical availability is no longer a hurdle in itself for both industrial and power applications. It is critical that R&I activities receive enough

[3] IEAGHG, Towards Net-zero Emissions, 2019.

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support to keep reducing the costs of CO_2 capture for investors and boost technological progress. In this respect, it is clear that the next developments of capture technologies will have a focus on increasing their efficiency, i.e. increasing capture rates.

Currently, challenges and barriers for CO_2 capture can be identified in two main areas:

- Reducing costs of CO2 capture at industrial sites and power plants
- Increasing the capture rate of capture technologies.

CO_2 transport

Captured CO_2 is then transported to a geological storage site or a utilisation facility. Transportation can occur/can be facilitated in a network of pipelines, using shipping or other modalities (rail freight, truck, etc.). Transportation of CO_2 is a well understood process, that has been taking place in Norway and North America for several decades. CO_2 transport by pipeline has characterised existing CCS/CCUS projects (Snøhvit, Sleipner), but CO_2 transport by ship will be crucial to enable the five PCIs to become operational.

There is a need to address matters such as the technical specifications for CO_2 streams, CO_2 purity, CO_2 flows, and the design of pipelines, ships, and other parts of the transport value chain – especially when retrofitted for low-carbon gases and CO_2 transport. Many of the technical challenges related to CO_2 transport are further outlined in a recent ZEP report on CO_2 transport. Further work is needed regarding whether or not the difference in quality requirements of captured CO_2 for utilisation influences the CO_2 transport specifications.

The development of CO_2 transport and storage infrastructure networks to connect industrial 'clusters' with other CO_2 capture sites and finally to CO_2 storage and utilisation sites and across international borders is key to progress CCS and CCU in Europe. Such CO_2 transport infrastructure can serve as a backbone for industrial decarbonisation, delivering negative emissions and enabling the delivery of early, large quantities of clean hydrogen from reformed natural gas with CCS. A central requirement for the efficient, safe design and operation of CO_2 pipeline transportation networks is the accurate transient flow modelling of fluid phase and composition of the CO_2-rich mixture along the pipeline network and at the point of injection into the storage site. Further study is needed to assess the quality of CO_2 streams, as well as CO_2 density and pressure, ensuring ongoing monitoring of CO_2 flows and pipeline safety during operations. Further work should also address the combination of scenarios relating to changes in future energy supply mix and industrial landscapes alongside the development of CO_2 pipeline transport networks.

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European, cross-border CO_2 transport and storage infrastructure would also rely on transport modalities other than pipeline. It is critical that other modes of CO_2 transport, like ship, truck, or barge, are studied and thoroughly understood to enable upcoming large-scale CCS projects, including where these modalities may interact in a network.

When kicking off a CO_2 infrastructure project, it is important to consider that the different parts of a CCS/CCUS value chain/CO_2 infrastructure – capture, transport, storage, utilisation – will most likely be developed and realised at different times, raising the counterparty risk in the value chain for potential investors.

Facilitating the technical and commercial operation of such networks under clear legal frameworks, along with investable developed business models and regulatory structures, needs to be the focus of further CO_2 transportation development, as well as the limited ratification of the amendment to the London Protocol, enabling the export of CO_2 between countries, will need to be addressed to ensure the large-scale development of CCS and CCU projects in Europe.

A recent report, "A Trans-European CO_2 Transportation Infrastructure for CCUS: Opportunities & Challenges"[4], further outlines the challenges related to CO_2 transport.

CO_2 storage

CO_2 geological storage is a safe and mature technology ready for broad implementation, as evidenced by over twenty years of successful storage offshore in Norway, combined with more recent onshore storage in Canada and the USA. In Europe, CCS benefits from a clear set of regulations and requirements under the 2009 EU CO_2 Storage Directive that ensure the identification of appropriate storage sites and the safety of subsequent operation[5]. The CO_2 is injected into the microscopic pore space within storage formations (such as depleted oil and gas fields or saline aquifers), where it becomes permanently trapped.

The EU CCS Directive[6] is a robust regulatory framework, which ensures that CO_2 storage activities are undertaken to the highest safety standards.

Challenges associated with CO_2 storage in Europe are further outlined hereafter:

- The matter of CO2 liability risks for long-term storage needs further clarification. It is particularly important to assess how private investors and governments should share long-term CO2 storage risks.

[4] Zero Emissions Platform, 2020, A Trans-European CO_2 Transportation Infrastructure for CCUS: Opportunities & Challenges. Available at https://zeroemissionsplatform.eu/a-trans-european-co2-transportation-infrastructure-for-ccus-opportunities-challenges/
[5] ZEP, CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive, 2019
[6] European Commission, Directive on geological storage of carbon dioxide, 2009

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- In order to deliver large-scale decarbonisation and reach climate neutrality by 2050, there is a paramount need to invest, support and further develop CO2 storage by incentivising storage appraisal at both offshore and onshore sites. The development of a European storage atlas, with the use of artificial intelligence and big data, is also an important milestone and target of the SET-Plan.
- As highlighted in previous engagements, it is important that Europe makes the most out of funding instruments for low-carbon technologies, such as the Innovation Fund. Facilitating the individual applications of projects aiming to develop CO2 storage offshore or onshore should be considered under the Innovation Fund. This would effectively set the basis for the backbone of European CO2 infrastructure, to which CO2 emitters from across Europe can connect.
- Storage appraisal activities should also look at the development of CO2 storage sites for small emitters.

CO_2 utilisation

Captured CO2 can also be used as a feedstock for a variety of industrial purposes (e.g. methanol and synthetic fuel production, in building materials, used as solvents, or in greenhouses). An alternative to the permanent storage of CO2 is CCU (such as the production of synthetic fuels). The CO2 abatement potential of CCU technologies depends on the origin of CO2 (fossil, biogenic, or directly captured from the air), the emissions associated with the process used, and any possible emissions from use of the final product. Therefore, it is of key importance to properly monitor, account, and report the full lifecycle of the CO2 to correctly reflect the actual carbon footprint.

CCU comprises technologies at different levels of maturity and process complexity. From a technical point of view, a more rapid deployment of CCU technologies can be achieved through the large-scale development of:

- Novel and cost-effective materials (membranes, adsorbents, absorbents) with high durability and recyclability for capture that is performant and tailored to the purity requirements of the subsequent use.
- New catalysts and materials for energy- and resource-efficient conversion technologies into fuels and chemicals (electrochemical, photoelectrochemical, thermochemical, biological).
- Integrated systems that can combine capture and conversion in one reactor, addressing the need for input synchronisation during continuous operation (e.g. CO2, renewable energy availability).

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At the same time, logistical considerations are also important for the development of certain CCU pathways (e.g. accommodating large volumes of waste fractions for CO_2 mineralisation due to limited CO_2 uptake rate, ensuring symbiotic infrastructure among CO_2 emitters and CO_2 converters in clusters of concentrated industrial activity).

Currently, an increasing number of LCA studies regarding the environmental benefits of CCU are being published. It will be crucial to systematically follow this up to provide evidence of the mitigation potential of CCU technologies.

Policy and regulation

A favourable policy and regulatory framework is key for the large-scale development of CCS and CCU technologies and the kick-off of European CCS and CCU projects in this decade. While the mitigation role of CCS is demonstrated and acknowledged, the political support for the technology has been proven to not be sufficient, causing delays and proving to be a major barrier for large-scale CCS projects in the early 2000s.

It is crucial that the European Union sends a strong message in support of CCS and CCU development, giving predictability to companies for long-term investments and ensuring that a coordinated policy framework is in place to facilitate the uptake of CCS and CCU technologies across Europe. In this respect, raising awareness with policymakers about the benefits and the challenges of CCS and CCU is vital.

At the same time, it is important to raise awareness with industrial stakeholders, especially those for which CCS and CCU technologies will prove to be the lowest-cost route to large-scale decarbonisation. For industries such as cement, lime and steel – where electrification will only have limited potential – CO_2 transport and storage infrastructure will not only deliver real decarbonisation, but it will also protect existing jobs, industrial manufacturing, and income; and there is a possibility for CCU to allow them to become circular by reusing their emissions.

Referring to conclusions from the most credible Integrated Assessment Modellings, in order to reach climate neutrality, it will not be enough with climate mitigation technologies – we also need Carbon Dioxide Removals (CDR). To stimulate the development and deployment of CDR, there is a need to deploy CCS and also introduce clear functioning incentives for CDR. As an example, if you are already producing energy based on biomass, it must be economically feasible and attractive to invest in CCS to create CDR. In this context, it is of key importance to properly monitor, report, and account for the emissions and removals of CO_2 associated with CCS and CCU to correctly reflect their actual carbon footprint. A robust carbon removal certification mechanism (as announced in the Circular

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Economy Action Plan) will allow tracking of the CO_2 fluxes, especially for CCU technologies that are not yet commercially mature. Such certifications can allow regulatory incentives for market uptake of CCU products, which may be slow in the short term due to high investment costs.

Legal challenges that are specifically highlighted within the context of networks refer to cross-border transport of CO_2 and the coordination of CO_2 streams from different sources. Since October 2019, parties to the London Protocol that wish to participate in a cross-border CO_2 network for (also) offshore CCS can now unilaterally declare the provisional application of the 2009 amendment and enter into respective agreements with other parties, allowing the export of CO_2 for offshore storage.

More coordination at EU level is needed to address existing differences in legal requirements with regards to the construction and characteristics of pipelines for cross-border pipeline projects, as well as clear guidelines regarding specific requirements for CO2 pipelines.

At EU level, the European Commission's Directive 2009/31/EC ensures third-party access to CO2 networks, following precise CO2 specifications with the aim to guarantee access and compatibility in the network. The EU will still need to coordinate this network by issuing guidelines on the requirements of CO_2 streams.

Political support for the five cross-border CO_2 Projects of Common Interest[7] (PCI) is vital. These projects are on the right track to become operational before 2025. A solid policy framework providing a degree of predictability for long-term investments should be a priority for European policymakers. CO_2 infrastructure projects call for European legislators to extend the scope of existing legislation – such as the TEN-E regulation and EU ETS directive – to prepare for the rollout of CO_2 and clean hydrogen infrastructure.

As indicated in the European Taxonomy for Sustainable Finance (Taxonomy), all modes of CO_2 transportation to permanent geological storage – pipeline, ship, barge, train, truck – are allowed. This outcome is critical and should be preserved and reflected in revised TEN-E and EU ETS regulation, as it will allow near-ready CO_2 transport and storage projects to be realised and to create opportunities for numerous CO_2 emitters throughout the entire EU area to have access to low-cost decarbonisation pathways.

[7] European Commission, "Technical Information on Projects of Common Interest", 2020

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Another challenge is captured CO_2 from biogenic sources and how to store it. There are no incentives for CDR under the EU ETS.

While both CCS and CCU are included in the proposed regulation on the establishment of a framework to facilitate sustainable investment[8], CCS is defined as an eligible technology in the Taxonomy while CCU is not yet included. This is due to a lack of evidence regarding its mitigation effect and the issue has been forwarded to the Taxonomy Platform. The Zero Emissions Platform (ZEP) is working on input to the Taxonomy Platform regarding screening criteria, which can accompany evidence on mitigation effect and provide a basis for a new decision regarding the inclusion of CCU.

The Taxonomy also currently disqualifies all CO_2 transport assets that are connected to CCU. This is a very important barrier to eliminate[9].

There is still not enough political acknowledgement of the role of CCS and CCU for the decarbonisation of energy and industry sectors, especially energy-intensive industrial value chains. The National Energy and Climate Plans and long-term strategies of European member states provide an indication of national attitudes towards the technologies. An early assessment shows that 12 countries have included the development of R&D activities around CCS in their NECPs, while four countries have included the development of a CCS strategy and large-scale projects by 2030.

As part of the European Green Deal, several policy initiatives and revisions have been announced that will be relevant for CCS and CCU and others will be presented. Overall, the political momentum for low-carbon technologies created by the European Green Deal creates a unique opportunity to enable a supportive policy and legal framework for CCS and CCU in the European Union.

The provisional implementation to the London Protocol in force since October 2019 has removed the legal barrier to export CO_2 for offshore storage. However, the solution is a provisional implementation and it would be a strong political signal if those member states, that have not yet done so, will ratify the amendment to Article 6 and reduce the gap to the threshold for the formal enforcement of the amendment.

A legal storage challenge concerns the lack of general regulation for depleted oil or gas fields to do a proper assessment of CO_2 storage potential at decommissioning (however, this is more of a national issue).

[8] Article 6, COM(2018) 353
[9] Zero Emissions Platform, 2020, Future-proofing the Taxonomy regulation regarding CO_2 transport infrastructure. Available at https://zeroemissionsplatform.eu/future-proofing-the-taxonomy-regulation-regarding-co2-transport-infrastructure/

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As far as CCU is concerned, this is the opportunity for legislative packages that are crucial for rapid deployment to be more supportive. For example, the announced revision of REDII should take into account industrial realities as far as the conditions for renewability, additionality, and temporal and geographical correlation of electricity use in CCU. Furthermore, the ETS should also be expanded to enable emitters not to surrender allowances from the moment that CO_2 is further reused in CCU applications. For example, mineralisation of CO_2 into a construction product is sequestering CO_2 in a way that is equivalent to geological storage and it is important to be recognised as such also in the ETS.

Business models and funding

The biggest hurdle for CCS and CCU deployment is the market failure that prevents the creation of viable business cases.

Investing in shared CO_2 transport and storage infrastructure is the ultimate European project, and it represents a strategic and instrumental policy decision to preserve Europe's welfare and to make European society future-proof for a climate-neutral economy. As several CO_2 capture projects are near-ready for large-scale deployment, European CO_2 transport and storage infrastructure would connect CO_2 emitters (industrial hubs and power plants) to storage sites and enable the extensive decarbonisation that will be needed to meet the climate neutrality target. Timely development of this infrastructure is crucial and will also enable industry to take a proactive role in the discussions around 2030 and 2050 climate targets.

Funding mechanisms are a vital element to unlock private investments in CCS and CCU large-scale projects. The European Union is currently offering funding opportunities through the R&I programme Horizon Europe, the Connecting Europe Facility and the EU ETS Innovation Fund. Some countries – e.g. the Netherlands, Norway, and the UK – are also studying/introducing national funding schemes (subsidies, carbon tax, incentives, etc.) to support the development of early, large-scale CCS projects.

The cross-value chain risks (counterparty risks) that are inherent between the different parts along any CCS/CCU value chain (capture – transport – utilisation/storage) remain a high business risk. No compensation mechanisms are currently previewed by the European Commission to mitigate the business exposure for any party in a CCS/CCU value chain in the event one party is underperforming, especially under the Innovation Fund. This is

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preventing the optimal use of funding to create shared transport and storage infrastructure.

In the absence of a "functional" (global) carbon price (minimum EUR50-60/tCO_2), investment in CCS will have no market driven business case and will largely depend on public funding and policy incentives (e.g. to purchase zero-carbon products, such as clean steel or cement). It is therefore crucial to fund R&I activities to develop an infrastructure backbone and reduce costs. Public support and incentives will be necessary in this case to create and maintain the market and reduce high initial investment costs for upscaling and reaching commercial maturity.

CCU is facing similar issues despite the fact that the business case exists with the production of a marketable product that can be a substitute for a conventional one.

Necessary steps to support the development of the European CCS sector are:

Recognition and political support for common European CO_2 infrastructure – the EU has a key enabling role to ensure that European industry has access to CO_2 transport and storage and utilisation: shared CO_2 infrastructure can deliver clean, competitive industrial sectors, clean and flexible energy systems, an early, large-scale clean hydrogen economy, and negative emissions.

An enabling policy framework, making it economically feasible for companies to invest in the whole value chain of CCS and CCU:

- In the short term, incentives to support timely large-scale deployment of all parts along the CCS and CCU value chain – support for both CAPEX and OPEX.
- In order to reach all European emitters, CO2 transportation modalities other than pipeline – such as ship, rail, or truck – must be included in all relevant legislation.
- An Innovation Fund that can support both part of and the whole CCS and CCU value chain including the development of hubs.

It is imperative that EU and national funding programs are coherent and coordinated.

A functional and relevant carbon price – a robust EU Emissions Trading System – is expected to support investment once the technology is more mature (similar to other mature technologies). The development of a market for low-carbon/climate-neutral products is also foreseen as important.

The current funding instruments need to be *deployed in pursuit of the European Green Deal and the green recovery*. Policies and legislation on EU, regional and national level (also using

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the NECPs as a tool), as well as funding programs (Horizon Europe, SET-Plan targets and activities, etc.) and instruments, must be assessed and revised based on the new EU Climate Law and updated targets.

Social challenges

In general, there is limited awareness of the value and benefit from CCS and CCU technology. There is a great need to clearly describe the value and also highlight how CCS and CCU technologies affect the everyday life of EU citizens and consumers' choices – both regarding why these technologies are necessary and the applications that can be chosen from; everything from hydrogen for transport and heating to specific low-carbon products. It is necessary to help both policymakers and citizens/consumers to see and understand these values and benefits.

Bringing together policymakers at local, regional, national and EU level with companies and other societal actors, such as trade unions and environmental NGOs, will be a key driver for the development of CCS and CCU projects and raise awareness about their climate and economic benefits. Education of pupils at schools and visits to CCS/CCU facilities should be encouraged as a way to inform and promote their interest for the technology and develop increased awareness.

At European level, the European Commission has a good opportunity with initiatives such as the upcoming CCUS Annual Forum, which was recently announced as part of the Strategy for Energy System Integration. This opportunity can bring together stakeholders from different groups to learn more about CCS and CCU technologies and highlight the challenges that they encounter and the value and benefits that CCS and CCU can bring.

Conclusions

The dramatically changing political landscape of the European Green Deal and the EU ambition to reach net-zero GHG emissions by 2050 requires immediate action. All economic sectors will need to contribute to reach the target and, in order to ensure a cost-efficient yet irreversible pathway towards decarbonisation, CCS and CCU need to be deployed and tested at scale by 2030.

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The renewed interest for CCS and CCU as a cost-effective technology for large-scale decarbonisation in industry and power reinvigorates the positive momentum seen at a European and national level, with announcements such as the Longship project and funding awarded through the Connecting Europe Facility for Energy (CEF) programme to European CCS and CCU projects (Porthos, Athos, Antwerp CO_2, Acorn Sapling, Ervia).

To support these recent positive developments, existing barriers for the large-scale deployment and development of CCS and CCU need to be tackled. The European Union's increased climate ambition represents a prime opportunity to revise some key pieces of legislation in order to enable the take-off of CCS and CCU projects and to introduce incentives for the technologies. R&I activities will help address current technical challenges along the value-chain, and in this respect, continued support for R&I activities at lower and higher TRL levels is crucial to reduce the costs of the technologies and improve efficiency.

Social acceptance challenges still remain and will require the action of a wide group of societal stakeholders to be addressed. Local administrators, NGOs, academia, and other economic stakeholders play a central role in increasing the awareness around CCS and CCU and facilitating an informed debate around it.

To conclude, CCS and CCU can support the EU's decarbonisation pathway, delivering climate change mitigation and circularity, carbon dioxide removals and early, large-scale volumes of clean hydrogen for industry and homes. CCS and CCU can deliver clean economic growth, safeguarding industrial manufacturing, preserving existing jobs while creating new ones.

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