CCUS SET-PLAN

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CCUS ROADMAP TO 2030

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Executive Summary

The 2020s will be a critical decade to set Europe on the right track to achieve climate neutrality by 2050. With this climate target now enshrined in EU legislation, low-carbon technologies such as Carbon Capture Utilisation and Storage (CCS and CCU) will play a role in decarbonising industry and energy sectors and will offer the possibility to achieve carbon dioxide removals (CDR). It is crucial that CCS and CCU are developed, deployed, and scaled up during this decade to support the EU's decarbonisation trajectory towards net zero greenhouse gas (GHG) emissions by 2050, as well as higher climate targets for 2030 – a net reduction of 55% GHG emissions, compared to 1990 levels.

Roadmap

The CCUS Roadmap to 2030 aims to identify and stress the actions that will be necessary for the large-scale development and deployment of CCS and CCU in the 2020s, build on the work done within the CCUS SET-Plan, and provide an overview of the status of the technologies today. The roadmap also includes a list of actions to be taken by European and national policymakers to underpin the European development of CCS and CCU.

After a brief introduction, the Roadmap looks at the contribution of CCS and CCU to climate change mitigation, as examined by scientific modelling scenarios, and discusses the status of the technology and the progress made so far. Within the Roadmap, the new targets of the CCUS SET-Plan are also reported as a basis to take quick action and support the upscale of these technologies. Chapter five focuses on the way forward and the actions to be taken in the 2020s from a technological, policy, legal, and funding perspective and across the entire CCS/CCU value chain. Recommendations and actions for policymakers are summarised in the final chapter of the Roadmap. Complementing the Roadmap is an extensive, free-standing document containing the annexes.

Actions

Urgent action is needed to support CCS and CCU in this decade. European and national policymakers play a critical role in raising awareness and driving the development of CCS and CCU.

An EU strategy for CCS and CCU is a crucial tool for the development and deployment of CCS and CCU and CO_2 infrastructure and should outline the EU's vision for 2030 and 2050, proposing targets, policies, business models, allocating responsibilities, and taking into account the synergies and areas for cooperation with non-EU partners.

Such an approach is needed to create predictability for companies and the finance community to invest in CCS, in particular, for breakthrough projects and the scaling of the technology in the next decade. An EU strategy for CCS and CCU would fit with and complement the already published EU strategies for Hydrogen and Energy System Integration, supporting the pathway towards climate neutrality by 2050.

In practice, to ensure that planned and upcoming European CCS and CCU projects move forward towards becoming operational, specific policy support is needed:

- The National Energy and Climate Plans (NECPs) and the industrial transition pathways arising from the EU Industrial Strategy should be used as a basis to draft decarbonisation pathways and highlight the role of CCS and CCU. The sector-specific voluntary roadmaps envisaged under the European Climate Law offer opportunities to create synergies with the transition pathways under the Industrial Strategy.
- EU member states should be strongly encouraged to ratify the amendment to article 6 of the London Protocol, therewith effectively streamlining the legal/administrative work associated with export of CO_2 for permanent offshore storage.
- EU member states should be encouraged to implement complementary policy mechanisms on a national level to support the scale-up and deployment of CCS and CCU technologies.
- In the upcoming communication on a regulatory framework for CDR, the European Commission should set out clear definitions and a plan to incentivise CDRs, based on robust carbon accounting and full life-cycle analysis.
- The capture of biogenic and atmospheric CO_2 should be incentivised.
- Priority regions for appraisal should be identified, using the proposed online open-access European Storage Atlas as a foundation, and establishing recommendations and responsibilities for development.
- The sharing of good practices in these areas should be supported to enable all European regions to benefit from these early developments.

Policies

Several existing EU policies should be updated to enable the needed scale up of CCS and CCU. The following EU legislations can become real enablers for development and deployment of these technologies, provided that the following amendments are made:

- Trans-European Networks for Energy (TEN-E) regulation – The inclusion of CO_2 storage and all modalities of CO_2 transport is key. Shipping has recently been recognised as vital for the future. Support of Projects of Common Interest (PCIs) that have applied to be on the 5th PCI list – a record number of 8 PCIs in CO_2 infrastructure – is crucial to deploy and develop the necessary CO_2 infrastructure to ensure large-scale, cost-efficient European decarbonisation. Consistency between the revised TEN-E regulation and other legislation, such as the EU Taxonomy and the EU ETS Directive, is needed.
- EU Emissions Trading System (ETS) regulation – As proposed in the revised EU ETS Directive, all modalities for CO_2 transport should be included under the scope of the EU ETS and the connected Monitoring and Reporting Regulation (MRR) should be updated accordingly. Some applications of CCU, where CO_2 is stored in a manner intended to be permanent, should also be included. For other CCU products, where CO_2 is released again after use (e.g. fuels), the ETS should provide clear guidance that all emissions are accounted for but not double counted. There is a need to keep funding available under the Innovation Fund and ensure support for innovative low-carbon technologies.

- Hydrogen and Gas market decarbonisation package – CO_2 should be recognised in the upcoming Hydrogen and Gas market decarbonisation package. The transport of CO_2 should be enabled under the Gas Directive for those companies that wish to operate it, with clear provisions for National Regulatory Authorities (NRA) and Transmission System Operators (TSO). There is also a need for 'capacity building' at local governments in order to be able to provide regulatory guidance for CCS and CCU projects.
- Industrial transition pathways – Developed in connection with the European Industrial Strategy, these roadmaps will be crucial to highlight the role of CCS and CCU and low-carbon hydrogen for industrial decarbonisation, mapping the sector-specific options for cost-efficient decarbonisation.
- CEEAG State Aid Guidelines – The upcoming final version of the revised Climate, Energy and Environmental Protection (CEEAG) State Aid Guidelines, where multimodal CO_2 transport should be recognised under the definition of carbon dioxide networks, while any carbon source that can be captured should be also included under the definition of CCS.
- EU Taxonomy for Sustainable Finance – This regulation will be a central instrument determining the ease of access to funding for economic activities. When more scientific evidence of climate change mitigation becomes available, technical screening criteria for the inclusion of CCU technologies as sustainable economic activities can be developed, particularly for the environmental objectives of climate mitigation and transition to a circular economy.
- Renewable Energy Directive – The Renewable Energy Directive will need to allow energy-intensive pathways (e.g. CCU fuels) that are reducing GHG emissions in transport and industry to access additional renewable electricity in a harmonised and non-discriminatory way. EU member states need to provide a framework for the production of additional renewable energy based on the demand in different economic sectors.
- Important Projects of Common European Interest (IPCEI) – Exploring opportunities to promote CCS and CCU as IPCEI should be pursued.

Conclusions

Actions are needed urgently to set the foundations for a cost-efficient trajectory to climate neutrality by 2050. All net zero compliant technologies should be developed and scaled up to support this pathway. CCS and CCU will play a relevant role in the deep decarbonisation of EU industry, namely for emissions that cannot be avoided in a timely, cost-effective, or even technical manner.

Political support is necessary to move forward with all the parts of the CCS and CCU value chain – getting a funnel of projects across Europe aiming at capturing, transporting, storing or utilising CO_2. The renewed interest in CCS and CCU as cost-effective technologies 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 conclude, CCS and CCU can support the EU's decarbonisation pathway, delivering climate change mitigation and circularity, CDRs and early, large-scale volumes of clean hydrogen for industry and homes. CCS and CCU can deliver clean economic growth, safeguarding industrial manufacturing and preserving existing jobs, while creating new ones.

1. Introduction and background

1.1. Introduction to the SET-Plan and the work on CCS and CCU

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 11 European countries[1], the European Commission, industrial stakeholders, research institutions, and non-governmental organisations. The work is chaired by the Netherlands, Norway, and the Zero Emissions Platform.

The SET-Plan defined ten priority areas, covering a wide range of technologies including CCUS, wind, solar, geothermal, renewable heating and cooling, and biofuels. The Implementation Working Group 9 (CCUS SET-Plan) was established to help the progress of Research and Innovation (R&I) activities required to achieve the 2030 targets for CCS and CCU agreed by the European Commission, SET-Plan countries, and industry.

1.2. The role of Research and Innovation

Europe is an established global leader in CCS and CCU Research and Innovation activities, that are delivered by a broad range of organisations including industry, independent research organisations and universities. Key actors in the European CCS and CCU R&I scene include Horizon 2020 and its successor Horizon Europe, Mission Innovation, Innovation Fund, ERANET-ACT and national programs.

Non-technical research also makes important contributions, considering aspects such as economics/incentives, legal issues, and public perception.

1.3. Target audience

The Roadmap to 2030 is aimed towards EU and member state policymakers, companies interested/involved in decarbonisation, and the finance community, as well as the CCS and CCU community.

1.4. Scope

The Roadmap to 2030 aims to give as clear as possible information to policymakers at EU and member state levels as well as projects, companies, and the finance community on what needs to be done in the 2020s in order for Europe to be on the right track to become climate-neutral by 2050:

- The role of CCS and CCU for a just and cost-efficient climate transition – delivering decarbonisation for Europe, safeguarding industrial competitiveness and welfare, creating new jobs while preserving existing ones, and delivering climate benefits.

[1] Czechia, France, Germany, Hungary, Italy, Norway, The Netherlands, Turkey, Spain, Sweden, and the United Kingdom

- What will be needed in this decade referring to policy frameworks, business models, R&D&I, enablers, and barriers to tackle, etc.
- Showcasing Europe as a global leader on low-carbon technologies and just transition.
- A clear action plan for policymakers.

The roadmap will be connected to a set of annexes – a self-standing publication which will include the deliverables of the CCUS SET-Plan work. These annexes will be a living document and will be updated regularly until the end of the CCUS SET-Plan grant in April 2022.

2. European Green Deal – A climate-neutral Europe in 2050

The European Green Deal, Europe's new growth strategy, sets out a legally binding EU target of net zero greenhouse gas emissions by 2050 and a 55% emissions reduction by 2030, compared to 1990 levels. The political momentum generated by the European Green Deal and the legally binding objective of climate neutrality by 2050 have given CCS and CCU strengthened and growing interest from policymakers and industrial stakeholders. CCS and CCU will support Europe's pathway to achieving 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.

As part of the European Green Deal workplan, in July 2021, the Commission presented the 'Fit for 55' package, a legislative initiative aiming at revising key pieces of EU climate and energy legislation, such as the EU ETS Directive, the Renewable Energy Directive (RED), the Energy Taxation Directive (ETD) or the introduction of new instruments like the Carbon Border Adjustment Mechanism (CBAM), the ReFuel EU for Aviation, and the Fuel EU Maritime.

All of 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, the five Projects of Common Interest in CO_2 infrastructure (Porthos, Athos, Antwerp@C, Acorn Sapling, Ervia), and the North-CCU-Hub project.

2.1. Climate ambitions – and the impact on society

Reaching climate neutrality by 2050 requires strategic investment decisions. The pathway towards climate neutrality will bring about a major transformation of energy-intensive industries, such as cement, lime, steel, and chemicals, that are at the core of the European economy and provide products that are at the heart of how we live our lives. For these sectors, pathways including CCS represent the lowest-cost route to decarbonisation whilst maintaining industrial activity[2] and preserving existing jobs. CCS can capture and store emissions from industrial processes and it also plays an important role in the manufacturing of low-carbon hydrogen from natural gas.

With the right framework, CCS applied to industrial processes and power plants can secure jobs and incomes and ensure European industrial competitiveness in international markets while delivering sustainable growth. By providing a low-carbon alternative, existing jobs in those industries will be preserved.[3] This will make European regions competitive and attractive for forward-looking, long-term, low-carbon investments. Ultimately, CCS can enable European industrial regions to remain competitive in a net zero landscape.

In parallel, CCU will allow the diversification of business models towards less reliance on fossil resources. The aforementioned industrial sectors with hard-to-abate emissions will be able to reuse their process emissions to produce an array of marketable products. At the same time, CCU will provide an alternative carbon feedstock. Industrial activity can be maintained while leading to more

[2] Zero Emissions Platform, "Climate Solutions for EU industry", 2017
[3] GCCSI, "The Value of CCS", 2019

circular approaches and more symbiotic industrial relations where the emissions of one industry can be converted to feedstock for the other.

2.2. Science and the role of CCS and CCU

The central role that CCS and CCU must play to enable climate ambitions has been confirmed and reinforced by different sources. Completed in 2020[4], the report "Review of Carbon Capture Utilisation and Carbon Capture and Storage in future EU decarbonisation scenarios" shows the analysis of the role of CCS and CCU in the trajectory towards net zero.

The Intergovernmental Panel on Climate Change (IPCC) analysed several pathways that limit global warming to 1.5°C. In those pathways, a median of around 15 Gt CO_2 is captured using CCS and CCU in 2050. CCS and CCU have a particularly important role in decarbonising hard-to-abate industrial sectors, where emissions reductions by energy and process efficiency would not be sufficient to meet mitigation targets. Importantly, all pathways that limit global warming to 1.5°C with limited or no overshoot rely on CDR. CO_2 emissions captured and stored from bioenergy with carbon capture and storage (BECCS) reaching a median level of 5 Gt CO_2 in 2050.

Although showing smaller absolute numbers, the International Energy Agency (IEA) report "Net Zero by 2050" echoes the conclusions by the IPCC. The report foresees that a total of 2.4 Gt CO_2 is captured from the atmosphere by 2050, of which about 80% is permanently removed through a combination of BECCS and DACCS, while the remaining CO_2 is used to provide synthetic fuels.

The climate contribution of CCU remains unclear, as the carbon footprint is not extensively quantified in modelling and scenario building[5]. CCU technologies have the potential to contribute to emissions reduction, avoid generating new emissions by reusing existing emissions, and, in certain pathways, to also store CO_2 in a manner intended to be permanent. It is estimated that, by 2050, CCU could reuse up to 7 Gt of CO_2 for the production of fuels, chemicals, and materials[6].

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.

[4] Review of Carbon Capture Utilisation and Carbon Capture and Storage in future EU decarbonisation scenarios, 2020
[5] Detz and Zwaan, 2019; Bogdanov et al., 2019; EU Reference Scenario 2020 ; Ram et al., "Powerfuels in a Renewable Energy World - Global volumes, costs, and trading 2030 to 2050", 2020.
[6] Hepburn et al., 2019

3. Status of CCS and CCU and current progress along the value chain

3.1. Technical status and potential

CCS technologies involve capturing CO_2 produced by large industrial and energy plants, transporting the CO_2, and storing it permanently deep within rock formations or saline formations. For CCU technologies, instead of storage, the CO_2 is used as part of a conversion process, for the fabrication or synthesis of new products, or in non-conversion processes, where CO_2 is used.

From 75 million tonnes a year (Mtpa) at the end of 2020, the capacity of CCS and CCU projects in development grew globally to 111 Mtpa in September 2021. In Europe alone, there are now 35 projects in development[7]. CCS has been operational in Europe for over 20 years, with the Sleipner facility in Norway, having stored approximately 1 million tonnes of CO_2 per year since 1996. The total amount of CO_2 being captured in Europe is approximately 2.5 million tonnes per year.

Carbon capture technologies can be applied to a variety of carbon dioxide emitting processes: power and heat generation, cement production, iron and steel, waste-to-energy plants, low-carbon hydrogen manufacturing, and other industrial processes. The CO_2 is separated from the process emissions by chemical or physical processes, or through selective membranes for physical separation of CO_2. When CO_2 is separated from a stream where parts or all the CO_2 stems from biogenic sources, and is permanently stored, CDRs are realised (Bio-CCS/BECCS, Waste-to-Energy with CCS, etc.). Direct Air Capture, where CO_2 is separated directly from the air, is another CDR technology that has emerged in later times.

Carbon capture technologies currently capture up to 95% of the CO_2 emissions, however it is technically feasible to achieve capture rates >95% with only minor efficiency and financial penalties compared to a capture facility capturing at 90%. Capture rates above 99% are possible, as technologies develop through continued R&I and deployment.

Many different capture technologies have been tested at pilot scale in a lot of national and European research projects. This comprises absorption by liquid solvents, adsorption by solid sorbents, oxy-combustion, membranes, solid looping, low-temperature separation, and others. Absorption by liquid solvents is by far the technology which is most developed and commercially available at a large scale.

Transport of CO_2 is primarily done by pipeline, but other modes of transport, like ship, rail, or road transport, will be increasingly important. The development of shared CO_2 transport infrastructure to connect industrial clusters to storage locations is key to unlock economies of scale on a regional, national, and European level. To meet decarbonisation targets across the EU, it will also be necessary to extend the deployment of CCS and CCU to small emitters and to stranded emitters for which direct connection to pipeline transportation network infrastructure may not be feasible. Crucial for the development of CO_2 networks is the change from point-to-point solution to the creation of hubs and clusters – where CO_2 infrastructure is shared among different emitters.

[7] GCCSI, The Global Status of CCS, 2021

Permanent and safe CO_2 storage is achieved deep underground, using natural processes that trap CO_2, similar to how oil and gas is trapped for millions of years. Oil and gas fields and deep saline aquifers have similar geological features required for CO_2 storage: a layer of porous rock to store the CO_2 and overlying impermeable layers of cap rock which seals the porous layer underneath, trapping the CO_2. The European Directive on the geological storage of CO_2 provides a regulatory framework that enables storage operators to demonstrate the permanent and safe storage of CO_2 deep underground. Many projects worldwide have now demonstrated that CO_2 storage is safe, technically feasible and cost-effective, with the Norwegian Sleipner project being one of the longest-running projects globally. Now, a portfolio of European storage sites are being appraised and developed, creating a pipeline of storage that will support the first CO_2 capture and transport networks. However, many more storage sites will need to be provided in more regions to enable Europe to achieve its climate mitigation goals.

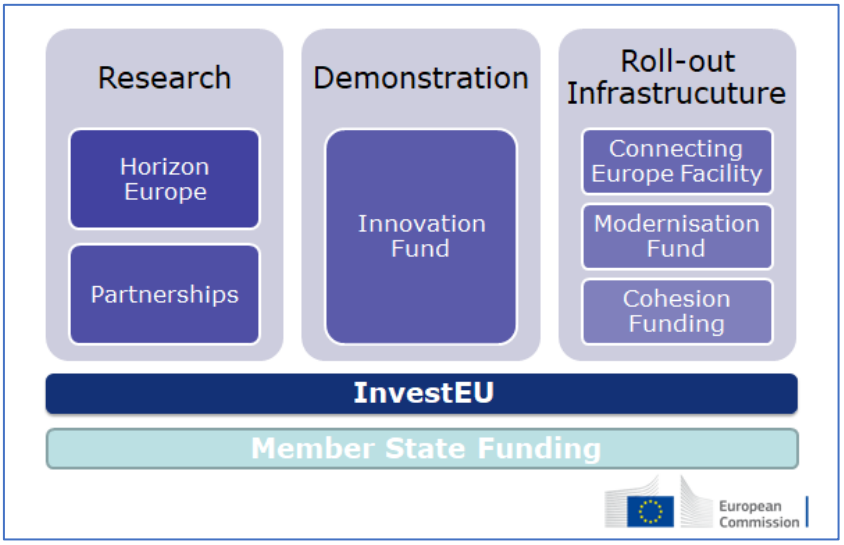
Utilisation is the process of using captured CO_2 in industrial processes or products. CCU technologies are used for the production of everyday products based on CO_2 including building materials, synthetic fuel, chemicals, plastics, and for horticulture. CCU will thus replace incumbent products, decrease reliance on fossil resources, and help to transition to a carbon circular economy. As for all environmental technologies, to determine the climate benefits of each CCU application, full lifecycle analyses (LCA) are required and are becoming available in some areas. Commercialisation of CCU technologies is at an early stage and a series of ongoing and announced projects will reach industrial scale within the next five years.

Potential – CCS and CCU are key technologies in the decarbonised future of the planet. The deployment of CCS and CCU at industrial scale will enable the technologies to be applied to many different sectors and applications, which in turn will accelerate innovation and improve technological efficiencies.

Removal of CO_2 from the atmosphere at industrial scale can be achieved with CCS, through the capture of CO_2 from biomass sources, also known as BECCS. CO_2 can also be directly captured from the air through Direct Air Capture (DAC) and the CO_2 permanently stored, though this is a less mature technology. Removals may also be achieved by utilising captured CO_2 from biomass or DAC and permanently storing it through mineralisation. The European Climate Law and many climate models have confirmed that the removal of CO_2 will be a vital component of future climate and energy systems to address residual emissions from other parts of the economy.

3.2. Making the technologies investable – funding opportunities

During this decade, it is crucial to put in place an enabling policy and regulatory framework for the large-scale deployment of CCS and CCU technologies, making the technologies investable. While the mitigation role of CCS is demonstrated and acknowledged by several modelling scenarios, securing broad political and public support for the technology has been a barrier for large-scale CCS projects in the early 2000s, and it is crucial to build awareness and political support in this decade to ensure the necessary scale-up.



European R&I funding streams for low-carbon technologies, including CCS and CCU

Horizon Europe

Several European funding synergies exist and are coordinated in support for CCS and CCU. Among those, *Horizon Europe* is one major pillar for public funding for CCS and CCU in Europe, where it features as an area for R&I. The Horizon Europe work programme for 2021 and 2022 was recently launched, and the main calls relevant for CCS and CCU focus on CO_2 capture, CO_2 storage, CO_2 conversion, integration in hubs and clusters and CDRs. Alignment of member state and European funding is key to the success of the SET-Plan.

The Clean Energy Transition Partnership (CETP) aims to empower the energy transition and contribute from a R&I perspective to the EU's goal of becoming the first climate-neutral continent by 2050. With robust investment in innovation and technology development, the CETP will pool national and regional resources/funding programmes, thus overcoming a fragmented approach. CCS and CCU is one of the areas described in the Strategic Research and Innovation Agenda (SRIA).

Innovation Fund

The Innovation Fund is one of the largest funding support schemes in Europe for pre-commercial projects in the areas of renewable energy, energy efficiency, energy storage, CCS and CCU, that can provide substantial GHG emission reductions and reach financial close within four years. Among the applications received, several projects include parts of the CCS and CCU value chain. The award winners of the first round of the Innovation Fund call will soon be announced. Meanwhile, on 26 October the European Commission launched the second call for large-scale projects.

Connecting Europe Facility for Energy (CEF-E)

For CO_2 infrastructure projects that have gained the status of European Projects of Common Interest (PCIs), funding is made available under the Connecting Europe Facility for Energy. This funding stream is connected to the Multiannual Financial Framework (MFF), and for the 2021-2027 period, the budget available under the CEF-E is €5.84 billion.

Currently, five CO_2 infrastructure projects are included in the 4th PCI list and eight have applied to be on the 5th PCI list, to be presented by the end of 2021. The 5th PCI list is the first one to be adopted with the objective of net zero GHG emissions enshrined in EU law.

ERA-NET Accelerating CCS Technologies

Another main pillar for public funding of CCS and CCU R&I in Europe is the corresponding partnership ERA-NET ACT. With an ever-growing number of partners countries and members, funds have successfully been allocated to CCS projects and evaluations are ongoing.

Important Projects of Common European Interest (IPCEI)

The Important Projects of Common European Interest is a valuable mechanism that allows EU member states to support large-scale transnational projects of pan-European interest beyond State aid rules. IPCEI are based on Strategic Value Chains, two of which are particularly interesting for CCS and CCU, i.e. Hydrogen Technologies and low CO_2-emission industries. For the moment, the Hydrogen IPCEI is ongoing with several member states[8] having already opened an expression of interest or having already identified industrial projects at national scale and starting the process of coordinating European cooperation through these projects.

UK Ten-Point Plan

UK policy has developed rapidly in recent years, driven by an increasingly clear recognition of the role that CCS and CCU might play in meeting the UK's legally binding target to have 'Net Zero' greenhouse gas emissions by 2050. In June 2019, the UK's Climate Change Act 2008 was amended to make the Net Zero target legally binding. In November 2020, the UK Prime Minister published a ten-point plan which was further supported in the 2020 UK Spending review, and further updated with the Net-Zero Strategy in October 2021.

The key headlines from the Ten Point plan of most relevance to UK CCS and CCU policy development are:

- £12 billion Government investment is planned by 2030 which will leverage up to £42 billion private investment. This will support 90,000 jobs in this parliament and up to 250,000 jobs by 2030.
- Net Zero is planned to be achieved through only domestic actions, i.e. no offsetting of emissions will be included.
- The introduction of 10Mtpa by 2030 target for CO_2 storage.
- The introduction of a 5GW hydrogen production capacity by 2030.

In order to support the development of CCS and CCU, commercial frameworks are currently being developed and are due to be published in 2022. They are expected to be based on a Contracts for Difference model to complement current renewable frameworks.

The Net Zero strategy, published in October 2021, further increases the ambition:

[8] For example Germany, France, Austria, the Netherlands

- Increased ambition to 20-30 Mt of CO_2 storage per year in 2030. At least approximately 50 Mt CO_2 capture per year is expected to be reached by the mid-2030s.
- This will include 6 Mt of industrial CO_2 emissions per year by 2030, expected to grow to 9 Mt per year by 2035.
- A target of 5 Mt CO_2 per year by 2030 has been introduced for engineered GHG removals.

3.3. Testimonials: the value of CCS and CCU for the European economy

Port of Rotterdam: Porthos offers companies the opportunity to reduce their CO_2 emissions during the period in which they have not yet made the transition to biobased, renewable, or circular. This enables companies to contribute to the Netherlands' climate objectives and to the energy transition, even if the alternatives are still not sufficiently available or developed. It is set out in the Dutch Climate Agreement that half of the industry's CO_2 reduction in 2030 will be achieved by CCS. As for the other half, the industry concentrates on efficiency, electrification, solar and wind farms, and green hydrogen.

Bellona: Both CCS and CCU will likely play a relevant role in the deep decarbonisation of EU industry, namely for the emissions that cannot timely, cost-effectively, or even technically be otherwise avoided. In particular for the cement and steel industries, but also parts of chemicals, there is an urgent need to provide open and fair access to CO_2 storage, to enable ambitious climate action and end political blockage. Narratives and vague plans for decarbonisation decades ahead will not help save our remaining carbon budget. CCS deployment for industry in the next years can.

Climate innovation in industry is not threatened by such access but held back by the lack of it – as soon as we have large scale, real projects operating, no company can hide behind greenwashing or small-scale pilots anymore. We are out of time – industry investment decisions taken today will lock in emissions well beyond climate tipping points or, if decisions are right, get us on the path to net zero.

French Club CO_2: Due to the deep decarbonisation of the energy in France, French CO_2 emissions were 465 MtCO_2e in 2017, of which 350 Mt are CO_2 emissions. The French Low Carbon Strategy published in April 2020 sets four priorities to reach carbon neutrality by 2050: 1) fully decarbonise energy production, 2) significantly reduce energy consumption in all sectors in particular through an increase of energy efficiency and sobriety, 3) reduce non-energy-related emissions as much as possible, and 4) increase natural and technological carbon sinks. By 2050, France will reach a level of 80 Mt of CO_2e emissions considered as incompressible, due to agriculture and industrial processes. These incompressible CO_2 emissions will have to be compensated with carbon sinks, both land sector sink and capture and storage sink. CCS is estimated to contribute to a reduction of 15 Mt CO_2 per year: 5 Mt to reduce "hard-to-abate" industrial emissions and 10 MtCO_2 to achieve negative emissions thanks to BECCS.

North-CCU-Hub is a public-private consortium of >20 partners developing a CCU strategy for the North Sea Port region (Belgium – Netherlands). The consortium consists of companies representing different sectors (steel, chemistry, energy, dredging, logistics), knowledge institutes and local/regional governmental agencies (city, province, port authority, innovation clusters). The

consortium aims at creating sustainable CCU-based value chains for local green economy based on industrial symbiosis. The first flagship project of the North-CCU-Hub is the North-C-Methanol project, which aims to produce 46,000 tonnes of green methanol for local use, by synthesis from local CO_2 and green hydrogen, generated by renewable energy in a new 65 MW electrolyser plant. Side products like oxygen and heat are also used locally. In the future, North-CCU-Hub wants to build further on the North-C-methanol project to increase capacities and diversify products.

Equinor: Norway Energy hub is Equinor's industrial plan for Norway's future energy industry, placing Norway at centre stage in accelerating the energy transition. Together with partners, Equinor is investing 50 billion NOK in emissions reductions on the Norwegian Continental Shelf, developing offshore wind, CCS, and early phase hydrogen projects. Equinor plans on investing further 100 billion NOK in the energy transition.

4. Where Europe needs to be in 2030 – decarbonisation pathway

4.1. Checkpoint 2030: getting on the right track for climate neutrality by 2050

Europe has set a target to reach climate neutrality, defined as net zero GHG emissions by 2050. At the same time, the European Commission has proposed to increase intermediate 2030 targets to a 55% emissions reduction. This has entailed the revision of key EU climate and energy policies, such as the EU ETS Directive. In order to achieve higher climate targets, Europe will need to develop and deploy CCS and CCU at a large scale. Therefore, CCS and CCU need to become investible technologies during the next ten years. The scale up of CCS and CCS supports the EU transition, enables, and supports a just transition for European industry – preserves jobs, stimulates economic growth and diversifies supply chains into new industries – and thus develops Europe as a global leader in the clean, competitive economy of the future.

To be on the right track to achieve higher climate targets, the CCUS SET-Plan has also adopted higher targets, which are illustrated in the table below and reflect the increased climate ambition of the European Union and the more ambitious goals at a European level.

These targets represent the basis for further developments over the next decade and set the foundation for the deployment of a European CCS and CCU industry in its several applications – CDRs and hydrogen. To achieve climate neutrality by 2050, Europe should be on track to meet these intermediary targets.

Going forward, it will be crucial to integrate CCS and CCU in national and European strategies.

	CCUS SET-Plan targets for 2030
1	Delivery of 15 commercial-scale CCS projects linked to industrial CO_2 sources. Further 10 projects having completed a FEED study and five having made an investment decision.
2	Delivery of 10 commercial-scale CCS projects for clean, flexible power and heat generation (including waste-to-energy plants), complementary to increased renewable energy generation in the energy mix.
3	EU member states and external SET-Plan countries having completed national and regional CCS roadmaps for the development of dedicated CO_2 transport infrastructure (new, retrofitted, and repurposed), including clusters of CO_2 sources and shared, cross-border CO_2 infrastructure. The infrastructure being included in the European Ten-Year Network Development Plan (TYNDP).
4	At least 10 additional EU Projects of Common Interest (PCI) for CO_2 transport infrastructure, with a focus on Central, Eastern, and Southern Europe. Experience from the first full-scale CCS project should be taken into account in the SET-Plan activities linked to targets 3 and 4.
5	An up-to-date and detailed inventory of the most suitable and cost-effective geological storage capacity (based on agreed methodology), identified and accepted by various national authorities in Europe.
6	At least three pilots of capture technologies at TRL 7-8 in different industrial applications, including one enabling low-emission hydrogen production. At least six pilots of capture technologies at TRL 5-6, of which at least two pilots to test climate positive solutions such as Bio-CCS and direct air capture (DAC).

7	An interim target of at least six new CO_2 storage sites in preparation or operating in different settings (i.e. obtained or ready to submit an application for a storage permit). A target by 2030 of a further nine sites to be appraised to the same level, in a range of geological settings, both onshore and offshore.
8	By 2030, several demonstration installations producing CO_2-based fuels, chemicals, and materials at the scale of tens of kilotons per annum (kt/a) and contributing to EU 2030 and 2050 climate and circularity objectives.
9	By 2030, first large-scale CCU commercial installations enabled by a supportive regulatory framework and risk-sharing financial measures at national and EU level including IPCEIs in the context of new industrial alliances mentioned in the New Industrial Strategy for Europe.
10	All European countries having identified, if applicable, the need for CCS and/or CCU as part of their strategy (producing a national CCS roadmap) for their transition towards net zero by 2050 (included in their National Energy and Climate Plans).

5. What needs to be done to reach the targets and who needs to do what?

After highlighting the status of the technologies and the higher targets set out by the CCUS SET-Plan for 2030, this chapter will outline the necessary steps and actions to be taken in order to support the EU's trajectory to net zero and higher 2030 climate targets.

Enablers of and hurdles for CCS and CCU have been discussed in the report "Key enablers and hurdles"[9], produced in 2020. The report identifies current enablers and hurdles to address in order to develop CCS and CCU in Europe:

- Technical
- Policy and regulatory
- Funding
- Social acceptance

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 have yet to be addressed. To address these barriers, continued R&I is crucial. Ongoing and upcoming CCS and CCU projects will identify new challenges/barriers that can be solved by undertaking R&I in parallel with large-scale activities, which can increase the speed of delivery of CCS and CCU at scale. An iterative process is needed where R&I projects address specific challenges and barriers, with the results then implemented in large-scale projects.

Political and financial issues are closely linked with technical development. The cost and energy requirements of CCS and CCU must be further reduced to make these technologies more attractive from a political and financial perspective. CCS is needed and even though the technology will develop further, learnings that can achieve significant cost cuts can only be realised as technologies become utilised on a large scale in Europe.

To summarise, CCS and CCU can support the EU's decarbonisation pathway, delivering climate change mitigation and circularity, CDRs, 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.

5.1. Technical development and R&I needs along the value chain

In order to meet the European climate objectives for 2030, more operational CCS and CCU projects at commercial scale are needed. In many project lists, projects at different stages of progress are mixed. Some are ongoing, whereas others are at a planning stage and final investment decisions are not yet taken. The projects listed in the annex provide the most recent list of CCS and CCU projects – either separate projects or as part of full-chain CCS or CCU projects – which are ongoing, recently completed, or planned in Europe.

[9] Key enablers and hurdles impacting CCUS deployment with an assessment of current activities to address these issues – CCUS SET-Plan 2020

Full-scale commercial CCS projects will require all the parts of the value chain to be operational. The elements of the chain, i.e. capture, transport and permanent storage, must be developed and implemented in phase with each other. The technical development has reached a stage of maturity where the whole CCS value chain can be implemented and operated. The barriers might be more difficult to overcome on the political and financial side.

CO_2 capture

A large increase in CO_2 capture capacity is planned until 2030, with a large share of this coming from the manufacturing of low-carbon hydrogen produced from natural gas with CCS, which is a commercially available technology. Another large contribution to CO_2 capture will come from "capture clusters". Here, this term is used as an umbrella term, since for these projects, it is not fully clear which industry sectors will be involved in the end, and to which extent. Clusters can share transport and storage infrastructure and cooperate on the development process. From a technical point of view, there are no large barriers. The "risk sharing" and the possible reduced costs can make it attractive to be part of such a cluster.

Ongoing and planned CO_2 capture capacity is mainly located in Northwestern Europe. As most of the CCS activity is concentrated within a few countries, a broader implementation plan for CCS is needed for Europe.

By 2030, approximately 68 million tonnes of CO_2 are planned to be captured per year. The projects are at different stages in development, and it would appear that projects aiming to capture just above 3 million tonnes of CO_2 per year are funded or have finally decided to be implemented. If all planned projects are realised, Europe can meet the minimum capture volume in 2030 that is needed to match the 2-degree scenario[10], while falling far below the 2030 volume needed to be on track to meet the 1.5-degree scenario. Many more large-scale, commercial CCS projects will need to be in the pipeline in the short term to enable the possibility to reach a net zero scenario in 2050.

In this context, research and innovation have to play a major role to support the necessary advancements. The following R&I needs are identified as key to enable CO_2 capture at the level required to meet climate goals:

- Capture technologies should be developed to enable high capture rates (>95%) and CDR schemes. The development of a clear and shared framework for carbon accounting and for guaranteeing the sustainability of bioresources is fundamental to enable CDR solutions.
- The energy requirements for the CO_2 capture process are important factors to identify a suitable match between capture technology and industrial application. Technology development should be guided by considerations of accessibility to clean and sustainable energy sources.
- Other technical aspects should be given importance, such as flexibility, compactness, and potential for heat integration and process intensification.

[10] Review of Carbon Capture Utilisation and Carbon Capture and Storage in future EU decarbonisation scenarios, 2020

- Technological advancements are needed for the development of novel reactor designs, modularisation, and cost-effective materials.
- Cost reduction can be pursued both in terms of CAPEX and OPEX. The development of a funnel of large projects, based on CO_2 capture technologies at different high Technology Readiness Levels (TRL), will contribute to bring down costs.
- The formation of industrial clusters should be supported as they offer opportunities for energy integration, sharing of common infrastructure, and risk reduction for each cluster partner.
- Control of emissions and other health, safety, and environmental considerations are critical for reaching commercialisation of capture technologies. As such, they should be addressed early in the development of new technologies.
- Next generation CO_2 capture technologies must guarantee the quality and continuity of the industrial production or process where they are applied (for example via technology qualification).
- The development of a stable framework to enable early movers is essential to create the conditions to achieve climate goals: standards, funding and incentives, risk sharing, and business models. It is particularly important to support projects whose implementation contributes to developing a CCS and CCU network, for instance capture projects that will feed large transport and storage infrastructure projects (e.g. the Northern Lights/Longship project in Norway, which is the first European, commercial, full-chain CCS project to become operational).

CO_2 transport

Transport of CO_2 is a vital component of a CCS project, enabling CO_2 emitters across Europe to connect to safe and permanent storage. CCS projects, including both cross-border European Projects of Common Interest and domestic projects, will rely on different modalities for the transport of CO_2, such as pipelines, ships, barges, and trucks.

Many of the technical challenges related to CO_2 transport are further outlined in a recent ZEP report on CO_2 transportation. 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. A central requirement for the efficient and 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.

Although the majority of the transport of CO_2 is currently operated by pipeline, the role of shipping will become increasingly important – both maritime and inland rivers and canals. Transport of CO_2 by ship has been recognised both at EU level – in the European Taxonomy for Sustainable Activities, as well as within the revised EU ETS Directive – and on national level, for example in the Dutch SDE++ subsidy scheme and UK CCS and CCU programme.

For CCS projects aiming to transport CO_2 by ship, interoperability will be very important to optimise the development of CO_2 infrastructure. There is a need for standards on CO_2 specifications (composition, pressures, temperatures, etc.), ship design and specifications (e.g. referring to loading and off-loading). As many CCS projects will become operational in the mid-2020s, many new ships for CO_2 transportation will be needed within five years, making these standards urgent and needed.

Going forward, it will be critical for European countries to plan in advance and ratify the amendment to the London Protocol – effectively enabling the transport of CO_2 between two countries.

Areas for further R&I activities are:

- Value chain analyses (full chains, H_2, ammonia and liquid organic H_2 carriers)
- New CCS and CCU chain concepts and transport networks (including hubs, buffers)
- Impact of CO_2 composition and impurities
- Safety assessments and engineering design tools
- Non-pipeline transport of CO_2 (e.g. ships, rail, trucks, etc.)
- Injection of fluctuating CO_2 flows, particularly into low pressure reservoirs
- Improved understanding of thermophysical properties of CO_2 and CO_2 mixtures.

<u>CO_2 storage</u>

Permanent, deep, geological storage of CO_2 is the component that delivers climate change mitigation. For this reason, CO_2 storage should be developed and deployed alongside transport infrastructure. Geological storage resources are unequally distributed across Europe, meaning that not all countries will be able to store their CO_2 within their borders, making CO_2 storage an important cross-border good for collective EU climate mitigation.

A range of priority CO_2 storage appraisal activities should be supported to ensure that the required CO_2 storage resources are provided for CCS deployment, including, inter alia:

- Appraisal of storage regions which would include pre-competitive evaluation of storage options to encourage subsequent commercial project uptake.
- Although the feasibility of CO_2 storage has been established for decades, storage characterisation should include the testing of new formations to assess their feasibility for storage, which may be particularly important in onshore locations and for testing in saline aquifers, including management of produced waters. Enabling onshore CO_2 storage, through demonstration of technical and safe feasibility in test injection projects, which openly addresses the concerns of communities, will allow more rapid and lower-cost CCS deployment.
- Regulatory requirements for monitoring plans, especially following site closure, should be flexible and adaptable to take account of site-specific pressure regimes and containment

processes. For example, storage in pressure-depleted gas fields may not require any post-closure monitoring and therefore may offer lower cost solutions.

- Innovation to reduce costs of CO_2 storage operations, including reducing risks and uncertainties, reducing development and operational costs through e.g. innovative monitoring, drilling and asset management.

R&I activities supporting CO_2 storage appraisal, mapping and development are vital to develop European CO_2 storage capacity, to reduce costs of CO_2 storage and evaluate potential risks associated with storage. Understanding the impacts of growing capture and transport networks on CO_2 storage operations must also be addressed through R&I, including considerations of variable injection rates, pressure responses with multiple injection locations and capture from multiple sources. This would enable stakeholders to understand the nature of risks and the significance of potential impacts. Opportunities to investigate potential synergies with geothermal energy, hydrogen storage and other renewable power should be investigated. Other barriers – such as legal challenges, liabilities related to storage and social acceptance – also need to be explored in R&I activities.

CO_2 utilisation

CCU comprises technologies at different levels of maturity and process complexity. From a technical point of view, a more rapid deployment of CCU technologies will require:

- Further development of novel, durable and cost-effective materials for capture
- Novel catalysts for catalytic conversions, based on abundant raw materials
- Development of integrated capture and conversion systems
- Optimisation of process conditions for increased CO_2 uptake rates
- Metrology protocols and methodologies for accurate measurements of concentrations and quality of CO_2 streams
- Inclusion of CCU pathways in models and scenarios of future energy and industrial systems
- Non-technological assessments such as systematic Life Cycle Analysis, Techno-Economic Assessment studies, and comprehensive social acceptance studies.

When stimulating CCU innovations, there must be a perspective that the costs for these processes can be significantly reduced in the long term, so that these solutions can compete with other production routes. Access to affordable and abundant renewable energy will be crucial for large scale deployment of some CCU pathways (e.g. fuels and chemicals). Development of renewable hydrogen will have to match and synchronise with CCU requirements, since many CCU pathways are reliant on renewable hydrogen.

5.2. Policy/legal

An enabling and supporting policy framework is a necessary factor to ensure cost-efficient industrial decarbonisation, attract further industrial and private investments in CCS and CCU, and raise awareness of the multiple climate benefits of these technologies.

A European approach for development and deployment of CCS and CCU and CO_2 infrastructure is needed, outlining the EU's vision for 2030 and 2050, proposing targets, policies, business models, roles and responsibilities, and taking into account non-EU partners. Such an approach is urgently needed to create predictability for companies and the finance community to invest in CCS, in particular, for breakthrough projects and the scaling of the technology in the next decade. A European CCS and CCU strategy would fit and complement the already published EU strategies for Hydrogen and Energy System Integration, supporting the pathway towards climate neutrality by 2050.

- *Action: the European Commission should propose as soon as possible a European CCS and CCU strategy, setting out the foundation for a European, low-carbon CCS and CCU industry and a vision and objectives to be achieved.*

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 14 EU member states have included the development of R&D activities around CCS in their National Energy and Climate Plans (NECPs), while five have included the development of a CCS strategy and large-scale projects by 2030. CCU was also mentioned in national policy and measures of 12 member states, but with little detail on the concrete measures for deployment.

- *Action: Use the National Energy and Climate Plans (NECPs) and the industrial transition pathways coming out of the EU Industrial Strategy as a basis to draft decarbonisation pathways and highlight the role of CCS and CCU. The sector-specific voluntary roadmaps envisaged under the European Climate Law offer opportunities to create synergies with the transition pathways under the Industrial Strategy.*

Furthermore, some legal challenges 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 and the decision of the London Protocol, countries that wish to participate in a cross-border CO_2 network can now bilaterally agree with each other on the provisional application of the 2009 amendment to Article 6, allowing the export of CO_2 for offshore storage.

- *Action: EU member states should be strongly encouraged to ratify the amendment to article 6 of the London Protocol, therewith effectively simplifying the legal and administrative work associated with export of CO_2 for permanent offshore storage.*

Policy instruments complemented by incentives and subsidy schemes – such as the SDE++ designed by the Dutch government, carbon contracts for difference, or tax credits – will be needed to support the uptake of the emerging CCS and CCU industry. Carbon contracts for difference (CCfD) – as explicated in the revised EU ETS proposal and State Aid Guidelines for Climate, Energy and

Environment (CEEAG) – are essential to support the scale-up and deployment of CCS and CCU technologies. These should include the construction as well as operational phase to ensure abatement costs can be covered until the end of the depreciation period.

Yet, further clarifications on how the CCfD will be designed under the Innovation Fund are needed. It is also critical to understand what the scope of the scheme is and how it will interact with other grant schemes under the Innovation Fund.

- *Action: EU member states should be encouraged to implement complementary policy mechanisms on a national level to support the scale-up and deployment of CCS and CCU technologies.*

CDRs must be certified through thorough carbon accounting. The certification work ongoing at the Commission will be instrumental in setting up a market for CDRs. Coordination with other ongoing initiatives, such as Puro.Earth, CCS+ etc, should be sought while designing a European policy framework to support the uptake of CDRs.

In particular, it must be considered how to incentivise BECCS and negative emissions either through the EU Emissions Trading System (ETS) or separate crediting schemes. Accounting, monitoring, and verification requirements for CDRs should be aligned with existing methodologies, such as the framework for monitoring, reporting and verification of EU ETS emissions.

- *Action: In the upcoming communication on a regulatory framework for carbon dioxide removals, the European Commission should set out clear definitions and a plan to incentivise CDRs, based on robust carbon accounting and full life-cycle analysis.*
- *Action: The capture of biogenic and atmospheric CO_2 should be incentivised.*

Detailed characterisation of storage sites across Europe to define the contingent storage resource and create a portfolio of 'permit-ready' sites that will meet future capture rates (including potential storage for greenhouse gas removal technologies such as BECCS and DACCS) will be necessary. These sites will serve both individual CCS projects, which will provide local solutions, and will enable development of storage hubs for CO_2 capture projects in strategic regions. These storage hubs can be driven by Projects of Common Interest (PCI) but should also support development in new regions. The portfolio of storage sites will include a mix of depleted oil and especially gas fields, and larger, regional saline aquifers.

Owners of hydrocarbon fields should be encouraged to investigate options for storage development as their fields and associated assets near end-of-life. Regulatory authorities can support this assessment and identify priority fields through ranking exercises undertaken via national storage atlases, and eventually the European Storage Atlas.

- *Action: Priority regions for appraisal should be identified, using the proposed online open-access European Storage Atlas as a foundation and establishing recommendations and responsibilities for development.*

Collaboration between countries to develop strategic storage resources, including alignment of policy and regulation, joint appraisal, and development of pilot injection testing, will greatly accelerate CCS. Collaboration should also include knowledge exchange with countries that have already gained experience in developing storage projects, including review of storage permit applications and supporting storage development and operation.

Assessment of long-term and post-closure storage liabilities (technical risk and uncertainty) and the development of technical, regulatory, policy and commercial solutions. Several countries (notably Netherlands, Norway and the UK) have developed policies that enable the sharing and transfer of liabilities between the storage developer and the regulatory authorities. Furthermore, some have also developed policies that would support future liability transfer between countries.

- *Action: The sharing of good practice in these areas should be supported to enable all European regions to benefit from these early developments.*

Current EU policies that need revising

- Trans-European Networks for Energy (TEN-E) regulation – The inclusion of CO_2 storage and all modalities of CO_2 transport is key. Shipping has recently been recognised as vital for the future. Support of PCIs that have applied to be on the 5th PCI list – a record number of 8 PCIs in CO_2 infrastructure – is crucial to deploy and develop the necessary CO_2 infrastructure to ensure large-scale, cost-efficient European decarbonisation. Consistency between the revised TEN-E and other legislation, such as the EU Taxonomy and the EU ETS Directive, is needed.
- EU Emissions Trading System (ETS) regulation – As proposed in the revised EU ETS Directive, all modalities for CO_2 transport should be included under the scope of the EU ETS and the connected Monitoring and Reporting Regulation (MRR) should be updated accordingly. Some applications of CCU, where CO_2 is stored in a manner intended to be permanent, should also be included. For other CCU products, where CO_2 is released again after use (e.g. fuels), the ETS should provide clear guidance that all emissions are accounted for but not double counted. There is a need to keep funding available under the Innovation Fund and ensure support for innovative low-carbon technologies.
- CO_2 should be recognised in the upcoming Hydrogen and Gas market decarbonisation package. The transport of CO_2 should be enabled under the Gas Directive for those companies that wish to operate it, with clear provisions for National Regulatory Authorities and Transmission System Operators. There is also a need for 'capacity building' at local government level in order to be able to provide regulatory guidance for CCS and CCU projects.
- The EU Industrial Strategy can support the transition pathways of energy-intensive industries by stressing the role of CCS and CCU and low-carbon hydrogen for industrial decarbonisation and ensuring coordination with the voluntary sectoral roadmaps that will be developed under the European Climate Law.
- The upcoming final version of the revised Climate, Energy and Environmental Protection (CEEAG) State Aid Guidelines, where multimodal CO_2 transport should be recognised under

the definition of carbon dioxide networks, while any carbon source that can be captured should also be included under the definition of CCS.

- The EU Taxonomy for Sustainable Finance will be a central instrument determining the ease of access to funding for economic activities. When more scientific evidence of climate change mitigation becomes available, technical screening criteria for the inclusion of CCU technologies as sustainable economic activities can be developed, particularly for the environmental objectives of climate mitigation and transition to a circular economy.
- The Renewable Energy Directive will need to allow energy-intensive pathways (e.g. CCU fuels) that are reducing GHG emissions in transport and industry to access additional renewable electricity in a harmonised and non-discriminatory way. EU member states need to provide a framework for the production of additional renewable energy based on the demand in different economic sectors.
- Important projects of Common European Interest (IPCEI) on low CO_2 emissions industries should be realised and support large-scale CCS and CCU projects.

5.3. Making the technologies investable – Funding

The 2020s will be crucial to develop and deploy CCS and CCU technologies, to scale up deployment, and to bring down costs across the entire value chain. Since 2020, the European Union has another tool that will support its pathway towards net zero GHG emissions – the European Taxonomy for Sustainable Activities. This comprehensive list of economic activities aims at helping investors, financial institutions, and companies to identify net zero compliant or enabling economic activities. Most importantly, CCS is recognised among the technologies that enable manufacturing processes and other activities to decarbonise.

The accelerated deployment of CCU technologies will depend on the cost-competitiveness of the production chain compared to the price of the conventional/incumbent product that the CCU product replaces. With renewable energy costs decreasing significantly and continuously throughout the years and the price of CO_2 increasing recently, this cost-competitiveness can be achieved in the future. Support mechanisms that will help to create the initial market for CCU products and funding support for industrial upscaling of pre-commercial scale installations (e.g. Innovation Fund, IPCEI) will be necessary in the following years to kick-off the development before CCU products can earn their market share and prove their emissions reduction potential.

At European Union level, several funding opportunities are available for CCS, CCU, and CO_2 infrastructure, covering different parts of the value chain:

Horizon Europe

- In work programme 2021-22: Calls for proposals on capture, utilisation, storage and CDR, a new area for R&I is Direct Air Capture with CCS
- A call for proposals on transport and infrastructure is expected in work programme 2023-24.

EU ETS Innovation Fund

- With a higher carbon price of approximately €60/tonne, the increasing funding pot of the Innovation Fund is firmly at the core of the EU's funding instruments to support first-of-a-kind, low-carbon technologies and projects. Also, while acknowledging that the Innovation Fund is spread out over a seven-year period, the oversubscription in the initial round shows that the budget and frequency of the calls needs to be increased to realise a wide array of important investments in the next five years. Carbon Contracts for Difference (CCfD) are an important instrument that should also be harmonised within the EU; applications for projects outside the EU should be considered as well, i.e. via the EU state aid guidelines and a guidance paper for EU member states.

Connecting Europe Facilities for Energy

- A source of funding for infrastructure projects connected to energy networks that is open for European Projects of Common Interest.

InvestEU

- Since the Regulation and Investment Guidelines explicitly refer to CCS (although the funding is based on EIB loans).

Other possibilities (although channelled through national programmes or plans)

- The Recovery and Resilience Facility, the European Regional Development Fund, and Cohesion Fund or the Just Transition Fund.

IPCEI on hydrogen technologies and low-CO_2 emission industries

- An instrument of pan-European relevance. As such, it will prove important for showcasing the need for cross-border CO_2 infrastructure and the need for a European CCS and CCU strategy.

National schemes

- Carbon price – Norway
- SDE++ – The Netherlands
- UK contracts for difference
- Germany CO_2WIN and German concept for carbon contracts for difference (https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/eckpunktepapier_klimaschutzvertraege_ccfd_bf.pdf)
- Upcoming Swedish system of reversed auctions for CDR

Promoting the creation of funding ecosystems that combine public funders, private investors and industrial investors should also be prioritised. All these actors are necessary for CCS and CCU technologies to scale up and for them to reach commercial levels to deliver their GHG reduction potential.

Additionally, the EU should set the foundations for a transition towards a climate-neutral economy and incentivise decarbonised industrial products. Introducing public procurement standards and further market-pull mechanisms are examples of how to encourage the uptake of low-carbon products. Coupled with a functional CO_2 price, this should enable the CCS and CCU industry to become self-sustainable in the long-term after the initial support mechanisms that are needed to demonstrate technologies at a large scale in Europe.

Actions

EU member states should prepare plans to deploy CCS, CCU, and CO_2 infrastructure and allocate funding.

- *Action: National funding should complement and be synchronised as much as possible with funding at European Union level. Instruments such as the Recovery and Resilience Facility should be utilised to promote the greener transformation of different economic sectors, thus the inclusion of CCS and CCU in national recovery plans is critical.*

5.4. Social acceptance

As CCS and CCU projects come closer to becoming operational, there is a need for 'capacity building' at the level of local governments in order to be able to provide regulatory guidance for CCS and CCU projects. Activities to improve the knowledge and expertise about CCS and CCU projects should be carried out and be aimed at local and regional officers.

In general, there is limited awareness of the value and benefit of CCS and CCU technologies. In the next decade, it will be important to build a positive message around the climate benefits of CCS and CCU, describing how these technologies work and highlighting how they are relevant to the everyday lives of EU citizens.

It is equally necessary to bring together policymakers at local, regional, national, and EU levels with companies and other societal actors, such as trade unions and environmental NGOs, to engage in a transparent dialogue on the benefits of CCS and CCU projects for communities.

At EU level, the European Commission has a good opportunity to increase the understanding around CCS and CCU with initiatives such as the CCUS Forum, which should continue on a yearly basis. This Forum provides an opportunity to bring together stakeholders from different groups to learn more about CCS and CCU and highlight the challenges that they encounter and the value and benefits that these technologies can bring.

6. Conclusions

The CCUS Roadmap to 2030 is aimed at EU and national policymakers, outlining necessary steps and actions to take to support and underpin the development and deployment of CCS and CCU in the 2020s.

The 2020s will be a critical decade to set Europe on the right track to achieve climate neutrality by 2050. Low-carbon technologies such as CCS and CCU will play a role in decarbonising industry and energy sectors and will offer the possibility to achieve CDRs. It is crucial that CCS and CCU are developed, deployed, and scaled up during this decade to support the EU's decarbonisation trajectory towards net zero GHG emissions by 2050, as well as higher climate targets for 2030 – a net reduction of 55% GHG emissions, compared to 1990 levels.

Urgent action is needed to support CCS and CCU in this decade. European and national policymakers play a critical role in raising awareness and driving the development of CCS and CCU.

An EU strategy for CCS and CCU is a crucial tool for the development and deployment of CCS and CCU, and CO_2 infrastructure, and should outline the EU's vision for 2030 and 2050, proposing targets, policies, business models, allocating responsibilities, and taking into account the synergies and areas for cooperation with non-EU partners.

Several existing EU policies should be updated to enable the needed scale up of CCS and CCU. Funding mechanisms at national and European level are critical to support these technologies.

Annexes (The roadmap will be connected to a set of annexes – a self-standing publication which will include the deliverables of the CCUS SET-Plan work).

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+32 2 791 75 74 impacts9@ccsassociation.org www.ccus-setplan.eu

CONTACT DETAILS

Carbon Capture & Storage Association
Square de Meeus 37
B-1000 Brussels
Belgium

CO_2 Value Europe AISBL
Avenue de Tervueren 188A
B-1150 Brussels
Belgium