CCUS SET-PLAN

Deliverable 3.1

RECOMMENDATIONSON THE STEPS REQUIREDTO DELIVER THE R&I ACTIVITIES 1: DELIVERY OF A WHOLE CHAIN CCS PROJECT OPERATING IN THE POWER SECTOR

APRIL 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 842214

Project's name: IMPACTS9. IMPACTS9 is a Horizon 2020 project (Coordinated and Support Action) funded by the European Commission for 3 years (from 1 May 2019 until 30 April 2022). Its purpose is to accelerate the progress realised within the CCUS SET-Plan and to support delivery of the R&I activities in the CCUS Implementation Plan.

https://www.ccus-setplan.eu/

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Introduction about the SET-Plan, CCUS SET-Plan and the European Green Deal

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. The Implementation Working Group 9 (CCUS SET-Plan) 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.

The CCUS SET-Plan is composed of 11 SET-Plan countries (Czechia, France, Germany, Hungary, Italy, Norway, The Netherlands, Turkey, Spain, Sweden and the UK), industrial stakeholders, non-governmental organisations, and research institutions. The work is chaired by the Netherlands, Norway, and the Zero Emissions Platform.

Reaching climate neutrality by 2050 will require major efforts from all economic sectors and European society. Higher climate goals mean that all low-carbon technologies under the European Commission's SET-Plan will be crucial in contributing to the transition to a climate neutral economy by 2050 and to accelerate knowledge development as well as technology transfer and up-take. CCS and CCU will play an important role in the delivery of climate neutrality by 2050, enabling a cost-efficient trajectory towards a low-carbon economy with EU's climate objectives.

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 CO2, Acorn Sapling, Ervia).

The European Green Deal, Europe's new growth strategy, set the legally binding target of net-zero greenhouse gas emissions by 2050, formally adopted 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).

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Updating the SET-Plan target on large-scale CCS projects

Assessing the target

Following the announcement of the European Green Deal and the new political landscape of climate neutrality by 2050, the CCUS SET-Plan started the process of reporting and assessing the current targets of the Implementation Plan, set in 2016. The majority of the targets had been reached or was well in progress to be achieved by 2030. While the areas where the targets have been formulated remain relevant in the 2030 context, it became clear that an increased EU target of 50-55% greenhouse gas emissions reduction by 2030 calls for immediate and substantial action to scale up CCS technologies within this decade and lay the foundations of CO_2 infrastructure across the EU. To reflect the increased climate ambition of the European Union, the current CCUS targets therefore need to be updated – report on the follow-up on current CCUS SET-Plan Implementation Plan targets.

R&I activities are important for the deployment of CCUS. Building industrial scale CCS and CCU projects will identify many new challenges that can best be solved by undertaking R&I in parallel with large-scale activities, e.g. increasing the technologies' efficiency and bringing down the costs. From the assessment it was clear that target 1, Delivery of a whole chain CCS project operating in the power sector – that was defined based on the closed ROAD project – it was clear that this target would not be reached in its current formulation and will for this reason needed to be updated. It was also clear that regarding both CCS and CCU, the next developments will be brought forward by industrial clusters on a regional level, calling for strong cooperation and coordination within European regions and for a clear and supportive pathway from national and European authorities.

The targets were assessed in 2020, below for target 1:

Description and relevance target 1 – Delivery of a whole chain CCS project operating in the power sector

The need for early deployment of commercial-scale CCS projects is a key priority for Europe. The increasing global commitment towards climate mitigation targets, the Paris Agreement and the IPCC Global Warming of 1.5 °C report, the renewed interest for CCS in Europe, brought about by the European Green Deal, and the target of net-zero GHG emissions by 2050 make CCS projects crucial for the delivery of a clean, flexible and integrated European power sector.

With the European Taxonomy for Sustainable Finance and the European Investment Bank's new climate strategy and Energy Lending Policy, decreasing the Emissions Performance Standard to 250g CO_2/kWh, unabated gas/fossil fuel energy projects will no longer be financed and an alternative for power generation is needed.

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Over the last years, the focus has shifted away from the delivery of whole-chain CCS projects and moved to a structure where capture projects - standalone or clustered - from the power sector or industry are connected to a Europe-wide CO_2 transport and storage infrastructure.

Also, while CCS in the power sector historically has been viewed as a baseload provider, the role of CCS in the power sector has lately evolved towards a means to provide clean, flexible power generation, a well-integrated and readily deployable tool to balance the intermittency of RES sources in the energy system.

Progress

With the withdrawal of the ROAD project, it was clear that this target was not going to be achieved within the 2020 timeframe.

Although there are no commercial scale CCS projects in the power sector, a number of projects are currently under development. Below are some examples:

- Capture of CO_2 at the waste-to-energy plant Fortum Oslo Värme in Oslo.
- Net Zero Teesside Cluster, UK includes plans for CO_2 capture on a new build CCGT (formerly known as the Clean Gas Project – led by OGCI).
- Zero Carbon Humber, UK includes plans for CO_2 capture on biomass power generation at Drax.
- H2M, Netherland, clean hydrogen production in the Netherlands with CO_2 storage in Norway. The hydrogen will be supplied to an existing gas fired power plant which will be converted to use hydrogen as fuel.

Why this progress?

The progress outlined above and the positive developments for CCS in the power sectors, with upcoming commercial CCS projects in the power sector, is an acknowledgement of the great need for CCS to reach the climate targets in certain jurisdictions.

The main reasons behind the failure to meet this target is the lack of support structures for low-carbon firm generation:

- The lack of EU and/or national support schemes that could carry projects in the absence of a functioning price on carbon – a non-delivering EU European Trading System (ETS). As a comparison, the deployment and development of RES was supported with several financing schemes over the years (e.g. the cost of the RES support in Germany, Italy and Spain in 2016 was in the range of 500-600 EUR/ton CO_2 at the same time as the EU ETS price was 5-6 EUR/ton CO_2).
- High political uncertainty.
- Lack of a clear strategy on clean hydrogen. Clean hydrogen production from natural gas reformation and CCS can produce at volume scales of hydrogen, some of which may be used to drive CCGTs and

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provide a flexible energy generation role in a predominantly renewables dominated grid. However there has been a lack of hydrogen strategy at both a national and EU level.

Even though some uncertainties and barriers have been overcome, such as the London Protocol October 2019 resolution on provisional application of cross-border transport of CO_2 for offshore storage, there are still many uncertainties on the timelines for the deployment of CCS and CCU and on the relative role of power CCS, hydrogen and renewable generation in a net-zero energy system at both the member state and EU level.

In addition, when the target was set, the future of coal-fired power plants in those jurisdictions that were developing CCS on power had great uncertainty. The decision to phase out coal (including newer power stations) has cancelled CCS development on coal, but created increased interest in CCS on natural gas, both post combustion and pre-combustion (via clean hydrogen).

Pathway to 2030

The global climate commitment with the Paris Agreement, the IPCC report on Global Warming of 1.5°C and the European Green Deal commitment with the target of net-zero GHG emissions by 2050 set out a clear pathway where commercial-scale CCS is essential.

The European Taxonomy for Sustainable Finance and the EIB's new climate strategy and Energy Lending Policy will also effectively stop further energy projects based on unabated gas/fossil fuel.

The ongoing development, including the five cross-border CO_2 transport and storage infrastructure projects approved as part of the fourth list of projects for common interest, as well as the five proposed CCUS industrial clusters in the UK, make up a good basis for development in light of 2030.

There is an increased interest for CCS in the power sector and especially in combination with biomass (Bio-CCS/BECCS) and waste-to-energy.

In the absence of a functioning carbon price, several conditions regarding policies and funding opportunities at EU and national levels need to be in place for the deployment and development of commercial-scale CCS projects. There should be a full recognition of the value of clean, firm back-up power to support intermittent RES, i.e. accepted technology for capacity support mechanisms, battery funding policies, strategic infrastructure investment, energy storage technologies, etc.

At the European level, key initiatives to follow are:

- European Climate law.
- Strategy for smart sector integration.
- Horizon Europe, Clean Energy Transition Partnership, etc.
- Innovation Fund, connecting Europe Facility, Just Transition Mechanism, etc.
- EUs taxonomy for sustainable finance.

Different National support mechanisms also exist:

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- The UK, Contract for Difference for power CCS– to be confirmed by Government.
- The UK CCUS infrastructure fund (£800m) and explicit support for at least two CCUS clusters to be operational by 2030, including at least one containing power CCS.
- The Norwegian support scheme, CLIMIT.
- The Dutch SDE++ (only for industrial CCS but can cover hydrogen production).
- Etc.

The KPI for 2030 on 10 commercial scale CCS projects in the power sector will also have to be updated.

Is the target valid?

The timeline for the target needs to be updated but the target itself – on early deployment of commercial scale CCS projects – is definitely valid and remains a key priority for Europe. It has been further strengthened by the European Green Deal and the European Climate Law.

DEVELOPMENT OF CCS AND CCU IN EUROPE:
CCS IN THE POWER SECTOR – TARGET 1

Delivery of a whole chain CCS project operating in the power sector

Relevance and validity: Very relevant, very valid, needs update and new timeline

- Early deployment of commercial-scale CCS projects is a key priority – CCS is crucial for the European Green Deal, to reach net-zero GHG emissions by 2050 – Sustainable Taxonomy and the EIB's new climate strategy and Energy Lending Policy
- With increasing intermittent RES, CCS in the power sector will also take on a clean balancing role

Progress: Target is not achieved within the set 2020 timeframe – although positive development:

- Fortum Oslo Värme waste-to-energy plant - Norway, Ervia Cork CCUS Project - Ireland, Net Zero Teesside Cluster and Zero Carbon Humber – UK, H2M – Netherland
- Focus has shifted from whole value chain CCS projects to separate/clustered capture projects, connected to a separate widespread CO2 transport and storage infrastructure

Why this progress: (1) Lack of EU/national support schemes that could carry projects in the absence of a functioning carbon price, (2) High political uncertainty, (3) Lack of a clear strategy on clean hydrogen

Pathway to 2030: (1) Functioning carbon price, (2) Fully recognising the value of clean firm back-up power to support intermittent RES, (3) Need to update target for 2030

Updating the target

Lacking updates from the European Commission on reference scenarios where climate-neutrality by 2050 is included, the updated CCUS SET-Plan Implementation plan targets were based on the current list of European market-ready CCUS, providing an indication of the number of projects and possible amount of CO_2 emission reduction that can be delivered in the timeframe to 2030. The updated estimation of CO_2 captured by CCS in 2030 was set to 50 Mtpa, compared to the previous estimation of 15 Mtpa in the original CCUS Set-Plan Implementation Plan. When discussing the update with the CCUS community, it was highlighted that this

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target for 2030 may seem ambitious based on current position but given the strongly increased ambitions on emissions reductions targets for 2050 and 2030, this volume will most probably turn out to be an underestimation of the volume required.

The original target 1: Delivery of a whole chain CCS project operating in the power sector

The updated target: Delivery of 10 CCS projects for clean, flexible power and heat generation, complementary to renewable energy generation.

In the discussions with the CCUS community regarding the updated target, the following was highlighted:

- This target focuses on the application of commercial-scale CCS in power and heat (including power, CHP, Waste-to-Energy plants) to deliver a clean, flexible and integrated energy system, supporting renewables in the intermittency challenge, linking directly to the EU Energy system integration.
- Integration in regional CO_2 transport infrastructure, connecting to storage, is the main path *but there will also be whole chain projects*.
- Should there be a specific target on negative emissions?
- Early delivery of whole value chain CCS project is an absolute priority. The ambition needs to be increased, aiming for 2030.
- Based on the strong political direction towards climate-neutrality – the European Green Deal, including a number of policy developments such as the proposed climate law and Sustainable Taxonomy – CCS is necessary to reach net-zero by 2050.
- CCS in the power sector has historically been viewed as a baseload provider, the European Green Deal targets and the strong increase in intermittent RES makes a clean balancing role a priority for CCS in power.
- Areas to highlight stronger here are also the role CCS can play in decarbonising other, harder to reach sectors, including heating and heavy goods transport via hydrogen and carbon-negative technologies via carbon dioxide removals (CDR), especially BECCS and possibly DACS, included in section 3 below.
- Economies of scale can be achieved to reduce costs and increase rates of penetration where CCS is integrated into regional infrastructure, but it is also recognised that 'point-to-point' projects may be necessary too.

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Status and progress

Background

The past couple of years have seen strong momentum for CCS and CCU in Europe. Globally, the project pipeline – projects in development and construction – reached the capacity of 111 Mtpa in 2021, on top of around 40 Mtpa already provided by operational projects (Global Status Report - Global CCS Institute).

The need for early deployment of commercial-scale CCS projects is a key priority for Europe. The increasing global commitment towards climate mitigation targets, the Paris Agreement, and the IPCC Global Warming of 1.5 °C report, the renewed interest for CCS in Europe, brought about by the European Green Deal, and the target of net-zero GHG emissions by 2050, make CCS projects crucial for the delivery of a clean, flexible, and integrated European power sector.

Over the last years, the focus has shifted away from the delivery of coal fired power whole-chain CCS projects and moved to a structure where capture projects – standalone or clustered – from the power sector or industry are connected to a Europe-wide CO_2 transport and storage infrastructure. Also, while CCS in the power sector historically has been viewed as a baseload provider, the role of CCS in the power sector has lately evolved towards a means to provide clean, flexible power generation, a well-integrated and readily deployable tool to balance the intermittency of RES in the energy system.

The difficulties experienced in the 2010s – lack of support schemes, high political uncertainty, and lack of hydrogen strategy – and the barriers and uncertainties still to be managed, are described in the previous chapter.

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.

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. 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, hydrogen manufacturing, and other industrial processes. The CO_2 is separated from the process emissions by chemical or physical processes, e.g. 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.

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Today's carbon capture technologies are typically designed to capture up to 95% of the CO_2 emissions, however it is technically feasible to achieve capture rates >95% with 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 and deployed 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.

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.

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

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will be a vital component of future climate and energy systems to address residual emissions from other parts of the economy.

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Strengthened focus on CCS in power – inclusion of natural gas in the Taxonomy CDA

The European Commission has approved the Complementary Climate Delegated Act of the EU Taxonomy (CDA), including nuclear power and natural gas as sustainable activities. Approval or rejection by the Council and European Parliament are still to come during the first half of 2022, and there has been criticism expressed by the Member States Expert Group and the Platform on Sustainable Finance, in the context of the expert consultation, ahead of the Commission's approval.

The inclusion of natural gas in the CDA will strengthen the role of CCS for 'Electricity generation from fossil gaseous fuels' and 'High-efficiency co-generation of heat/cool and power from fossil gaseous fuels'. The CDA mentions that both activities are defined as "transitional as referred to in Article 10(2) of Regulation (EU) 2020/852"; and abatement for facilities is mentioned "including carbon capture or use of renewable or low-carbon gases".

Any pathway to climate neutrality by 2050 in Europe will require deep electrification of our economy, with strongly increasing volumes of renewable energy sources. The increase in renewables calls for better understanding of energy system integration, and base load versus flexible power: The higher the share of electricity from RES, which are mainly wind and solar PV, the higher the need for flexible power generation to stabilise the electrical grid and ensure reliable power supply. This is also further intensified by REPowerEU as Europe diversifies its gas supplies and enhances its renewable energy production capabilities.

Target 2 of the CCUS SET-Plan Implementation Plan identifies CCS for clean, flexible power and heat generation (including waste-to-energy plants) – complementary to increased renewable energy generation in the energy mix – as a key milestone for successful deployment of CCS.

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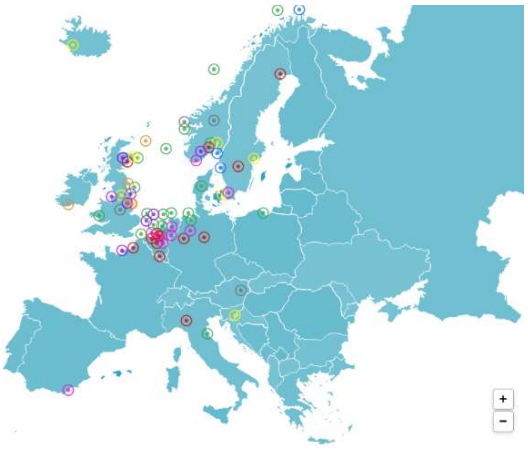
European carbon capture projects

There are over 50 market-ready projects (projects that will become operational before 2030, given the right policy and funding frameworks) across Europe – covering the whole CCUS value chain, including also low-carbon hydrogen and carbon dioxide removal. The full list of projects on the Zero Emissions Platform website.



To reach net-zero GHG emissions by 2050, CCS technologies will be an important tool to enable climate change mitigation at sufficient scales. Several projects are particularly promising, currently at different stages of development, as outlined below with a special focus on energy generation:

- **In Sweden**, Stockholm Exergi is building a full-scale BECCS facility with support from the Innovation Fund. The facility has potential to remove around 0.7 million tonnes of CO_2 over the first ten years of operation. On the Swedish western coast, a further CCS pilot is taking place on the Preem Refinery. This project aims to CO_2 capture from the local hydrogen production facility in Lysekil, leveraging storage options provided by the Norwegian CO_2 storage sites nearby. It thus aims to capture and store 0.5 million tonnes of CO_2 by 2025.
- **In Italy**, Eni is leading the development of a CO_2 hub in the Ravenna area. The project aims to capture CO_2 from combined-cycle gas turbine power plants located in Ravenna, Mantua, and Ferrara. Storage opportunities are provided by offshore depleted gas reservoirs in the Adriatic, off the Ravenna coast, where estimated storage capacity reaches 500 million tonnes of CO_2.
- **In Denmark**, a pilot project has started to remove CO_2 from the emissions of the incinerator at the Amager Bakke waste-to-energy Plant – one of the largest in northern Europe. As the pilot succeeds, and should the right regulatory framework be provided by competent authorities, the project will move on to developing a plant capable of capturing 0.5 million tonnes of CO_2 per year. Moreover, in Copenhagen, a carbon capture cluster is being developed with the potential to reduce around 3 million tonnes of CO_2 from connected utilities companies. More than half of these reductions will come from BECCS.
- **In Belgium,** ENGIE and Equinor announced plans to develop low-carbon hydrogen projects in the region. The first of which, called H2BE, consists in the production of low-carbon hydrogen from natural gas in Belgium. The project will employ autothermal reforming combined with CCS, enabling capture rates above 95% at competitive costs. In Antwerp, work is also ongoing to develop carbon capture infrastructure to decarbonise the energy and chemicals companies located in the port area,

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leveraging storage opportunities in the North Sea (link). For that project to work, bold support for CO_2 transport infrastructure will be crucial.

- **In the Netherlands**, many projects are ongoing, especially in the Rotterdam area. H-vision aims for a large-scale production of blue hydrogen that will allow the local industry to substantially reduce emissions. The Hydrogen 2 Magnum (H2M) project is also working on a clean hydrogen value chain, with the potential to reduce CO_2 emissions by 2 million tonnes per year from 2024. Similarly, other assessment studies are being conducted to produce blue hydrogen in the country, with companies such as Air Liquide, ExxonMobil, and Shell moving towards start of operations by 2024. All of these activities are underpinned by the fast deployment of CO_2 transport and storage projects, e.g., Porthos and Aramis, and projects being developed in the Dutch North Sea.
- **In Norway**, several projects are being deployed as the country positions itself to become a forerunner of European CCS. In the Oslo area, a waste-to-energy CCS project led by Hafslund Eco and other partners is underway, aiming to capture 0.4 million tonnes of CO_2 per year. Europe's first large-scale carbon-neutral ammonia plant is also under development in northern Norway, led by Horisont Energi, harnessing significant carbon storage capacity available off the Finnmark coast. Today Norway is a European leader in CCS development and deployment, as attested by the Longship project – the world's first full-fledged CO_2 infrastructure, connecting captured emissions from industry and power plants to safe storage in the North Sea.
- **In the UK**, CCUS clusters are under development at a fast pace. These clusters aim to connect emission hubs to safe offshore storage, while offering opportunities for energy integration, sharing of common infrastructure, and risk reduction for each cluster partner. Several companies joined the development of these clusters, with several projects harnessing the potential of the CO_2 infrastructure. Examples are listed below:

  East Coast Cluster unites cluster projects from both Teesside and Humber as well as the Northern Endurance Partnership (BP, Equinor, National Grid, Shell, and Total). We count 6 CCS for power projects and 4 hydrogen projects:

  - Net Zero Teesside
    - NZT Power aims to develop a gas turbine combined cycle gas turbine plant with CCS, generating 860MW of low carbon electricity.
    - Alfanar Teesside is developing a CCGT plant.
    - Whitetail Clean Energy, aiming to generate up to 350MW of clean power.
    - Capture 90% of CO_2 emissions from waste to energy facilities at Haverton Hill in Teesside.
    - bpH2Teesside aims to produce 1GW of blue hydrogen by 2027.
  - Zero Carbon Humber

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- Keadby 3, delivering up to 910MW of low-carbon power with CCUS.
- Drax plans to retrofit CO_2 capture on the four units at Europe's largest biomass power plant (2.6GW)
- Hydrogen to Humber (H2H) Saltend, providing 1.8GW hydrogen to local industry.
- C.GEN Killingholme power plant to be retrofitted with CCS.

- V Net Zero Cluster (formerly Humber Zero)
  - VPI Immingham plans to retrofit carbon capture on their 1.2GW CHP at their refinery as well as producing hydrogen.
- Acorn Project
  - Acorn Hydrogen aims to be online by 2025.
  - The project also includes a new 900MW gas CCGT with CCUS at Peterhead in Scotland.
- South Wales Industrial Cluster
  - Power CCS and hydrogen CCGT opportunities are being explored as part of the South Wales cluster.
- HyNet
  - Viridor plans to retrofit carbon capture on their EfW facility at their Runcorn site.
  - Bioenergy Infrastructure Group (BIG) is looking to test carbon capture technology at 22MW biomass plant in Ince.
  - InterGen and HyNet plan to retrofit a 800MW gas CCGT to blended hydrogen power at the Rocksavage plant, Runcorn with hydrogen supplied by the HyNet project.

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Key barriers and enablers

Two CCUS SET-Plan reports – 'Key enablers and hurdles impacting CCUS deployment with an assessment of current activities to address these issues', and 'Recommendations developed on the Work Programme required to address the identified enabler or hurdle to the development of CCUS' – are looking into enablers and hurdles facing the efficient deployment of CCS and CCU technologies. The reports identify the current enablers and hurdles to address and recommendations on how to use the enablers and avoid the hurdles in order to develop CCS and CCU in Europe, based on four categories: Technical, Policy and regulatory, Funding, and Social acceptance. This latest report highlight clear recommendations applicable for 'whole chain CCS project operating in the power sector'.

It is not possible to mention enablers and hurdles for CCS projects without highlighting the crucial need for CO_2 transport and storage infrastructure. European, open-access cross-border CO_2 infrastructure – including transport by pipeline ship, truck, and barge – is a no regret investment that will enable clean and competitive industry and energy sectors, early large-scale clean hydrogen, and carbon dioxide removal, connecting emitters across Europe to safe storage of CO_2, preserving industrial activity and jobs while creating new ones.

In order to reach climate neutrality by 2050, Europe also needs carbon dioxide removal (CDR), why clear incentives are needed regarding both development and deployment. The EC Communication on restoring Sustainable Carbon Cycles is laying a good basis for this development, preparing a regulatory framework for certification of CDR. However, there is also great need for methodologies to calculate the climate benefit from different projects. The EC has declared that this will not be a part of their proposal that is expected at the end of 2022, why the market will have to rely on private initiatives regarding these methodologies. The EC is also planning to include calls for proposals on CDR in the Horizon Europe work programme for 2023-24, and there is a mission on CDR in the current Mission Innovation.

There is an increased interest for CCS in the power sector and especially in combination with biomass (Bio-CCS/BECCS) and waste-to-energy. Full recognition of the value of clean, firm back-up power to support intermittent RES is therefore needed. Apart from support for CCS for clean flexibility (CCS will be crucial to enable the integration and balancing of renewable electricity), also accepted technology for capacity support mechanisms, battery funding policies, strategic infrastructure investment, energy storage technologies, etc.

There is also a controversy around the use of biomass for power generation. The European Taxonomy for Sustainable Finance includes a section on biomass for electricity generation, which will be updated in light of the revised REDII proposal. However, there is still unclarity regarding the sustainability of biomass. Providing a solid policy framework based on thorough carbon accounting is needed. Noting that the interest in bioenergy combined with CCS – CDR/actively removing CO_2 from the atmosphere – is increasing in Europe, paving the way for large-scale volumes of CDR, there is a need to further study and clarify what defines sustainable biomass.

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It is crucial that the EC proposes an EU strategy for CCS and CCU, setting out the foundation for a European, low-carbon CCS and CCU industry and a vision and objectives to be achieved.

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Investability/funding

Achieving climate neutrality is a monumental political, economic, and technological mission. All low- and zero carbon technologies are needed to reach this target. All reliable modelling scenarios, including those from the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency, consider the deployment of carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies as critical to reach climate neutrality by 2050. During this decade, it is thus crucial to put in place enabling policy/regulatory and funding frameworks for the large-scale deployment of CCS and CCU technologies, making the technologies investable.

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 deployment and scale-up.

Coordinated and coherent funding instruments and programmes on EU and Member State level is crucial for Europe to reach its climate targets. To help achieve its climate goals, the EU is trying to integrate climate action across the entire EU budget (EU budget 2021-2027), and there are several international and interregional partnerships cutting across both of these levels. The CCUS SET-Plan report 'Opportunities for joint programming of R&I funding for CCUS' outlines the main funding options available in Europe today. The most important opportunities are highlighted below.

At the EU level:

- *Horizon Europe* benefits from a €95 billion budget and its work programme for 2023 and 2024 includes calls for CCS and CCU, system integration in hubs and clusters and CDR.
- The *Innovation Fund* is one of the largest funding support schemes funded by credits from the EU Emissions Trading System (EU ETS) in Europe for pre-commercial projects in the areas of renewable energy, energy efficiency, energy storage, CCS and CCU.
- *Connecting Europe Facility* (CEF) is another key EU funding mechanism. As many important CO_2 infrastructure projects have gained the status of European Projects of Common Interest (PCI), funding is now available under the CEF for Energy.

At the partnership level, funding options are varied, among which:

- *ERA-NET Accelerating CCS Technologies* (ACT) has proven a main pillar for joint public funding of CCUS R&I in Europe and globally. With an ever-growing number of partners countries and members, funds have successfully been allocated to CCUS projects in Europe and beyond.
- *Clean Energy Transition Partnership* (CETP) under the Horizon Europe, which aims to empower the energy transition and contribute from a R&I perspective to the EU goal of becoming climate-neutral by 2050. With robust investment in innovation and technology development, the CETP will pool

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national and regional resources/funding programmes, thus overcoming a fragmented approach. CCS and CCU are among the areas described in the Strategic Research and Innovation Agenda (SRIA).

At the Member State level there is increasing ambition with subsidy schemes being rolled out:

- In the Netherlands, the *Stimulation of Sustainable Energy Production and Climate Transition* (SDE++) subsidy scheme is intended for companies and organisations that produce sustainable energy or apply CO_2-reducing techniques. In 2021 a budget of €5 billion was available. This was raised to €12 billion in 2022.
- In the UK, several provisions exist under the Government's Ten-Point Plan:
    - CCUS Infrastructure Fund (£1bn) to support the deployment of at least two CCUS clusters to be operational by the mid-2020s; Contract for Difference (CfD) for power CCS, known as the Dispatchable Power Agreement – designed for flexible power plants to dispatch energy, enabling renewable electricity; and Industrial Carbon Capture (ICC) business model, CfD covering industrial emitters. Recently the ICC model was announced to cover combined heat and power (CHP) and energy for waste facilities as well as traditional industrial emitters.
- In Norway, €16 million was allocated for funding of R&I of CCS in 2022 under the *CLIMIT* programme. This budget is administrated by Gassnova and the Research Council of Norway, refreshed yearly. The programme can support all aspects of CCS, and current priorities are:
    - Clear emphasis on realisation of gains of Longship
    - A new focus area is the decarbonisation of industrial and energy resources
    - Hydrogen production, combined with CCS is a top priority
    - Increased focus on direct air capture and bioenergy combined with CCS
    - A clearer position of social scientific research
- In Sweden, the government has decided to provide subsidies for investments in bio-CCS, in reverse auctions. The first auction will take place at the end of 2022.

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