POLICY BRIEF

CARBON CAPTURE, UTILISATION AND STORAGE (CCUS)

CCUS technologies for climate change mitigation

PROJECT GROUP

CARMOF - *New process for efficient CO_2 capture by innovative adsorbents based on modified carbon nanotubes and MOF materials.*
Offering highly intensified technologies by using optimized structured adsorbents based on high-capacity adsorption materials in combination with highly efficient and rapid joule heating desorption and integrated cooling.
https://carmof.eu/

GA No. 760884

MEMBER - *Advanced MEMBranes and membrane assisted procEsses for pre- and post- combustion CO_2 captuRe*
Scaling-up and manufacturing of advanced materials (membranes and sorbents) and their demonstration at TRL6 in novel membrane based technologies that outperform current technology for pre- and post-combustion CO_2 capture in power plants as well as H2 generation with integrated CO_2 capture.
https://member-co2.com/

GA No. 760944

MOF4AIR - *Metal Organic Frameworks for carbon dioxide Adsorption processes in power production and energy Intensive industRies*
Demonstrating the performances of MOF-based CO_2 capture technologies in power plants and energy intensive industries.
https://www.mof4air.eu

GA No. 837975

SUMMARY

CARMOF, MEMBER and MOF4AIR are three European-funded projects aiming to demonstrate currently state-of-the-art capture technologies in real market conditions, promising new material solutions have been under development for the next generation of CCUS technologies that are expected to reach the markets in the next few years. Carbon capture, utilisation and storage (CCUS) is a key element in the EU low-carbon policy.
This Policy Brief aims at formulating concrete recommendations for maximising the deployment of CCUS solutions, therefore contributing to EC policy making towards its objective of a climate-neutral Europe by 2050.

1. BACKGROUND

1.1 CONTEXT
CARBON CAPTURE, UTILIZATION AND STORAGE

To mitigate future climate change, the European Union (EU) has accelerated the goal of cutting greenhouse gas emissions to reach a 55% reduction relative to 1990 by 2030*. **Power supply and carbon-intensive industries** (e.g., cement, steel, limestone, petrochemical and chemical plants and waste incineration) account for a large share of CO2 emissions. **The EU Taxonomy for Sustainable Activities** set a target of CO2 lifecycle emissions from heat and electricity generation of 100g CO2e/kWh by 2030. **Carbon, Capture Utilization and Storage (CCUS)** is one of the only technology solutions that can significantly reduce emissions from key industrial processes (all of which will remain vital building blocks of modern society) as well as from coal and gas power generation, for which, however, a range of other solutions can be considered.

CCUS consists of the **separation of CO2** from industrial and energy related sources, and either its **transportation** to a geological storage location for final long-term isolation from the atmosphere (CCS, with a focus on storage) or its **transformation** to other molecules, which can be valorised (CCU, with a focus on utilization). For CCU, a wide range of CO2 utilization technologies can be envisaged, including CO2 to chemicals, fuels, and durable polymeric materials, CO2 to mineral carbonation and construction materials, as well as CO2 to biological algae cultivation and enzymatic conversion. In CCS, Captured CO2 is geologically stored, either permanently or over geological time scales , in saline aquifer, oil and gas reservoirs, or potentially in unmineable coal seams. It is believed that CCS has the capacity to decrease CO2 emissions from CO2 intensive processes more rapidly than CCU, while CCU is a more economically viable and socially accepted than CCS. However it should be noted that geological sequestration of CO2 is not possible at all locations where the CO2 is captured.

The International Energy Agency (IEA) states that CCUS is an essential technology to reduce CO2 emissions and achieve **net-zero emissions by 2050****. According to the IEA plans, 1.6 bn tons of CO2 should be captured per year by 2030, and 7.6 Gt by 2050. However, the progress of R&I on CCUS technology is still too slow to reach these objectives. In 2018, the Advisory Council of the European Zero Emission Technology and Innovation Platform concluded that CCUS is crucial to achieving deep reductions in CO2 emissions in the most affordable and economically sustainable way***.

*2030 Climate Target Plan (europa.eu)
**About CCUS – Analysis - IEA
***ZEP-Role-of-CCUS-in-below-2c-report.pdf (zeroemissionsplatform.eu)

1.2 CO2 CAPTURE TECHNOLOGIES

CO2 capture is one of the first steps of **CCUS**. Many different technologies have been developed during the last 25 years. Currently, different ways exist for carbon capture, and they are divided into **three process categories**: pre-, post-, and oxy-combustion, although new processes integrating the CO2 capture in the reaction process are also being developed.

Post-combustion CO2 capture is one of the most developed technologies because it is easier to integrate the carbon capture step in the existing facilities, so it has been widely developed. Absorption by **liquid solvents** are amongst the most mature technologies. Commercial absorption-based systems are already available, normally based on **amine solvents**. However, amine scrubbing does not offer sufficient performance nowadays. The main drawbacks that have been associated with the amine-based CO2 capture are: energy-consuming regeneration, oxidative and thermal degradation of amines during regeneration, amine foaming and corrosion making the sorption process deteriorate. Therefore other solvents are also being developed to reduce energy consumption, increase selectivity and limit hazardous emissions. In addition to the conventional amine solvents, the range of liquid solvents includes: physical solvents, Benfield process and variants, sterically hindered amine, chilled ammonia process, water-Lean solvent, biphasic solvents, amino acid-based solvent, precipitating solvents, encapsulated solvents, Ionic liquids. Their **Technology Readiness Level (TRL)** spans from 3 up to 9 for the different liquid solvents, where amine solvents and physical solvents are at level 9.*

Adsorption by solid sorbents is another capture technology with certain options at TRL levels of 9, such as pressure and vacuum swing adsorption (PSA and VSA) in a pre-combustion setting, as well as TRL levels of 6 for post-combustion CO2 capture. Other technologies are Sorbent Enhanced Water Gas Shift (SEWGS), Sorption Enhanced Reforming (SER) and enzyme catalysed adsorption but at lower TRL than PSA / VSA technologies.

In addition to the liquid solvents and solid sorbents, other capture technologies are being developed. Such as, **membranes** (i.e. H2/CO2 separation in pre-combustion CO2 capture and CO2/N2 separation in post-combustion CO2 capture), **solid looping** (i.e. calcium looping, chemical looping combustion, chemical looping steam reforming) and **low-temperature separation**, hybrid processes combining several capture technologies, fuel cells with CO2 capture, direct air capture, inherent CO2 capture, and oxy-combustion capture technology. Within each technology there are different options with a range of TRL levels. However, in general these technologies are less mature than absorption with amine solvents and, to some extent, solid sorbent adsorption.

The **cost and energy requirements of CO2 capture** must be further reduced to make it more attractive as an emissions reduction pathway. **To meet the European climate objectives for 2030, more operational CCUS projects at commercial scale are needed in a short timeframe**. Commercial technological solutions exist and will need to be deployed. However, **technological development is essential to reduce the cost and energy requirements** of CCUS and make it more attractive as an emissions reduction pathway.

*Technology Readiness Level (europa.eu)

2. RECOMMENDATIONS

This policy brief aims at formulating recommendations that are deemed essential for the development of CCUS solutions in Europe, to ensure CCUS can play its role in the reduction of CO2 emissions by carbon intensive industries.

2.1 IDENTIFIED NEEDS FOR CCUS DEPLOYMENT IN EUROPE

Technology development will play an important role in reducing the cost of CCUS. In this regard, the following aspects would need to be included in the future roadmap for CO2 capture technology:

- Technological advancements are needed for the development of novel reactor designs for process intensification, modularisation, and cost-effective, upscalable materials as they can reduce the cost and energy demand of the CO2 capture process by process intensification.
- Manufacturing Readiness Level increase is needed to facilitate the replication of the successful technology and the go-to market strategy. While the Technology Readiness Levels (TRL) is used to assess the maturity of a technology it does not address the manufacturing maturity of key materials and components. However, matters of manufacturing readiness and producibility are as important to the successful development of a system as those of readiness and capabilities of the technologies intended for the system. Therefore manufacturing readiness level should be improved together with the technology improvement to facilitate the supply chain development for the replication at large scale of the successful technology and the go-to-market strategy. Maybe a separate recommendation?
- Technology development and the identification of suitable capture technologies for a specific industrial application should be guided by considerations of accessibility to clean and sustainable energy sources and the potential for heat integration at the plant site.
- Further developments are needed to improve the efficiency of the capture process (capture rate >95%)

2.2 INCENTIVES TOWARDS INDUSTRY & INDUSTRIAL CLUSTERS

The formation of industrial clusters should be supported financially as they offer great opportunities for a wider deployment of CO2 capture by cost reduction and de-risking through:

- energy integration (e.g. use of industrial waste heat from plant A for carbon capture at plant B) and sharing of infrastructure for clean energy production ,
- economy of scale
  - sharing of CO2 transport, utilisation and storage infrastructure
  - CO2 capture from small volume industrial facilities, which might not be economically viable for individual facilities while a number of small scale emitters can account for considerable CO2 emissions.
- National, local and EU government **financial support** is currently being given (e.g. Northern Lights project, Porthos) but government-backed loans and grants for developing and supersizing CO2 transport and storage infrastructure are at present insufficient to fill the cost-revenue gap and address the full scale of the global challenge (e.g. the EU Innovation Fund is oversubscribed by a factor of 20).

More support is needed for the commercial-scale demonstration of CCUS in industry-led initiatives, to allow to identify cost reductions and make **investment decisions**

- The development of a clear and shared framework for carbon accounting and for guaranteeing the sustainability of bioresources is fundamental to implementing dioxide removal solution schemes.
- The provision of incentives to the industry to use captured CO2 in their products. Encourage the rebuilding of value chains of products (steel, cement, lime, chimical , glass, ...) to minimise CO2 emissions or even reach zero CO2 emissions, in part through CO2 reconversion. Implement a progressive carbon footprint tax on products that accounts for the entire product lifetime

2.3 REGULATIONS, STANDARDISATION AND POLICY AT EUROPE LEVEL

Regulatory barriers, which can only be resolved at the European level, still hinder the industrialisation of the CCUS chain. The adjustment of the regulatory context will be important to frame the development of CCUS technologies and infrastructures in the coming years, and the role CCUS can play in CO2 emissions mitigation.

- A carbon capture, transport and storage **strategy and policy** is needed on the European level, that coordinates with member-state policy. There is a need for support for the proactive development of strategic CO2 transport and storage infrastructure solutions. CO2 transport plays a crucial role in CCUS systems, including highways, railways, pipeline, and shipping infrastructure, with; the pipeline being the primary means of CO2 transport. Increase infrastructure capabilities for CO2 transport, with easy access to transport infrastructure for raw materials and to markets for end user products thus limiting additional CO2 emissions via transportation.
- CCUS regulation must manage the risks and liabilities of CCUS but unanswered questions act as barriers to a comprehensive regulation. The first industrial CCUS clusters will provide great insights and answers to these questions by expanding the scientific and technical knowledge.
- Increasing carbon taxation on both direct and indirect emission can make CCUS more competitive

2.4 CO2 CAPTURE

The development of next-generation CO2 capture technologies will require a range of validation steps, from pilot testing up to commercial scale. The availability of accumulated experience from development and maturing of existing capture technologies can prove very helpful for the development of the next-generation technologies that will advance CCUS deployment in Europe. Main recommendations:

- Capture technologies should be developed to enable high capture rates (>95%) and carbon dioxide removal schemes (CDR). The development of a clear and shared framework for carbon accounting and guaranteeing the sustainability of bioresources is fundamental to enable CDR solutions.
- The identification of suitable capture technologies for specific industrial applications should include considerations on the match between the energy requirements and the energy availability at plant sites. Technology development should be guided by considerations of accessibility to clean and sustainable energy sources.
- Technological advancements are needed for the development of novel reactor designs, modularisation, and cost-effective materials. Given importance to other technological issues, such as flexibility, compactness, and the potential for heat integration and process intensification.
- The support of a funnel of large projects, based on CO2 capture technologies at different high Technology Readiness Levels (TRL), will contribute to bringing down costs decreasing both CAPEX and OPEX.
- 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.
- On the other hand next generation CO2 capture technologies must guarantee the quality and continuity of the industrial production or process where they are applied (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.

2.5 CCUS VALUE CHAIN

CCU technologies are likely to be very attractive to large or average sized CO_2 industrial emitters , especially in areas where it might not be possible to geologically store CO_2 via CCS.

The utilization of captured CO_2 as a feedstock in the chemical industry offers both an opportunity to reduce CO_2 accumulation and increase independence from fossil resources by substituting fossil-derived and energy-intensive materials. It also makes it possible to achieve effective use and storage of intermittent renewable energy sources and thus facilitate their deployment.

A wide range of CO_2 utilization technologies are possible, including CO_2 to chemicals, fuels, and durable materials, CO_2 to mineral carbonation and construction materials, as well as CO_2 to biological algae cultivation and enzymatic conversion.

The different steps of the CCUS chain : capture, transport, sequestration or use must be taken into account at the earliest possible stage when choosing the optimal set of technologies.

- Infrastructure capabilities for CO_2 transport should also be considered, as well as easy access to transport of raw materials and to products market, to limit additional CO_2 emissions via transportation. CO_2 transport plays a crucial role in CCUS systems, including highway, railway, pipeline, and ship; the pipeline being the primary way to transport CO_2.
- Take into account the specifications required for the transport of CO_2 (state/pressure: gas, supercritical, liquid; purity and tolerated impurities) by integrating the different purification steps and the condition of the CO_2 in the choice of the capture technology.
- Highlight in the value chain of products (steel, cement, lime, chimical , glass, …) that they are low CO_2 emissions or even zero CO_2 emissions and that the CO_2 is reconverted.
- Regularly assess the market for CO_2-sourced products
- Integration on the same site, if possible, capture and conversion unit to reuse excess energy from conversion unit to the capture unit to reduce thermal energy consumption even to be self-sufficient.
- Availability of utilities and cost (renewable electricity) for conversion units.

2.6 INDUSTRIAL CLUSTERING

- The formation of industrial clusters should be supported financially and by a proper policy as they offer great opportunities for a wider deployment of CO_2 capture by cost reduction and de-risking through:
  - energy integration,
  - sharing of CO_2 transport, utilisation and storage infrastructure and
  - CO_2 capture from small volume industrial facilities, which might not be economic for an individual facility while a number of such small scale emitters can sum up to considerable CO_2 emissions.
- National, local and EU government financial support is currently given (e.g. Northern Lights project, Porthos) but government-backed loans and grants for developing and supersizing CO_2 transport and storage infrastructure are currently insufficient to fill the cost-revenue gap and to address the global challenge (e.g. EU Innovation Fund is oversubscribed 20 times); more support for the commercial-scale demonstration of CCUS
  - Industry-led initiatives, close work with industry to identify cost reductions and make investment decisions
- A carbon capture, transport and storage strategy and policy is needed on the European level, that coordinates with member-state policy. There is a need for support for the proactive development of strategic CO_2 transport and storage infrastructure solutions.
- CCUS regulation must manage the risks and liabilities of CCUS but unanswered questions act as barriers to a comprehensive regulation. The first industrial CCUS clusters will provide great insights and answers to these questions by expanding the scientific and technical knowledge.

2.7 SOCIAL ACCEPTANCE

Lack of social acceptance

Social acceptance of local societies is lacking on the implementation of CCUS projects and overcoming the negative perception of CCUS technologies are crucial to develop CCUS solutions. There are several negative perceptions in local societies regarding capture infrastructures, and particularly the storage of CO2. Possible leaks and seismicity caused by injection of CO2 is an important obstacle for the acceptance of CCS infrastructure. Another obstacle to capture projects is the "NIMBY" (Not in My Backyard) concept. CO2 capture as a technology to reduce CO2 emissions is also questioned to be the most appropriate alternative solution.

Better communication is necessary to increase public acceptance on CCUS. Studies on social acceptability published or ongoing are highlighting the necessity to foster social acceptance of CCUS projects for their successful development*.

Concrete recommendations

a. Public engagement**

To boost the acceptability of CCUS, an effort should be made to foster public engagement. Public engagement is a two-way process that includes: (i) public communication, (ii) public consultation, and (iii) public participation (Fig. 1). Public communication refers to the information that is provided to the public participants (usually local authorities and societies) by the project developers and operators; it is a one-way process. Public consultation refers to the information that is given to the project developers and operators by the public, without interaction between the two sides. Public participation refers to information that is exchanged between the two sides through a dialogue process.

Figure 1: Levels of community engagement activities

*L'acceptabilité au prisme du stockage géologique de CO2 : retour sur un débat non émergé, | Cairn.info ; GÉFISS - Social Governance for Subsurface Engineering (gefiss.eu)

**Karytsas, S., and Polyzou, O. (2021) "Social acceptance of geothermal power plants", In: Ozgur Colpan C., Akif Ezan M., Kizilkan O. (Eds) Thermodynamic Analysis and Optimization of Geothermal Power Plants (65-79). Elsevier, Amsterdam, Netherlands.

Public engagement strategies include:

- Execution of a socioeconomic study of the location under consideration during the project development's initial stages.
- Formation of a group of local actors with the representation of government authorities, members of surrounding communities, environmental conservation associations, representatives from the agriculture and business sectors, etc. Provide the audience with details about the activities of the company and forthcoming plans and discussion with the intention of achieving shared trust.
- Dialogue covering a substantial portion of the surrounding communities.
- Application of awareness programs aimed toward all stakeholders, namely local governmental authorities, government agencies, local people, NGOs, local groups (e.g., consumers), private companies, etc.
- Methods that can be applied to inform the diverse types of audiences comprise project site tours, seminars, websites, brochures, media releases, an education center, a contact office, social media, creation of a demonstration site, involvement in activities, coordination of scientific meetings, and collaboration with groups with relevant interests.
- Communication strategies toward the local communities should be developed and implemented before the start of a CCUS project, defining concretely who will be involved in the communication on the project toward local communities and population. All stakeholders related to the CCUS project should be involved in local communication strategies to the public, especially local political representatives, not only industrial actors.
- CCUS project success stories should be highlighted, to raise awareness about the positive impact of CCUS projects.

b. Global strategies and roadmap

A European Strategy (and national strategies) for decreasing carbon emissions should be developed and integrate CCUS projects, including strategies for communicating on CCUS projects, defining the stakeholders that should be involved, the main message to be conveyed, the target audiences, the timeline (communication should start way ahead of the start of the project)…

Public debates at the national level to involve local communities should be organised as part of this strategy. Debates should be organised before, during and after projects implementation. Local public engagement strategies in the framework of the development of CCUS projects should stem from these global European and national strategies.

b. Technical and safety specifications

Technical and safety specifications should be developed to foster social acceptance of CCUS infrastructures, and notably of storage sites. The technical and safety specifications include environmental studies and hazard studies. The following aspects should be covered in these studies: probability of CO2 leakage, penalties to the company in case of leakage, measurement of the impact on seismicity, monitoring of seismicity induced by CO2 injection, financing of study in safety and monitoring (already done by the ADEME)…
These specifications' development should involve local communities, while the monitoring should also involve service companies and external actors. The regulatory status and authorisation linked to the project should be validated with local authorities, who can endorse the projects to local communities.

CARMOF

MEMBER

MOF4AIR