September 2020

DRAFT – CETP-SRIA Input Paper Thematic Cluster: Enabling technologies

Challenges 6 - Carbon Capture Utilisation & Storage

Contents

This Living Document describes ONE technology specific GROUP of challenges in **Chapter 3 of the CETP Input paper**. At the end of the process they will all be combined into ONE Input Paper for Cluster 1&2. **Please note that this is work in progress. For information or additions, please contact the co-authors.**

1 Introduction

In 2019, the European Commission presented the European Union's new growth strategy – the European Green Deal, setting the target of reaching climate neutrality by 2050 within the European Union. Instrumental to the achievement of this objective are Carbon Capture, Storage (CCS) and Carbon Capture and Utilisation (CCU) technologies.

CCS and CCU technologies will ensure deep decarbonisation of European industrial and energy sectors, enabling Europe to reach climate neutrality by 2050 in a cost-efficient way. When applied to industrial processes and power plants, CCS and CCU can preserve and decarbonise existing energy-intensive value chains, which lie at the very core of the European economy and provide products that are the basis for our lifestyle. By preserving and also diversifying these value chains, CCS and CCU can help create and safeguard jobs and industrial activity and maintaining European industrial competitiveness in international markets, allowing European Industry to excel. This becomes even more important now as Europe deals with the aftermath of the COVID-19 health and economic crisis.

CCS technologies have been in operations since the 1980s, are scientifically-proven and environmentally safe, and their mitigation potential is understood and acknowledged. Commercial CCS projects have captured and stored more than 260 million tonnes of CO_2 emissions from human activity over 40 years, with an estimated 40 million tonnes of CO_2 captured and stored per year today[1]. In Europe, the Sleipner and Snøhvit CCS facilities are currently operating in the North Sea area, and they are expected to be joined in the 2020s by other CCS projects connecting from the Netherlands, Ireland, Belgium and the United Kingdom.

CCU technologies present different levels of maturity, depending on the final product. Life Cycle Assessments and further scientific evidence describing their climate mitigation potential will be needed to make a case for these technologies. In some cases, CCU applications have a limited potential for CO2 abatement at scale, yet they could provide a valuable means of incentivising investment in enhanced CO_2 capture technology in the short term.

CO_2 transport and storage infrastructure will enable Europe-wide clean, competitive and flexible energy and industrial sectors, early large-scale volumes of clean hydrogen, and negative emissions/Carbon Dioxide Removals (CDR) to balance residual, non-avoidable emissions.

The CCS and CCU technologies' potential for carbon emissions abatement and removal is scientifically proven and acknowledged by the Intergovernmental Panel on Climate Change (IPCC)[2] and the European Commission's Clean Planet for All reference scenarios.

[1] Global CCS Institute, 2019 Global Status of CCS, 2019

[2] IPCC Special Report on the impacts of global warming of 1.5°C

In order to create the best opportunities for Europe to cost-efficiently reach climate-neutrality by 2050, during the next ten years there is a need to support early deployment of, and establish the foundation for, CCS and CCU to become investible technologies in order to scale up and support the EU transition – enable and support a just transition for European industry – preserving jobs, economic growth and diversifying supply chains into new industries – and thus develop Europe as a global leader in the clean, competitive industries of the future.

CCS and CCU technologies have the potential to play a key role to succeed in the transition, and R&I activities are crucial. 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: an iterative process is needed where R&I projects address specific challenges, with the results then implemented in large-scale projects.

2 Technology Status

CCS technologies involve capturing CO_2 produced by large industrial and energy (electricity and thermal energy) plants, transporting the CO_2 and storing it permanently deep within rock formations. For CCU technologies, instead of storing, 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.

There are 20 full-scale CCS projects operating globally today with 31 in various stages of construction and development. In 2019, the operational projects injected more than 25 million tonnes of CO2[3]. When fully operational all the current proposed facilities will be able to capture and store at least 100 million tonnes of CO_2 per year. 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.

Carbon capture technologies can be applied to a variety of carbon dioxide emitting processes, where the CO_2 is separated from process emissions by physical and chemical processes.

- Power generation, industrial processes (ammonia, iron and steel, cement, chemicals, ceramics, glass, petrochemical, fertiliser, natural gas etc.), low-carbon hydrogen manufacturing, net removal and permanent storage of CO_2 from the atmosphere / carbon direct removal (Bioenergy + CCS, Waste-to-Energy + CCS, Direct Air Capture + CCS, etc.).

Transport of CO_2 is primarily done by pipeline, but other modes of transport are also used, like ship, rail or road transport. There are over 5,000 kilometres of underground pipelines in North America, which have been successfully transporting CO_2 for more than 30 years over long

[3] Global CCS Institute, 2019 Global Status of CCS, 2019

distances[4]. The development of shared CO_2 transport infrastructure to connect industrial emission '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 deployment of CCUS to small emitters (less than 0.5 million tonnes of CO_2 per year) and to stranded emitters for which direct connection to pipeline transportation network infrastructure may not be feasible[5].

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 key 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.

Utilisation is the process of using CO_2 in industrial processes or products (CCU). The most common form of CCU is Enhanced Oil Recovery (EOR); a process where CO_2 is injected into oil fields to increase the recovery fraction of oilfields. Such fields have been operating in Texas, USA since 1972. CCU technologies are more interesting to be used for a variety of other products, including building materials, synthetic fuel, chemicals, plastics, and for horticulture. To determine the climate benefits of each CCU application, full lifecycle analyses (LCA) are required and in some areas are becoming available.

CCS and CCU technologies are mature and have been operational for several decades at pilot, demonstration and industrial site scale. CCS is ready to be deployed at industry-wide scale, using shared CO2 infrastructure networks to permanently store CO2 emissions from power generation, industrial processes and low-carbon hydrogen production. CCS also enables the capture and net removal of CO2 from the atmosphere at scale. CCU technologies can be used in many new-products or industrial processes and will require full life cycle analyses to determine their climate mitigation potential. The CCU industry is young and LCAs are becoming available in some areas.

3 Ongoing Research

Europe is an established global leader in CCS and CCU R&I activities. R&I is delivered by a broad range of organisations including industry, independent research organisations and universities. Key funders for European CCS and CCU R&I include ERANET-ACT, Horizon 2020, Mission Innovation and National Programs.

The 2018 Low-Carbon Energy Observatory CCUS Technology Development Report provides a useful review of projects funded by Framework Programs and Horizon 2020, illustrating the value delivered by connected projects that have progressed knowledge and delivered

[4] Global CCS Institute, 2019 Global Status of CCS, 2019

[5] ZEP, A Trans-European CO2 Transportation Infrastructure for CCUS: Opportunities & Challenges, 2020

innovation thanks to sustained support over several years. These projects have been complemented by National Programs in many of the European Countries that are most interested in the development and deployment of CCS and CCU.

Current technical activities in CCS and CCU R&I consider Capture, Transport, Storage and Utilisation. Non-technical R&D – considering aspects such as economics/incentives, legal issues and public perception – also make important contributions. As CCS and CCU concepts move through the TRLs, there is typically excellent collaboration between research organisations and industry to ensure that 'blue skies' research is developed into technology that can be deployed effectively.

Today's CCS and CCU R&I include significant activities to use "building blocks" from both technical and non-technical research to develop effective and flexible low carbon energy systems (e.g. through level supporting the development of Carbon Neutral Clusters). Several projects and programmes are also exploring and developing key links between CCS/CCU and other important parts of low carbon energy systems (e.g. hydrogen and biomass).

4 Technical potential

CCS and CCU are key technologies in the decarbonised future of the planet. CCS and CCU projects can capture emissions from many industrial processes, for which few alternative decarbonisation technologies exist, such as industrial emissions (cement, steel, refineries, fertiliser), flexible power generation in support of greater renewable penetration and fast ramp-up of cost-effective low-carbon hydrogen production. CCS and CCU are also amongst the few technologies that can remove CO_2 that has already been emitted to the atmosphere.

The deployment of industrial scale CCS and CCU projects will enable the technology to be applied to many different applications, which in turn will accelerate innovation and improve technological efficiencies.

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 (<3%) efficiency and financial penalties compared to a capture facility capturing at 90%. Capture rates above 99% are possible, and as technologies develop through continued R&I and deployment, capture technology efficiencies are expected to improve[6].

Net 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. Net removal may also be achieved by utilising

[6] IEAGHG, Further Assessment of Emerging CO2 Capture Technologies for the Power Sector and their Potential to Reduce Costs, 2019

captured CO_2 from biomass or DAC and permanently storing it through mineralisation (e.g. building materials). Many climate models have predicted that the net removal of CO_2 from the atmosphere will be a vital component of future climate and energy systems to address residual emissions from other parts of the economy.

The deployment of CCS and CCU technologies at industrial scale will accelerate innovation and technological development. Capture rates have scope for improvement reaching close to 99% for some processes. CO_2 removal from the atmosphere using DAC and BECCS technologies will be key to enable the net CO_2 removal required in the net zero energy and climate systems of the future.

5 Socio-economic potential

CCS technologies offers one of the lowest cost routes to transform and decarbonise energy intensive industry and power generation towards climate neutrality. A well-developed CCS industry could reduce the global cost of the energy transition by USD 4 trillion[7].

CCS and CCU are vital technologies to safeguard many thousands of jobs in hard to abate industries in the energy transition. Additionally, CCS will require skills currently employed in the oil and gas sector, such as working in the subsurface, handling high pressure fluids and managing large-scale projects.

Shared CO_2 transport and storage infrastructure will attract clean sustainable investments for industry activities, energy applications, carbon dioxide removal and the hydrogen economy. Access to sufficient volumes of blue hydrogen will attract industrial investments and pave the way for the development of green hydrogen.

CCS is crucial to the development of the hydrogen economy as the transport and storage infrastructure supports the development of blue hydrogen, thereby securing timely availability of large-scale volumes of clean hydrogen, nationally and globally. The hydrogen economy will not only reduce carbon emissions but can also build a potential global market worth up to USD 2.5 trillion per year in 2050[8].

CCS and CCU are key technologies as part of a cost-efficient energy-transition. Large scale demonstrators together with further R&I will decrease the cost of abatement and accelerate the growth of decarbonised product markets.

6 Challenges and ways forward

In order to create the best opportunities for Europe to cost-efficiently reach climate-neutrality by 2050, during the next ten years there is a need to support early deployment of, and establish

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[7] Global Energy Transformation – Irena 2018

[8] Hydrogen Council Roadmap

the foundation for, CCS and CCU to become investible technologies in order to scale up and support the EU transition – enable and support a just transition for European industry – preserving jobs, economic growth and diversifying supply chains into new industries – and thus develop Europe as a global leader in the clean, competitive industries of the future.

Specific challenges for CCS and CCU for the coming years to make this possible:

- Getting the commercial framework right
- Accelerating timely deployment at scale of CCS and CCU technologies
- Driving costs down – through R&I, learning by doing and economies of scale
- Enabling rapid scale-up to deliver on the climate goals
- Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring.

Challenge 1 - Getting the commercial framework right

Making CCS and CCU investable technologies for industry and energy stakeholders requires an appropriate legal framework that provides long-term predictability for private investments and a reliable business model. The standardisation and regulatory issues, such as incentives for innovative technologies and the harmonisation on reporting mechanisms, coupled with support for capital expenditure and operational costs, will be crucial for the development of CCS, CCU technologies in Europe. Other barriers – such as legal challenges, liabilities related to storage and social acceptance, etc. – also need to be explored in R&I activities.

These challenges are further articulated in 6.3.6, 6.3.7 below.

Challenge 2 - Accelerating timely deployment at scale of CCS and CCU technologies

Early deployment of industrial-scale CCS and CCU projects as well as accelerated development of European cross-border CO_2 transport and storage infrastructure is vital to connect CO_2 emitters and capturers in "remote" clusters with CO_2 storage sites, collecting CO_2 from various sources with variable composition Europe-wide.

R&I activities supporting the mapping of CO_2 sources and investing in CO_2 storage appraisal, mapping and development are vital to develop European CO2 storage capacity, to reduce costs of CO_2 storage and evaluate risks associated with storage.

These challenges are further articulated in 6.1, 6.2, 6.3.4, 6.3.5 below.

Challenge 3 - Driving costs down – through R&I, learning by doing and economies of scale

To ensure the development of industrial-scale CCS and CCU by 2030, R&I activities to reduce cost of current CCS/CCU technologies (both CAPEX and OPEX) are essential. R&I activities are also vital to support new, innovative technologies for CO_2 capture with higher capture rates at industrial sites and power plants, including Direct Air Capture. The role of CCS and CCU technologies are crucial and must be considered when assessing the potential for clean/low-carbon hydrogen production, carbon dioxide removals (upon a thorough carbon accounting and LCA) and for clean flexible power generation.

6.1, 6.3.1, 6.3.2, 6.3.3 provide areas for further R&I on CCS and CCU technologies.

Challenge 4 - Enabling rapid scale-up to deliver on the climate goals.

For Europe to lead on clean, competitive industrial and energy sectors, it is crucial to undertake R&I activities in parallel with large-scale activities as iterative processes. Combining existing datasets with specific analyses of industrial areas or plants, supported by the use of artificial intelligence, is recommended. Priority research topics best addressed through R&I range from CO_2 capture at industrial and power plants, to CCU technologies, CO_2 storage and regulatory issues.

The R&I activities associated with this challenge are further detailed under point 6.3 below.

Challenge 5 - Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring

It is crucial to bring all societal actors on board and to showcase the benefits of CCS and CCU technologies not only for the European society as a whole but also for the European citizen in day-to-day life – e.g. domestic heating, cooking and transport/travel. Social sciences, humanities and AI can help engage EU citizens in a positive dialogue around the need for technological solutions to fight climate change and a narrative that focuses on the most advantageous consumers' choices. Developing public awareness, creating confidence in these technologies is vital.

R&I topics associated with this challenge are listed under 6.3.7 below.

6.1 Development of industrial-scale CCS and CCU

The early deployment of industrial-scale CCS and CCU projects remains a key priority for Europe. The level of deployment by key milestones, e.g. 2030, must be consistent with reaching net-zero GHG emissions by 2050. Europe should enable widespread application of CCS and CCU for all industrial sectors.

- Industry: Adaptation of current capture methods to new areas as well as development and deployment of higher TRL capture
- CCU technologies at commercial scale to achieve carbon circularity
- The role of CCS in enabling clean hydrogen, including the role of blue hydrogen as bridging technology for the introduction of green hydrogen
- The role, feasibility and scale of Carbon Dioxide Removals (negative emissions)
- Flexible Power Generation, developing low-carbon power generation facilities to support the deployment of increasing renewable power.

6.2 Development of European CO_2 infrastructure

The development of European CO_2 transport and storage infrastructure, including regional CCS and CCU clusters, enabling cross-border cooperation across all European regions is crucial for the possibility to reach climate neutrality by 2050. CO_2 infrastructure is deployable today and already operational in Europe, although challenges remain, which is why further R&I is needed. Recommended focus areas are:

Projects of Common Interest (PCI)

Economic instruments that can support the deployment of CO_2 infrastructure are critical. The TEN-E Regulation/ CEF/ Projects of Common Interest (PCI) remain very important tool and should be updated:

- The full range of transport modality options, e.g. barge, ship and rail, should be utilised.
- CO_2 storage infrastructure should be included.
- PCIs should be extended to also connecting member states without North Sea coastline to ensure that all European regions with potential can plan CCS and CCU infrastructure – the number of PCIs should be consistent with the development of the CO_2 infrastructure.

Reviews of infrastructure re-use (pipelines, wells, platforms from hydrocarbon industry) for transport and storage should identify those assets of strategic importance to PCIs and wider member state plans for CCS.

European CO_2 storage assets

A Europe-wide storage atlas will strongly support the strategic planning of activities to develop CCS.

A European CO_2 storage development programme

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. This should include:

- Appraisal of storage regions which would include pre-competitive evaluation of storage options to encourage subsequent commercial project uptake.
- Detailed characterisation of storage sites across Europe to define the contingent storage resource and to provide storage hubs for CO_2 capture projects. This could include the testing of new formations to assess their feasibility for storage.
- Assessment of long-term and post-closure storage liabilities (technical risk and uncertainty) and the development of technical, regulatory, policy and commercial 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.

European CO_2 sources/utilisation opportunities and longevity

- CO_2 sources and utilisation capacities across the EU should be mapped and assessed.
- Inventory of pre-commercial and/or industrial demonstration scale level CCU projects.

Both regarding CO_2 sources and storage, further exploring the use of big data and artificial intelligence is recommended.

6.3 Areas for CCS and CCU research

Building industrial scale CCS and CCU projects will also identify many new challenges that can best be solved by undertaking R&I in parallel with large-scale activities. An iterative process is needed where R&I projects address specific industrial challenges, with the results then implemented in large-scale projects. A recommended approach would combine existing datasets with specific analyses of industrial areas or plants, supported by the use of artificial intelligence. Priority research topics include the following areas and are best addressed through R&I at a range of scale from laboratory to pilot:

6.3.1 CO_2 capture in industrial clusters and energy applications

- Integration and synergies with other sectors and renewable solutions
- Process intensification, including utilisation of waste heat
- Retrofitability, part-load operation and flexibility
- Part-load operation and flexibility
- Buffer storage and shared transportation infrastructure
- Treatment of waste products from capture plants
- Degradation and life span of capture technologies
- Flexible electricity production
- Hydrogen applications (e.g. fuel switching, chemical conversions)
- Business models.

6.3.2 Cost reduction of CO_2 capture technologies

- High-TRL CO_2 capture technologies (from TRL 5-6 to TRL 7-9)
- Next generation CO_2 capture technologies
- Modularisation of capture technologies, compact capture technology
- Carbon removal technologies

- Fuel flexible combustion systems.

6.3.3 Technological elements for capture and utilisation

- Flexible, modular and energy efficient capture and purification technologies considering specificities of the downstream application
- Novel reactor design for efficient integration of capture and conversion stages
- Intensification for reduced energy consumption (including waste heat valorisation) and waste generation
- Novel and cost-effective materials (membranes, adsorbents, absorbents) with high durability and recyclability for increased capture rates
- Catalyst and material development for conversion technologies into fuels and chemicals (electrochemical, photoelectrochemical, thermochemical)
- Increased uptake of CO_2 during carbonation of primary and waste materials for the production of building materials (mineralisation)
- Increased direct uptake of CO_2 for polymer production
- Synthetic biology for increased conversion efficiencies in biological conversion and efficient downstream product processing.
- Artificial photosynthetic systems for efficient and direct conversion of solar energy to fuels and chemicals.

6.3.4 CCS and CCU transport systems

- 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.

6.3.5 CO_2 storage

- Develop experience with site conformance monitoring and assessment
- CO_2 flow behaviour near valves and chokes
- Storage optimisation through development of a range of injection strategies including in highly depleted reservoirs
- New geophysical techniques for examining and characterising legacy wells

- Deeper understanding of induced seismicity
- Effective prediction of CO_2 plume evolution under geophysical and geological uncertainty
- Dynamic storage capacity; understanding pressure responses, pressure-connected volume and pressure management techniques
- Storage of small volumes of CO_2 and scale storage if needed
- Storage appraisal to provide de-risked storage capacity to meet net-zero targets across Europe from a range of technologies
- Risk mitigation for storage value chain (financial, technical, regulatory)
- Strategic storage planning to optimise use of the deep subsurface, including interactions with other users.
- Innovation in monitoring technologies including, inter alia, use of robotics, autonomous machines, permanent monitoring, shared monitoring infrastructure, use of machine learning, continuous monitoring and large datasets.
- Effective simulation of CO_2 storage at semi-regional scale (several sites in communication) to enable optimisation of safe subsurface pore space utilisation
- Cost-effective ways to repair legacy wells.

6.3.6 Standardisation, regulatory and legal issues

- Standard CO_2 specifications
- Incentives for carbon negative solutions
- Incentives and market-pull mechanisms for low-carbon products
- Methods for measuring biogenic/fossil CO_2 ratio
- Data on emissions from CO_2 capture technologies
- CO_2 stream composition, including technical considerations such as pressure, temperature and physical state and MMV
- Harmonization of legal standards / regulations relevant for the development of a European CO_2 transport- and storage-network.

6.3.7 Social sciences and humanities

- Computational tools in process engineering & intensification (e.g. AI-driven process control, machine learning for catalyst development)
- Harmonised guidelines for life cycle sustainability assessment
- Public awareness and social acceptance of technology solutions towards achieving climate neutrality goals.

- Engaging communities in local projects through development of participatory monitoring programmes.

This list of proposed R&I activities summarises some of the most important and overarching areas for continued research efforts in the coming years. The list is non-exhaustive and new areas will be identified as CCS and CCU technologies are deployed.

7 Relation to cross-cutting issues

Integration into a single European energy system

- Energy system modelling and developing scenarios based on the results, to understand the scale, timing, options for and optimisation of CCS and CCU deployment to enable and support the transition in industrial decarbonisation and energy provision, including hydrogen and flexible electricity production and carbon dioxide removals.

Legal, policy and regulatory framework and market design (See under 8 below)

Fair and inclusive transition.

- Just transition – Shared Europe-wide CO_2 infrastructure will ensure that CO_2 emitters in all European regions can connect to permanent CO_2 storage.

Circularity

- CCS and CCU technologies are by definition introducing circularity. LCA including end of life impact together with real carbon accounting should be the basis for all energy technologies.

Digitalisation

- There is already a great variety and big volumes of data available. Explore the use of big data and artificial intelligence.

Technology acceptance and energy citizenship

- Public perception in parts of Europe, especially where onshore storage is considered – Inclusion of stakeholders in cities/regions is an enabler: Engaging communities in local projects through development of participatory monitoring programmes (co-design, co-ownership, co-decide, co-monitor); understanding stakeholder needs and opportunities to support transition through policy alignment (e.g. clean air and hydrogen economy); public awareness campaigns.

8 System level challenges that must be solved to realise potential

Crucial to set the European focus on GHG/CO_2 mitigation/removal

- Align all relevant policies with the European commitment to reach climate neutrality by 2050
- Take on a technology neutral approach and focus on clear CO_2 (GHG) thresholds – solve overlapping and contradicting policies.

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

- A functional and relevant carbon price – a robust EU Emissions Trading System
- In the short term, incentives to support timely large-scale deployment of all parts along the CCS/CCU value chain
- An Innovation Fund that can support the whole CCS/CCU value chain
- Coherent and coordinated EU and national funding programs
- Use national long-term strategies and National Energy and Climate Plans (NECPs) to track EU's progress towards climate neutrality and coordinate national and European research and innovation programmes. An early assessment of the NECPs shows that 13 Member States participate in European research initiatives aimed at accelerating CCS technology (including under the SET-Plan, ERA-NET CoFund ACT and EEA-grants 2014-2021)[9]

[9] IOGP