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Policy Paper

Benefits of Carbon Capture, Utilisation and Storage (CCUS) Technology

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Executive Summary

The carbon capture, utilisation and storage (CCUS) technology can play a key role in achieving carbon neutrality, in addition to preserving the Romanian industry's productivity and competitiveness, particularly in energy-intensive and difficult to decarbonate sectors.

CCS contributes to mitigating climate change by enabling the capturing of CO_2 emissions before they can reach the atmosphere or by removing historical emissions from the air. CCS allows the industrial sector to continue its operations with low CO_2 emissions, thus playing a key role in mitigating anthropogenic emissions. CCS can also help develop a platform for blue hydrogen, as an alternative energy source.

This policy paper explores the various types of CO_2 storage method, analysing the benefits, challenges and opportunities arising from these. Current CCS projects and relevant best practises in Europe and across the world are also analysed, providing a comprehensive understanding of the current state of technological developments in the sector as well as of the diversity of business models adopted in various states.

Adequate geological structures for CO_2 storage can be present both onshore as well as offshore, each type of geological formation presenting different opportunities and challenges. Geological storage is defined as the placement of CO_2 in an underground formation, so that it remains stored there safely and on a permanent basis.

According to recent scientific research relating to the CCS sector, saline aquifers can store between 1.000 and 10.000 Giga tonnes of CO_2. Concurrently, the storage capacity of depleted oil and gas geological structures amounts to 900 Giga tonnes of CO_2 (Bourg et al, 2015[1]). Specifically, the injection of CO_2 in hydrocarbon reservoirs can ensure the permanent and safe underground storage of a significant quantity of CO_2, while simultaneously improving the recovery of hydrocarbons (Enhanced Hydrocarbon Recovery), which allows a cut down in operational costs.

Depleted hydrocarbon deposits, both conventional and unconventional, could serve as geological storage of CO_2 after hydrocarbon production if they meet specific technical criteria and the economic analysis demonstrates the feasibility of the project. It is worth noting that the gradual recovery of residual hydrocarbons after CO_2 injection could reduce the costs of the CO_2 storage operation.

Attention must be paid to ensuring that CCS projects are designed and implemented while considering the whole value chain (from capturing, via transport to storage), given the importance of the CCS technology and its impact across various sectors, as well as public infrastructure. These include oil and gas, cement and steel, glass, paper, but also transportation, agriculture and environment. As upfront costs for developing CCS projects are significant, it is important to ensure that such initiatives are financially feasible and are accepted by all the parties involved.

Furthermore, as highlighted by numerous analyses and recent research conducted at international level, the CCS technology has the potential to generate new, highly skilled direct and indirect jobs across the industrial value chain. Sectors such as oil and gas, in light of their longstanding experience related to geology, reservoirs, in conducting drilling operations and operating oil and gas facilities and infrastructure, have unique expertise which can be easily transferred and used for the implementation of CCS projects, both in Romania and across the world.

Romania, as a country with long standing tradition in the exploration and exploitation of oil and natural gas, has an unique opportunity to implement and use the best practises and know-how at hand. Romanian oil and gas companies can significantly contribute to the development and implementation of CCS technology, given their expertise and skills in the sector.

With respect to implementing the legislative framework required to enable operators to use the CCS technology in Romania, we dive into details regarding the Directives like the CCS Directive and accompanying Guidance Documents outline guidelines for safe CO_2 storage operations, Emissions Trading System, the Net Zero Industry Act and national legislation.

All the while, we keep in mind that Social Acceptance is crucial, requiring effective communication strategies tailored to local communities.

While the EU framework provides a basis for CCUS development, addressing implementation challenges is vital for Romania's success in this area, Romania requires further regulatory adjustments and a national strategy for CCUS deployment, including identifying potential sites, engaging stakeholders and ensuring social acceptance.

All aspects covered in this policy paper are critical for the successful deployment of CCUS initiatives in Romania.

1 https://pubs.acs.org/doi/10.1021/acs.est.5b03003

1. Introduction: Carbon Capture, Utilisation and Storage (CCUS)

1.1. Definition

Carbon capture (sequestration) and storage is a set of technologies aiming to safely capture, transport and permanently store CO_2 that would otherwise be released into the atmosphere. Carbon capture and utilisation (CCU) technologies allow reusing captured carbon, increasing its circularity and potentially reducing its emissions to the atmosphere.

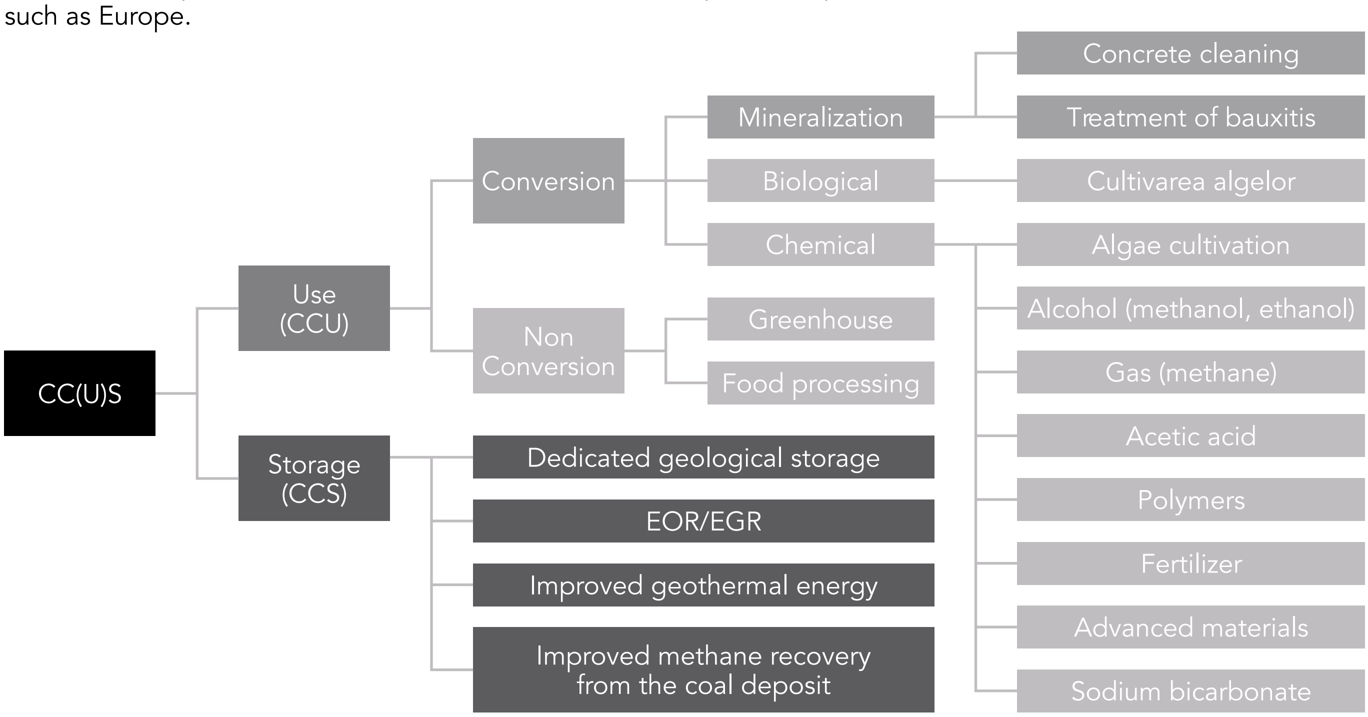
Geologic sequestration is a proven method of underground CO_2 storage where the latter is injected underground into deep rock formations for long-term storage. By capturing CO_2 and storing it deep underground, operators can prevent the release of CO_2 emissions into the atmosphere, thus helping to protect the environment and actively combat climate change in the long run by supporting decarbonising the "hard to abate" industries.

Carbon capture and storage is a term which encompasses the technologies aiming to capture the CO_2 and store it safely underground. Thus, CCS includes both capturing CO_2 from large emission sources (also known as point-source capture) as well as directly from the atmosphere. Point-source capture is when a large emission source, such as an industrial facility, is equipped with technology enabling the capture and diversion to storage of CO_2. It is worth noting that direct air capture and storage (DACCS) and bioenergy with capture and storage (BECCS) make it possible to remove **historical CO_2 emissions.**

Carbon utilisation encompasses a variety of applications where carbon dioxide is captured and utilised, either in its original form (without chemical alteration) or through transformation, for various purposes. Currently, CO_2 is predominantly utilised in the fertilizer industry and for enhanced oil recovery. However, emerging applications include the production of synthetic fuels, chemicals, and building aggregates using CO_2, which are increasingly gaining traction.

International climate experts agree that **CCS is particularly important for hard-to-abate sectors like cement and steel production,** where no viable clean options currently exist to decarbonise the manufacturing process, and for removing CO_2 already in the atmosphere. According to national and international experts, CCS presents unique opportunities to achieve **climate neutrality.**

CCS projects have become commonplace in North America and Europe, being supported by more robust policy regulations and carbon pricing. These jurisdictions are also developing comprehensive CCS regulation. However, the level of development of geological storage resource is outpaced by potential future demand, even in jurisdictions such as Europe.



Source: Analysis based on findings by the Kearney/Energy Transition Institute, 2021

2. How CCUS technology works

2.1. Technical features of CCUS

Geologic sequestration has been in use for decades. In the context of the emergence of more stringent general climate policies and regulations, one notes an acceleration of the development of new CCS projects. It should be taken into account that these projects usually take on average seven years to ten years to develop. Currently, we see stronger policy drivers with respect to the previous decade.

However, it is important to ensure that investments in CCS projects and climate neutrality initiatives make **economic sense.** With respect to storage, it is essential to bear in mind that investments must be feasible, considering that the CCS technology presents significant opportunities to achieve climate neutrality. More importantly, investors need to consider that before engaging in developing a CCS project, subsurface and lab studies, facilities engineering and safety studies, environmental impact assessments and feasibility studies need to be elaborated and approved. All these require significant financial and human/expert resources.

During capture, CO_2 is separated from flu gases produced in large industrial facilities, such as steel mills, cement plants, petrochemical facilities, or from the atmosphere. Currently there are **several capture ways in use, all of them being proven and effective,** with different methods applied based on the emissions source.

CO_2 can be captured from hydrocarbons before, during or after combustion. A Kearney analysis[2] highlights **four technologies to capture CO_2** in different stages across the combustion value chain.

These include:

- **Pre-combustion,** which means that a source of hydrocarbon fuels is turned into gas, by separating the CO_2 from the rest of gases. The H_2 is then used to fuel the power plant or to produce other chemical substances or synthetic fuels. This process is more efficient from an energy perspective than the post combustion one, but requires a new and costly powerplant project, such as an integrated combined gasification cycle.
- **Oxi-combustion,** where the fuel is burnt in pure oxygen instead of air, thus producing a concentrated CO_2 flux in the combustion gases. Oxi-combustion could be added to the current installations, but with significant redesign.
- **Post-combustion,** where the CO_2 is separated from combustion gases after combustion with air and may be conducted in power plants and industrial facilities, with relatively small costs and energy losses.
- **Desulphurisation of natural gas,** during which CO_2 is separated from raw natural gas in a refining facility.

Once the CO_2 is separated, it will be dehydrated and compressed for **transportation.** Pipelines are the most common way of transport for significant quantities of CO_2. Transport of CO_2 occurs daily in many parts of the world. However, significant investments in transportation infrastructure are needed to enable a decent scale of deployment.

Other means of transport of CO_2, in both gaseous and liquid states, involve the use of **tanks, and ships.** Liquid CO_2, which occupies less volume than its gaseous form, is typically compressed before transport. CO_2 pipeline operators established **a minimal composition specification** to prevent corrosion and other adverse effects on transport infrastructure and storage facilities. In the absence of a pipeline, rail or ship transport are options for access to warehouses. Large-scale CO_2 shipments resemble the transportation of liquefied gas, sharing commonalities with this global industry.

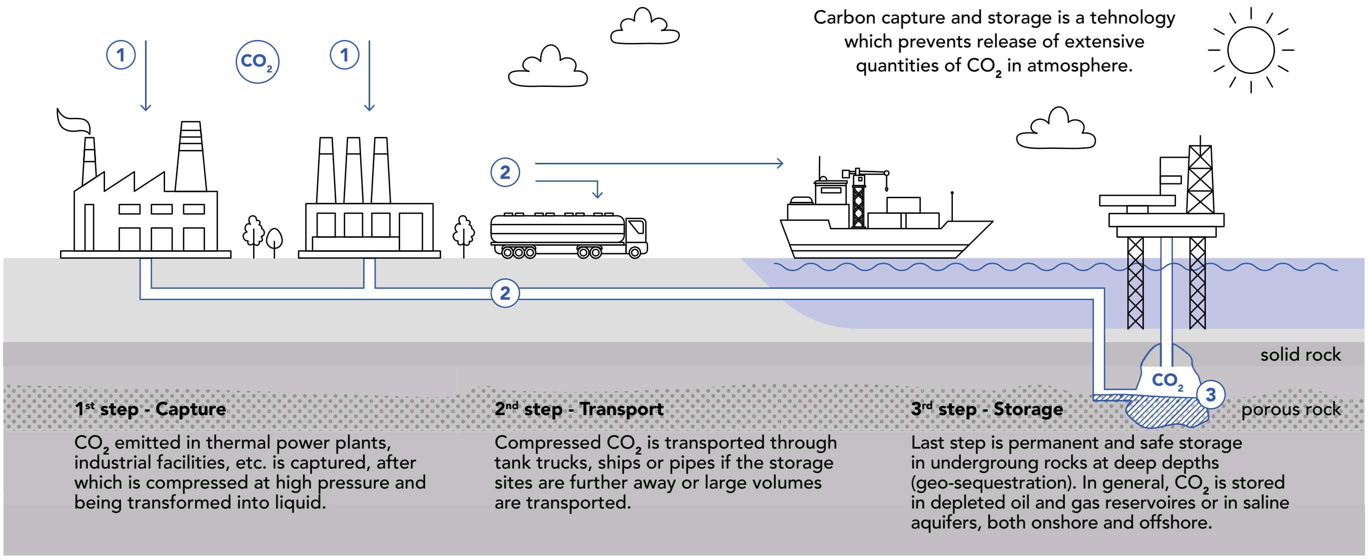
Carbon dioxide is much safer to transport than many other substances as it does not form flammable or explosive atmospheres, like oil or gas do. More importantly, CO_2 is not directly toxic to humans or the wildlife when released in air, except for the highly unlikely case that the release occurs very rapid and in high quantities. CO_2 pipelines and other transportation methods are safe and closely managed under international standards. Furthermore, there is significant experience for pipeline development and operation both on land and under the sea. Currently, there are around 50 CO_2 pipelines operating in the US, across more than 8,000 kilometres, transporting around 70 million tonnes of CO_2 every year.

Concurrently, pipeline infrastructure to support CCS projects will need to scale significantly, to allow the achievement of the climate targets. This will require between 70 – 100 capture facilities built every year, according to Global CCS Institute. These facilities will need to be supported by 200,000 kilometres of pipeline by 2050, with an average pipeline build rate of 5,200 – 7,200 km per year.

2 Carbon Capture Utilization and Storage - Kearney - https://www.kearney.com/documents/17779499/17781864/CCUS-2021+FactBook.pdf/718e94af-1536-b23e-1ac9-a4de74ffef25?t=1623398953000

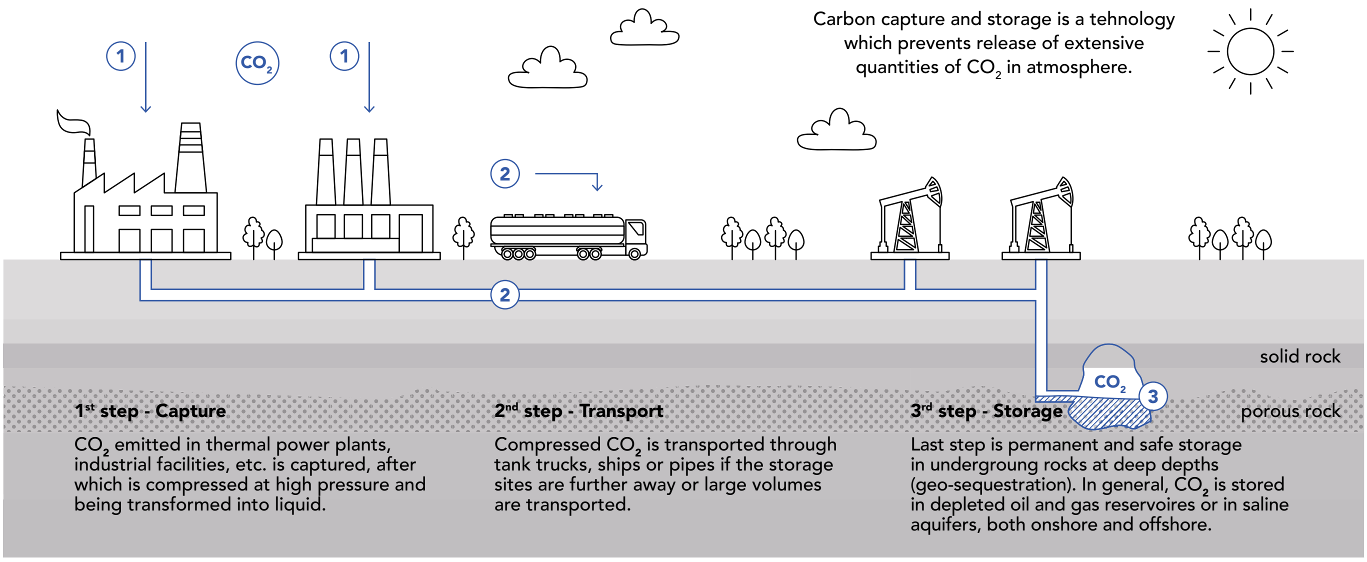
Following transport, the CO_2 is **injected into deep underground rock formations (onshore or offshore),** often at depths of one kilometre or more, where it is safely stored. The rock formations used for storage are similar to the geological structures which have kept oil and gas underground for millions of years. So far, **nearly 300 million tonnes of CO_2 have already been safely and successfully injected** underground.

The image below showcases the stages for carbon storage in offshore depleted deposits.



Source: FPPG, https://ccs.fppg.ro/en/

The image below showcases the stages for carbon storage in onshore depleted deposits.



Source: FPPG, https://ccs.fppg.ro/en/

The injection and storage of CO_2 represents the final stage in the CCS process. It is worth noting that the related processes are complex and costly. In terms of geology conditions, there are many geological systems around the world able to preserve CO_2 captured from industrial processes or directly from the air for long term.

Geological storage types include deep saline aquifers, depleted oil and gas reservoirs, carbon structures that are difficult to exploit and basalt structures. In addition, the following structures can be optimised to store CO_2:

(1) depleted oil and gas reservoirs;

(2) saline aquifer structures;

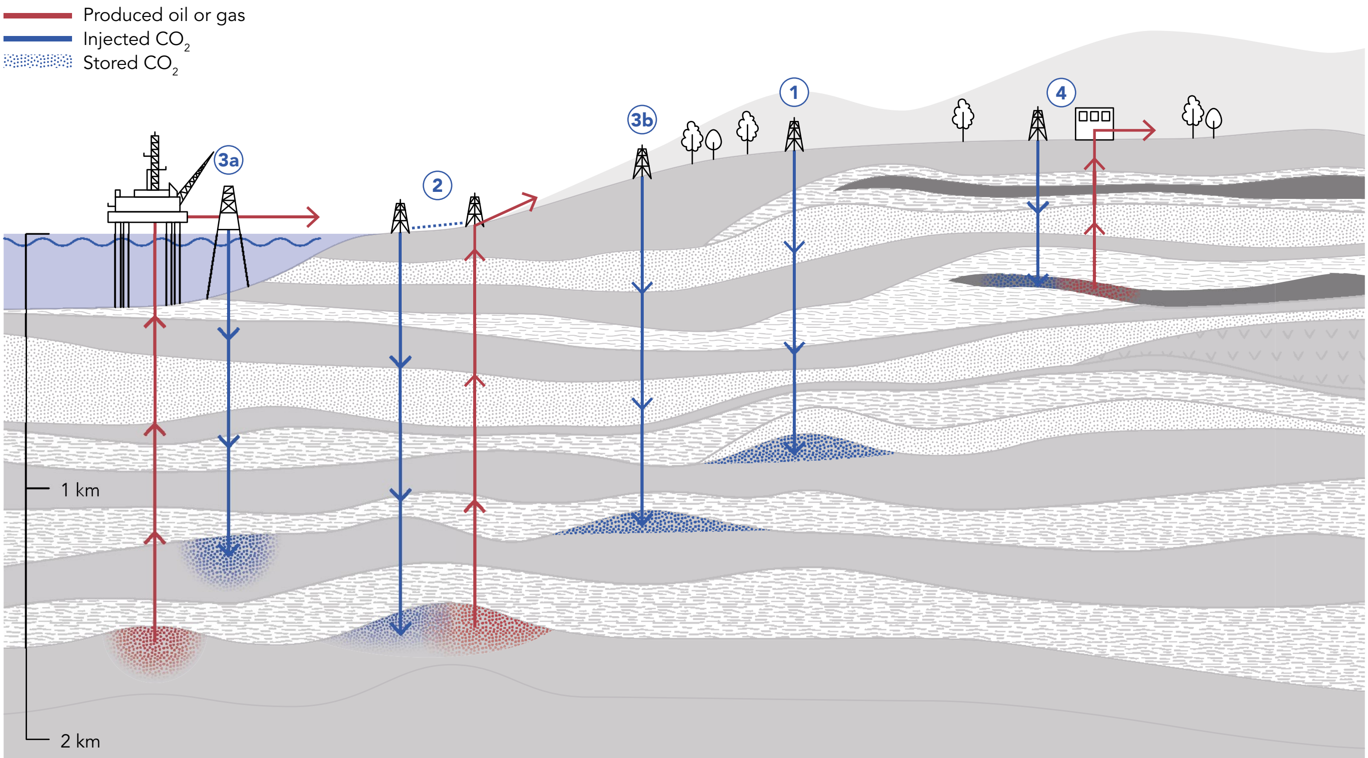
(3) deep coal formations;

(4) use for secondary recovery of hydrocarbons from hydrocarbon reservoirs;

(5) use for secondary recovery of methane from coal formations.

Overview of Geological Storage Options

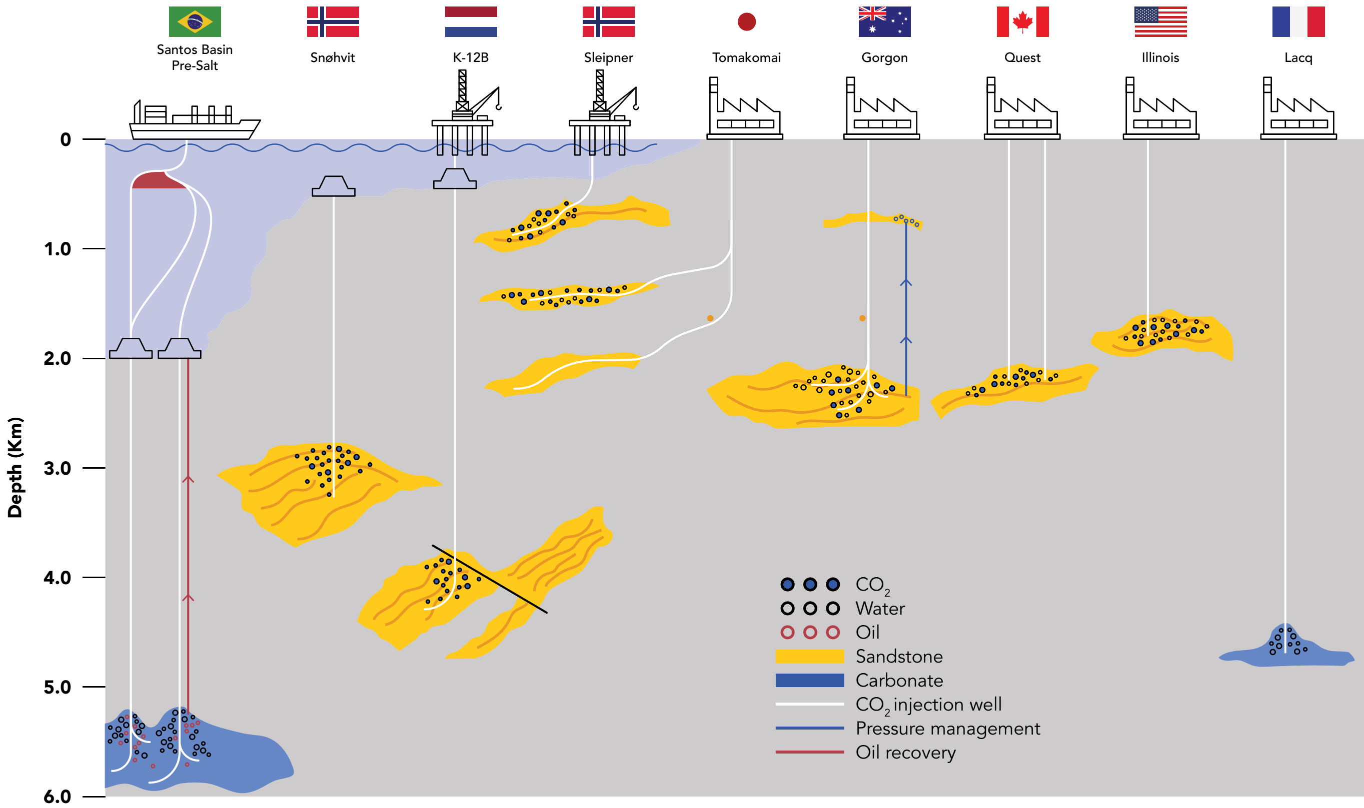
1. Depleted oil and gas reservoirs
2. Use of CO_2 in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore, (b) onshore
4. Use of CO_2 in enhanced coal bed methane recovery



Source: https://archive.ipcc.ch/publications_and_data/_reports_carbon_dioxide_graphics.htm

The **CCS technology is already present around the world.** There are currently 41 operating facilities worldwide, but the potential for implementing the CCS technology is far greater. According to the PWC - EPG study ***"The Potential for capturing and storage of Carbon Dioxide in Romania"[3],*** CCUS is the most efficient from a financial perspective when applied to large sources of CO_2, such as power plants and steel factories.

Research conducted by Global CCS Institute highlights that CO_2 has been injected and permanently stored across a wide range of jurisdictions, environments, and geologies, as highlighted in the graph below:



Source: Global CCS Institute

3 PWC - EPG study "The Potential for capturing and storage of Carbon Dioxide in Romania" - https://ccs.fppg.ro/en/#documente

2.2. Key benefits of the CCUS technology

Recent scientific work related to the implementation of CCS technology by injecting CO_2 into hydrocarbon reservoirs can improve the recovery factor of reserves. Depleted natural gas deposits present a higher storage capacity for CO_2, compared to oil reservoirs, given the high primary recovery factor in the case of the former (>60%). The natural gas recovery factor is nearly double compared to oil recovery (Kuhn and Munch, 2013[4]).

Although the CCS market is not yet fully mature, many studies point out the socio-economic impact of CCS projects. These include CCS's major role in reducing CO_2 emissions and **contributing to the net zero objective,** as well as achieving **a deep decarbonisation of the heavy industry** (specifically, the cement, iron, steel and chemical industries). Additionally, the CCS sector can generate new jobs, particularly during the construction phase of the infrastructure required to implement CCS projects. Once the building phase is finalised, the generation of new workplaces tends to decrease, with the number of jobs created across the related value chain amounting between 200 and 300, out of which up to 100 positions would be in the plant[5].

Furthermore, the CCS sector can allow **large scale production of hydrogen with low CO_2 emissions.** Hydrogen can play a major role in the decarbonisation of the above mentioned hard-to-abate-sectors, while also serving as an important energy source for the household sector and electricity generation.

Concurrently, the CCS sector can provide centralised power with low CO_2 emissions, as rapid decarbonisation of electricity generation is key to attaining the net zero objective. Power plants equipped with CCS technology thus play a major role. The CCS technology can also support further innovation efforts across the national economy, particularly in states with longstanding experience in the exploration and exploitation of oil and gas resources. As a result of this specific background, they have a deeply skilled workforce and knowledge.

Additionally, the large-scale implementation of the CCS technology is likely to generate new opportunities with respect to the generation of infrastructure and the provision of services and financing of products obtained with low CO_2 emissions. CCS can also enable the reutilisation of infrastructure and postponement of decommissioning costs in the oil and gas sector. Specifically, in the case of oil and gas fields which are about to become depleted, parts of the existing infrastructure used in this sector can be reused to transport and store CO_2. This would contribute to a set of benefits, such as reduced costs for the construction of the transport and storage infrastructure, and to some extent to reducing the authorisation period.

Investment and impact of a CCS project

Initial investment in a CCS project represents:

- The equivalent of the necessary investment for building a regional hospital
- Almost a quarter of government spending on early and primary education in 2019
- Approximately 10% of the total FDI inflow in 2019

The development of a CCS project would have a significant socio-economic impact both at local and national level:

- 400 mil. EUR capital influx for initial investment
- Decreasing CO_2 emissions with almost 1MT/year with positive impact both on the environment
- 200 - 300 jobs within the project and along the value chain
- Jobs with significantly higher salaries than the national average, as the activity involves technical/ specific skills
- Competitive advantage at regional level in terms of know-how and technology

Source: FPPG, https://ccs.fppg.ro/en/

4 Kuhn and Munch, 2013 - https://www.sciencedirect.com/science/article/pii/S0920410520307518
5 PwC - EPG study, 2022

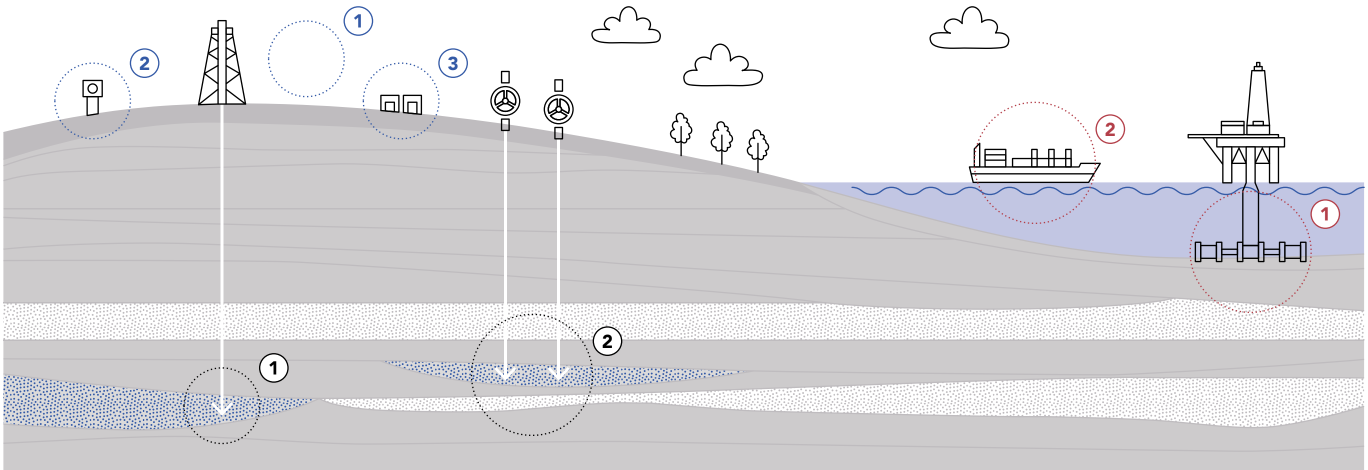
2.3. Risks and challenges of implementing the technology

CO_2 storage projects involve the safe containment of CO_2 underground (at depths of at least 700 m) while preventing negative impacts on the environment and human health. Any uncertainties relating to subsurface operations can be managed through specific measures and approaches. The CO_2 Storage Resource Management System (SRMS) Guidelines[6] provide some guidance on the uncertainties relating to assessing storage resource estimates. Uncertainties relating to a geological carbon storage project include site characterisation, field operations, post-storage monitoring, and post-closure activities.

A set of monitoring techniques are being implemented to ensure the constant surveillance of CO_2 storage sites. These include comprehensive regulatory and industry-led checks, with a low probability of leakage to the atmosphere, as highlighted by research conducted so far. Risk management helps operators prioritise monitoring efforts by identifying the areas and types of operations which pose the greatest risks, enabling organisations to focus their monitoring activity on mitigating and managing those risks more efficiently.

According to a recent report published by the International Association of Oil and Gas Producers (IOGP)[7], carbon storage projects are complex and present subsurface risks which require a comprehensive risk assessment and management of uncertainties. **Risk assessments** are designed to provide operators with valuable insights into the likelihood and potential consequences of various risks linked to geological storage of CO_2, as well as help them allocate resources effectively.

Uncertainty management is closely linked to risk management. The risk management process includes risk assessment and a set of analytical integration steps. **Field measurements and observations** are used to assess whether risks and associated outcomes are adequately evaluated. Measurements can be conducted in many ways. Examples include periodic downhole wireline logs, continuous temperature and pressure monitoring through sensors installed in monitoring wells, and exact readings of surface elevation changes. **Monitoring operations** may also involve comparing the current values of measured assets with previous values, including a baseline level that was measured before injection operations began.Some of these techniques are presented in the graph below.



① **Atmosphere**
Airborne EM
Airborne spectral
Satellite interferometry

② **Surface**
Eddy covariance
Surface gas flux
Soil gas concentrations
Ground water chemistry

③ **Surface**
2D/3D surface seismic
Land EM/ERT
Surface gravimetry
Tiltmeters

① **Sub-surface**
Downhole fluid chemistry
Downhole pressure
Downhole temperature
Geophysics logs

② **Sub-surface**
Cross-hole EM
Cross-hole ERT
Cross-hole seismic
Microseismic
Vertical seismic profiling
Well gravimetry

① **Offshore**
Boomer/Sparker profiling
Bubble stream detection
Multi-echo soundings
Sidescan sonar

② **Offshore**
Seabottom gas sampling
Seabottom geochemistry
Seabottom seismic
Seabottom EM

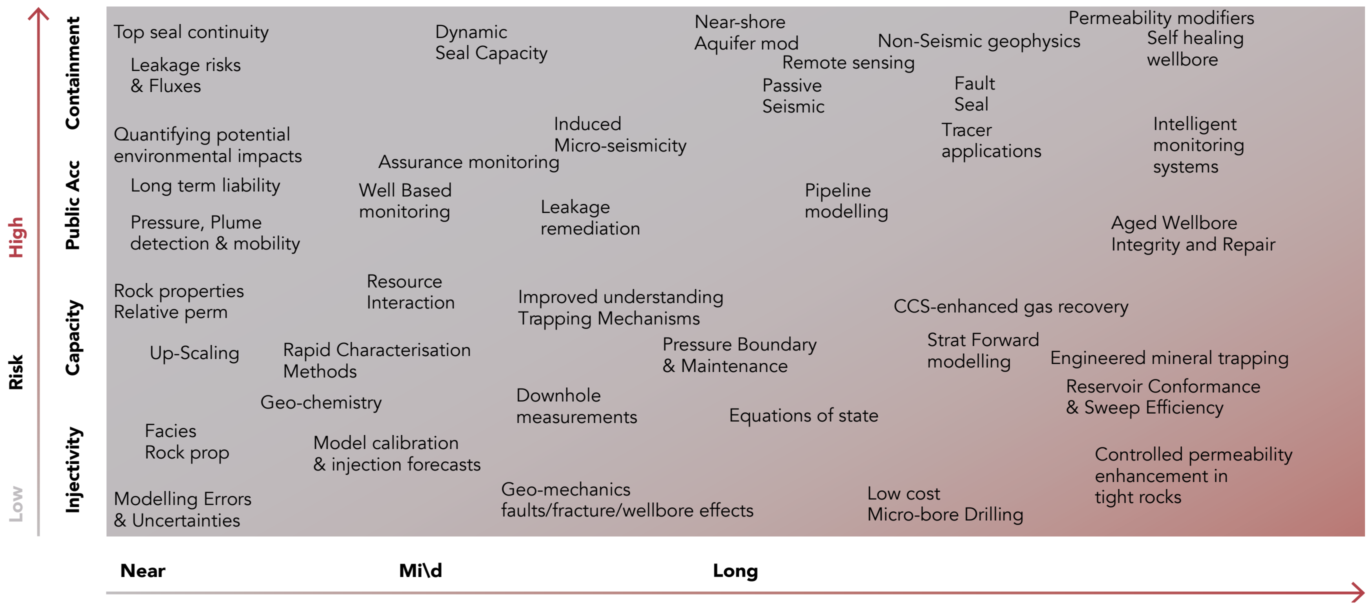
EM Electromagnetic
ERT Electrical resistance tomography

Source: https://www.petroraya.com/article/measurement-reporting-and-verification-in-carbon-capture-and-storage/

6 Society of Petroleum Engineers - https://www.spe.org/en/industry/co2-storage-resources-management-system/
7 IOGP Report 670 "Risk and uncertainty assessments for geologic storage of CO2", December 2023.

Recent research has focused on **the verification and optimisation of injection and storage operations,** whereas seismicity risks are low. Monitoring data contribute to periodically reassessing risks associated with a caprock integrity. Another part involves CO_2 plume modelling and prediction of the plume within the reservoir boundaries. The validity of models used can be confirmed by monitoring the injection pressure, as well as by measuring the movement of the plume[8] via frequent seismic surveys and possibly with geochemical analysis in fluid samples.

Injection pressure (max. bottom hole pressure) shall be kept well within the limits allowing for maintaining the sealing caprock's[9] integrity, derived from core analyses, caprock integrity and geomechanic studies. The typical risks associated with geologically storing CO_2 and related studies and work packs in a CCS development are illustrated in the graph below.



Risk assessments should be conducted on a site-specific basis and explore potential impacts related to subsurface operations. Such a subsurface risk assessment should aim to detect the various risks, while also helping to develop mitigation and monitoring, measurement and verification plans to address them. It is worth noting that the risk profile of a CO_2 storage project is likely to evolve throughout its lifecycle.

As a result, industry practices and regulatory requirements recommend that risk assessments should be reviewed and updated on a constant basis.

8 A plume represents a vertical body of one fluid moving through another.
9 In the petroleum industry, caprock is any nonpermeable formation that may trap oil, gas or water, preventing it from moving to the surface.

2.4. Contribution to reaching net zero targets

Climate change is the most pressing challenge facing humanity currently. International experts agree that **CCS will be vital for hard-to-abate sectors like cement and steel production,** where no viable solutions for decarbonising the manufacturing process currently exist, as well as for removing CO_2 already in the atmosphere. All recent analyses point out the urgency of reducing global emissions, in addition to the fact that any realistic plan forward on climate action will include CCS.

Almost all climate scenario models require the implementation of CCS. Currently, major international organisations, such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), have acknowledged CCUS technologies as necessary for climate mitigation in different degrees, across a wide range of scenarios to achieve net zero emissions. Under the IPCC AR 6[10] Scenario Pathway model, an average of 600 billion tonnes of CO_2 should be stored this century.

According to a 2020 report[11], CCUS technologies can contribute to generating opportunities and potentially preventing the negative social impacts of the transition to climate-neutral economy, for example by offering employment to workers from the oil and gas sector from the perspective of the similarities in required competence is between this sector and CCUS project implementation and management.

CCS is rapidly becoming a prominent element of public policy, from inclusion in an increasing number of countries' nationally determined contributions (NDCs) to the provision of targeted policies to encourage deployment and drafting of relevant regulations. An increasing number of large-scale CCS projects are currently announced, while the debate on the role of CCUS in climate change mitigation has shifted towards industrial emissions rather than on emissions linked to coal-fired power generation.

Furthermore, the diversity of industries in which CCS is being applied has significantly grown over the past several years. This supports its role in advancing net-zero goals across the world. CCS plays a key role in reaching net zero emissions by 2050, alongside other solutions such as reforestation, energy efficiency and the renewable energy.

CCS contributes to mitigating climate change by capturing CO_2 emissions before they can reach the atmosphere or by removing historical emissions from the air. CCS can also help develop a platform for blue hydrogen, as an alternative energy source. CCS allows the industrial sector to continue operating with low CO_2 emissions, thus becoming an important instrument in mitigating anthropogenic emissions.

10 https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/, https://www.iea.org/reports/net-zero-by-2050.

11 Bell, Rebecca, and Philippa Parmiter (2020), "The role of CCUS in a just transition. 3rd report of the Thematic Working Group on Policy, regulation and public perception", https://ccuszen.eu/sites/default/files/TG1_Briefing-Role-of-CCUS-in-Just-Transition_0.pdf.

3. Opportunities to introduce the CCUS technology in Romania

3.1. Storage

Petroleum systems are present in nine basins across Romania, as well as in the Romanian Black Sea continental platform. The Moesian platform covers more than 43,000 km^2, with over 160 oil and gas fields having been discovered in the reservoir rocks of this platform. The Transylvanian Basin is about 300 km long and about 200 km wide, with more than 110 gas fields discovered. The Romanian Black Sea continental platform is located on the extension of two main onshore structural units.

All these reservoirs could potentially serve as storage reservoirs for CO_2 storage, according to a European Association of Geoscientists and Engineers report[12] (note that extensive technical feasibility studies need to be conducted to confirm which of the reservoirs can finally be considered suitable for CO_2 storage).

Given the current situation, it is essential to emphasize that all initiatives regarding CO_2 capture and storage require comprehensive investigation. Ensuring adherence to safety protocols and legislative standards regarding storage, especially concerning depleted reservoirs, is of utmost importance.

Major emitters are located in the Gorj, Galați, Ploieşti, Constanța, Târgu Mureş and Bucharest areas. Romania has an important geological storage capacity for CO_2, with estimates of theoretical storage potential amounting to 22.6 gigatons[13]. However, additional studies are needed to refine these estimates as well as assess the technical and economic storage potential. The most comprehensive estimates relate to depleted hydrocarbon deposits, whereas **most of Romania's storage potential is linked to saline aquifers,** which are less documented.

Currently, only two major oil and gas companies have proposed to capture and store CO_2, with targets around 1.5 – 2 million tonnes per year, while **Romania's theoretical storage potential which includes saline aquifers which account for most of this storage potential, is estimated at around 22,600 million tonnes of CO_2.**

Romania ranked in 2016 in the top six member states which generated 56% of the EU's emissions, alongside the Czech Republic, Germany, France, Italy, and Poland.

3.1.1. Romania's geological potential (depleted hydrocarbon fields, saline aquifers)

There are three types of potential CO_2 gas storage reservoirs, depending on the rock in which they are created to be stored:

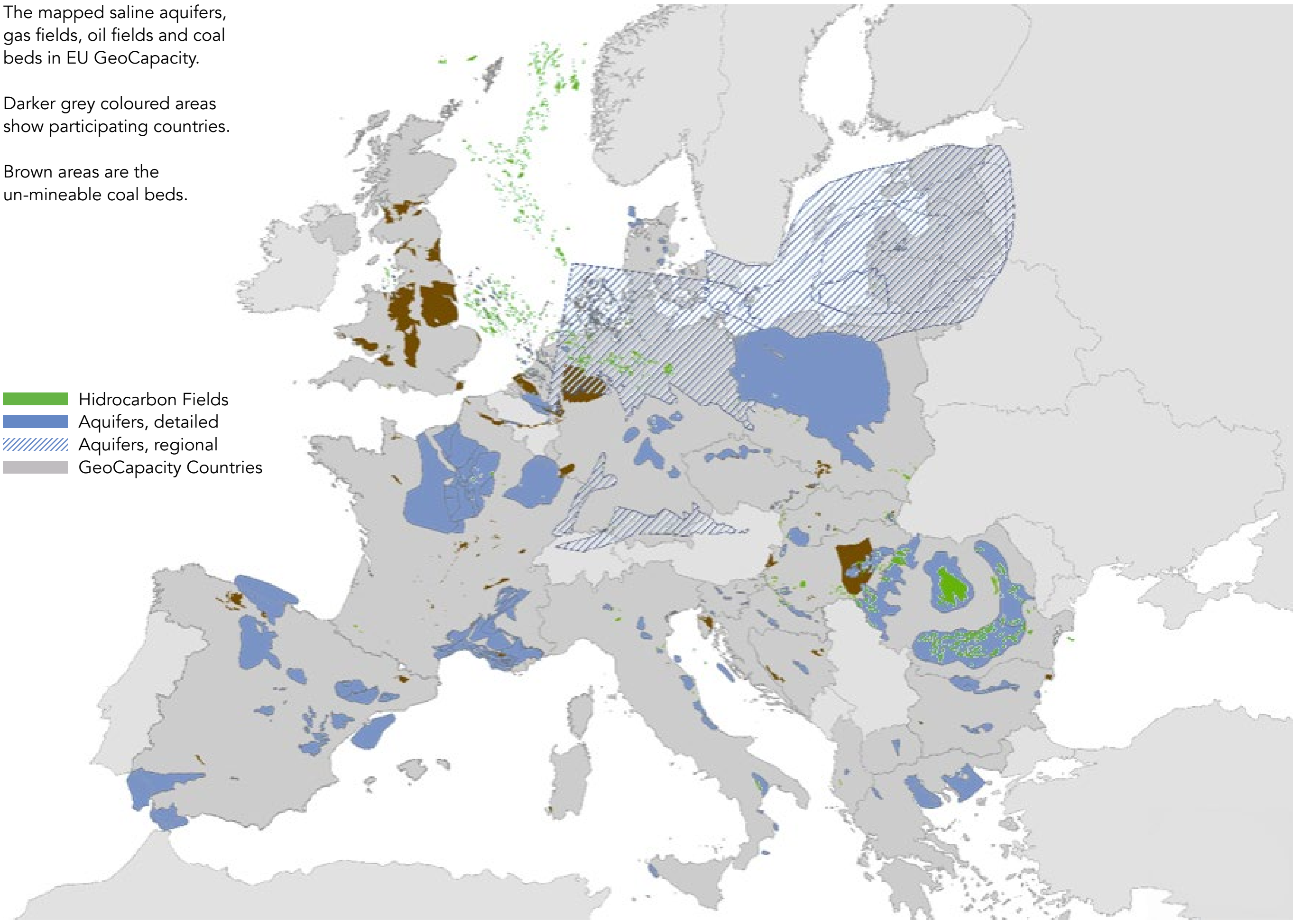
- Depleted hydrocarbon reservoirs;
- Saline aquifers;
- Salt mines.

There are several advantages to **depleted gas and oil fields.** Specifically, these fields have stored gases and liquids for millions of years, their geological characteristics are well understood, and there is significant remaining storing capacity. In fact, numerous oil and gas fields are coming close to their economic field life.

Saline aquifer structures need extensive exploration activities before CO_2 storage concepts can be developed and projects be matured.

12 Romanian Oil fields, Possible Natural Reservoirs for CO_2 Storage | Earthdoc.
13 EPG roadmap 2022

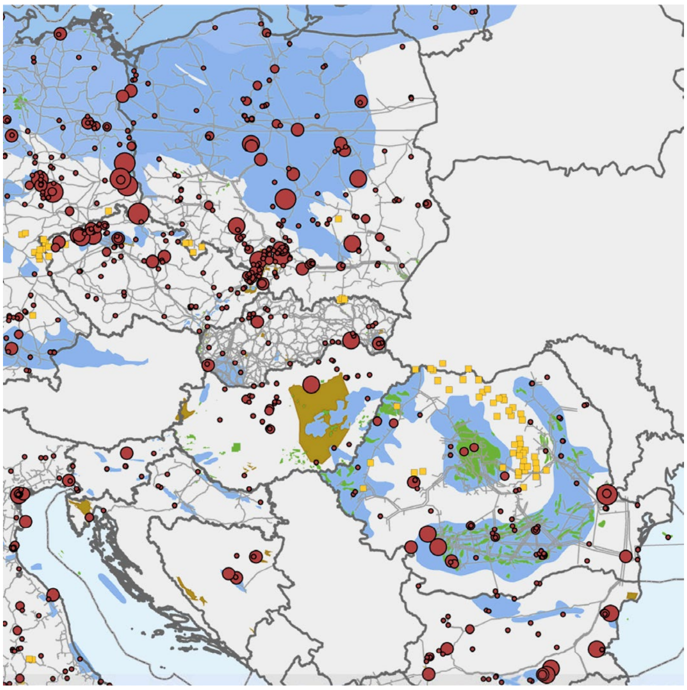
The image below shows the EU's storage capacities[14].



The mapped saline aquifers, gas fields, oil fields and coal beds in EU GeoCapacity.

Darker grey coloured areas show participating countries.

Brown areas are the un-mineable coal beds.



GeoCapacity maps of Sources & Sinks

Map of CO_2 emissions, infrastructure and storage capacity in Central-East Europe

CO_2 Sources Mt/year

- 0.001 - 1.000
- 1.001 - 2.000
- 2.001 - 5.000
- 5.001 - 10.000
- 10.001 - 32.000

- Natural CO_2 Sources
- Pipelines
- National Boundaries
- Aquifers
- Hidrocarbon Fields
- Coal Fields

Source: https://climate.ec.europa.eu/system/files/2016-11/geocapacity_en.pdf

14 https://panorama.ro/gaze-naturale-depozite-romania-gaz-iarna/

The proven track record[15] of **salt caverns and abandoned mines** for gas storage indicate these could provide alternative solutions for geological storage of CO_2, particularly where the conventional storage options are limited or not available near a CO_2 source. Salt caverns, along with depleted gas reservoirs and saline aquifers, have been used to store natural gas to meet seasonal cyclic or daily demand increase for several decades. Salt acts as a natural sealer, trapping the natural gas inside the cavern.

3.1.2. Romania's technological potential

Carbon storage technology can be applied to industrial installations such as cement or steel plants, as well as power plants. It can also be used to produce blue hydrogen in the first stage of implementation of the EU Hydrogen Strategy. CCS can generate negative emissions if it is combined with biogenic sources of CO_2, such as biomass. Biogenic emissions are emissions resulting from natural sources.

CCS technology can be implemented across sectors that are vital to the economy, including cement, steel, fertilisers.

Romania has extensive experience and know how in the field of CCS projects and technologies, from the perspective of its long-standing tradition in the exploration and exploitation of oil and gas. Furthermore, research in the CCS sector has continued in Romanian universities and research institutions. After the depletion of hydrocarbon reservoirs, Romania can use offshore deposits to become an important player in the development of this key decarbonisation technology.

3.2. Utilisation of CO_2

3.2.1. How it's done

The capture and utilisation of CO_2 involves operators to implement significant investments. All the operations involved by CSS projects require considerable financial resources.

CO_2 is used in industry for various purposes, such as:

- an inert gas in welding and fire extinguishers;
- a fluid for enhanced oil recovery;
- a critical fluid solvent in decaffeination of coffee and drying processes;
- a raw material in urea and fertiliser manufacturing.

According to the International Energy Agency[16], new directions to use CO_2 in the production of fuels, chemicals and building materials are generating increased global interest. The near-term market potential for key categories of CO_2-derived product and services includes **fuels, chemicals, building materials from minerals, building materials from waste,** and CO_2 use to enhance the yields of biological processes. All five categories could individually be scaled-up to market size of at least 10 megatons CO_2 per year.

CO_2 use can support climate goals where the application is scalable, uses low-carbon energy and replaces a product with higher life cycle emissions. Some CO_2-derived products also require permanent carbon retention, particularly building materials.

The market for CO_2 use is likely to remain relatively reduced in the short term. However, public procurement of low-carbon products can help create early markets for CO_2-derived products with verifiable climate benefits. In the long term, CO_2 sourced from biomass or the air could play a major role in a net-zero CO_2 emission economy, especially as a carbon source for aviation fuels and chemicals.

The use of CO_2 in building materials is an important opportunity, but it may require further trials and updating of standards for certain products. Also, CO_2 can be **an important raw material for products that require carbon.** Some chemicals require carbon to provide their structure and properties while carbon-based fuels may continue to be needed where direct use of electricity or hydrogen is challenging, such as in aviation. Worldwide, around 230 million tonnes of carbon dioxide are used every year. **The largest consumer is the fertiliser industry,** where 130 Mt CO_2 are used in urea manufacturing, followed by oil and gas sector, with a consumption of 70 to 80 Mt CO_2 for **enhanced oil recovery.** Other commercial applications include metal fabrication, cooling, fire suppression and stimulating plant growth in green houses.

15 Oil and Gas Science and Technology, https://ogst.ifpenergiesnouvelles.fr/articles/ogst/pdf/2005/03/shi2_vol60n3.pdf
16 **Putting CO_2 to Use – Analysis - IEA.**

The production of CO_2-based fuels and chemicals is energy-intensive, involving significant amounts of hydrogen. The carbon in CO_2 enables the conversion of hydrogen into a fuel which is easier to manage and use, for example as an aviation fuel. CO_2 can also replace fossil fuels as a raw material in chemicals and polymers.

In the transition to a net-zero economy, CO_2 would increasingly have to be sourced from biomass or the air. However, the future market potential for CO_2-derived products and services is difficult to assess. In theory, some CO_2 applications such as fuels and chemicals could grow to scales of multi-billions of tonnes of CO_2 use per year. Yet, in practice, they would compete with direct use of low-carbon hydrogen or electricity, which would be more cost effective in most applications.

As a result, **limitations to near-term scale up of CO_2 use are commercial and regulatory** rather than technological.

So far, in Romania, the National Agency for Natural Resources (NAMR) has supported projects such as Strategy CCUS, ECO-BASE (Establishing CO_2 Enhanced Oil recovery Business Advantages in Southeastern Europe), ALIGN-CCUS (Accelerating Low Carbon industrial Growth through CCUS). The agency is also a stakeholder in the REX-CO_2 project (Reusing drilling wells for CO_2 storage operations)[17].

3.2.2. Examples of CO_2 utilisation - Romanian and international projects

For instance, in Romania, **Azomureş has already developed capture and use facilities for carbon emissions.** As of September 2021, the company has presented[18] several solutions for carbon capture. These include a proposal to store CO_2 emissions in underground deposits where natural gas has been extracted for years, and which can now serve as reservoirs for significant amounts of emissions. This solution required investments, including from the state, particularly in logistics infrastructure. According to the company, "there is enough underground space, former natural gas and oil fields, which can now be reused for CO_2 storage", adding that such procedures are already conducted in Western Europe. In addition, **Azomureş is implementing CCU in its calcium carbonate unit** as an example of circular economy.

Another solution proposed by Azomureş is to restore a centralised heating system for households in cities which have industrial platforms in their proximity. Târgu Mureş is such an example, where the steam resulting from the technological processes of the company can serve as a source of heating for homes.

In **Israel, Shahar Solutions** has developed a prototype device capable of capturing 100% of carbon dioxide emissions from internal combustion engines before turning it into synthetic natural gas for long term energy storage. According to the Israeli company, the prototype, which is a special kind of balloon that can be sized to fit with a specific motor, collects emissions released from combustion engines of private cars trucks and even power plants. The various substances released in the combustion process, such as carbon dioxide, nitrogen and water vapours are collected inside the balloon, where they undergo various chemical processes that separate the carbon dioxide from the rest of the particles. In the last stage of the process, the carbon dioxide is converted into methane.

The carbon dioxide - methane production technology used by this company is based on *the Sabatier reaction*[19], a scientific principle discovered in 1897 by Nobel Prize-winning French chemist Paul Sabatier. In line with this principle, both methane and water can be produced by combining hydrogen and carbon dioxide at 400°C, and applying significant pressure in the presence of nickel.

Petra Nova CO_2 capture and use facility in Texas, US, is a telling case of how a technologically feasible project initially failed because of adverse external financial conditions. The facility was shut down in 2020 due to very low oil prices, after four years of operation. The $1 billion carbon capture, utilisation and storage project resumed operations in September 2023, after a three-year shut down. The Petra Nova CCS project, owned by a subsidiary of JX Nippon Oil and Gas exploration, aims to capture 1.4 million tonnes of carbon dioxide per year, being one of the world's largest CCUS initiatives.

17 Green Deal: România are capacități de stocare a gazelor de seră de 11.000 de ori mai mari decât stochează în realitate - CursDeGuvernare.ro.
18 https://www.azomures.com/en/press-release-co2-storage-solutions/
19 Israeli Startup Aims to Convert Carbon Emissions Into Natural Gas – Zavit.

The project began operating in 2016 at a coal-fired power plant in Texas, capturing CO_2 and storing it permanently underground. The Petra Nova was "cited as a viable example of the technology when the US Environmental Protection Agency proposed new emission standards for power plants"[20] in 2023. The project had received a $190 million grant from the US Department of Energy. Before shutting down in 2020, it captured around 3.8 million tonnes of CO_2 during a three-year period.

The Petra Nova project sent the CO_2 about 130 km by pipeline where it was pumped into an aging oil field to enhance output, a technique known as **enhanced oil recovery.**

3.3. Areas of interest for the implementation of the new technology

The CCS technology has the potential to be implemented across the entire market value chain, not only in the hard-to-abate or the oil and gas sector. The technology presents advantages for emitters, as well as for entities involved in carbon capture, use, transportation, and storage processes.

It is worth noting that, in 2011, Romania developed a carbon storage pilot project, known as Getica. At that moment, discussions relating to the pilot project took place in a context characterised by a high level of confidence among the various parties, resulting in a close coordination between the various authorities with the aim of transposing the EU's CCS Directive.

In the context of the legislative developments shaping up across the EU in 2011 with respect to the need for developing a legislative framework able to accommodate the requirements and specificity of the CCS technology, it is worth noting the Getica project as the first integrated CCS project at national level. The project was designed to cover the entire CCS value chain, meaning capture, transport and CO_2 storage. The entities involved in the project included Turceni Energy Complex SA, responsible for the CO_2 capture process, SNTGN Transgaz, as the transport operator, and SNGN Romgaz, tasked with the storage operations. The region selected for the implementation was Oltenia, which is a highly industrialised region.

The capture capacity envisaged for this project amounted to 1,5 million tonnes of CO_2 per year, at Unit 6 of the Turceni complex, through the modernisation of a carbon capture facility to the unit of 330 MW based on lignite. With respect to the transport part of the project, the CO_2 was supposed to be transported for a distance of 50 km away from the capture site, to be stored at a depth of around 800 m in onshore saline aquifers.

For Romania, CCS technology has come to the forefront, given the EU's ambitious climate commitments imposed by the NZIA regulation. According to the NZIA provisions, from 2023 onwards, out of the 50 million tonnes of CO_2 to be captured and stored by the EU per year, Romania is obliged to ensure the storage of approximately 9 Mtpa. In terms of this storage obligation, the cement industry alone needs a storage capacity of about eight million tonnes of CO_2 / year. Out of the 50 million tonnes of CO_2 assumed by the EU, **Romania has the obligation to ensure the storage of approximately 9 Mtpa.** As regards this storage obligation, the cement industry alone needs a storage capacity of eight million tonnes of CO_2.

CCS technology has the potential to support the just transition, by generating opportunities and potentially preventing a negative social impact over the transition on the national economy. This can be facilitated by the generation of new jobs for workers from the oil and gas sector, given the similarity required competencies and expertise between this sector and CCUS project development, implementation and management.

20 Carbon capture project back at Texas coal plant after 3-year shutdown | Reuters.

4. Examples of pilot projects successfully implemented at European and international level

According to the Global CCS Institute, carbon capture and storage is beginning to scale up, with CCS project pipeline having reached an unprecedented capacity. As of 31st July 2023, **the total CO_2 capture capacity of CCS commercial initiatives under development, construction and operation, across the public sector, amounted to 361 million tonnes per annum** (Mtpa), which is an increase of nearly 50% compared to that reported in the "2022 Global Status of CCS" report[21]. As of July 2023, there are 392 projects under development worldwide, out of which 41 are operational. Their total capture capacity amounts to 361 million tonnes per year.

As international CCS business models are currently designed, an important milestone was the first transboundary transport of CO_2 by ship from Belgium to Denmark for geological storage in 2023. It is worth noting that **most CCUS operational[22] projects around the world are associated with the oil and gas industry.**

Capture sites and transport networks are being developed to provide services for regional CO_2 sources. These sources are usually located less than 1,000 kilometres away from the storage resource. However, the sources may be significantly further in cases where the scale and project economics allow, in particularly where the main transport mode is by ship. These sites and networks establish shared CO_2 storage infrastructure for permanent CO_2 storage.

CCS networks are becoming **the dominant mode of CCS deployment.** CCS networks involve capture plants utilising shared transport and storage infrastructure. While many CO_2 transport and storage facilities are not linked to a specific CO_2 capture source, those same CO_2 transport and storage facilities still have a design capacity. For instance, a storage site announces its maximum annual injection rate, which will be reported as its capacity.

CCS networks have proliferated in 2023, with 101 CO_2 transport and storage facilities being identified by the Global CCS Institute worldwide last year. This distinct category of facilities represents a new CCS industry model. With respect to these, it is worth noting that examples of such multi-user, multi-industry CO_2 transport and storage facilities include: Wolf's Alberta Carbon Trunk Line CO_2 compression and pipeline operating in Canada since 2020; CarbFix CODA CO_2 transport and storage, shipping CO_2 from Europe before storing the carbon through mineral carbonation, and the Northern Lights open-source transport and storage network in Norway.

The Northern Lights project, expected to be operational this year (2024), will store deep under the seabed in the North Sea 0.8 million tonnes per year of CO_2 released by a cement plant in Brevik and a waste plant in Oslo. As of May 2023, the project includes another cross-border agreement with the city of Ørsted to transport and store an additional 430,000 million tonnes per year from two power plants in Denmark.

4.1. CCS onshore projects: France, Croatia

France case study

In France, the government's CCUS strategy involves launching a call for tenders through a Contracts for Difference scheme, to support project developers and scale up CCS deployment. Under this strategy, a framework for CO_2 transport will be developed, and various geological storage sites will be subject to pilot testing from 2024 – 2025 onwards.

The **Pycasso CCS** onshore programme, developed by the gas company **Teréga,** aims to exploit the significant geological storage resource identified as early as 2010 – 2013 in the Lacq successful project. The Pycasso initiative sets to collect CO_2 from across southwestern France as well as linking to Spain, either by ship to the port of Bayonne or by pipeline across the mountains. According to the Global CCS Institute[23], the depleted gas fields in southwest France offer onshore storage capacity of around 500 million tonnes. The region has supplied gas to France for 60 years, and benefits from wide industrial infrastructure, which was built around gas facilities. The project is expected to allow the storage of 15 million tonnes of CO_2 per year from emitters in France and northern Spain.

21 Global CCS Institute report "2022 Global Status of CCS".
22 PwC study, 2022.
23 https://www.globalccsinstitute.com/wp-content/uploads/2023/11/CCS-in-Europe-Regional-Overview-Global-CCS-Institute-pdf.pdf

The Pycasso Project[24] involves, apart from Teréga, thirty other institutional and industrial partners. Partnerships will also be established with the hydrogen industry in the Lacq basin to use some of the stored CO_2 in the form of methane or methanol. The project also seeks to contribute to achieving carbon neutrality in the Pyrenean region by 2040, by capturing CO_2, transporting it and safely storing it in the depleted oil and gas fields in this area.

Pycasso is a cross-border initiative covering the whole of the CCUS chain, being expected to generate value both at national and regional level. After several study phases, the first utilisation and injection is planned for 2030, with one to three million tonnes of CO_2 being stored every year. Phase two of this project is expected to be launched in 2035, with five million tonnes of CO_2 being stored every year.

An onshore project implemented on the French territory was the Lacq Pilot (near Pau, Southern France), now completed, which implemented to whole carbon capture, transport, storage chain and injected approximately 50 kt of CO_2 over 3 years in a deep depleted gas reservoir (Rousse, 4.5 km deep).

An interesting fact is that the fourth edition of the European Union CCUS Forum will take place in Pau, France on 10-11 October 2024 and will be co-hosted by the French Ministry for Energy Transition. This might imply that further CCUS development is to be expected in the area of Pau.

Croatia case study

In Croatia, two pilot projects aim to ensure that CO_2 emissions are reduced at an ammonia production plant and ethanol refinery. One pilot initiative is conducted at the **Petrokemija Kutina Ammonia** production plant. It involves capturing CO_2 and transporting it through an existing gas pipeline to depleted oil and gas fields. The project aims to capture 190,000 tonnes of CO_2 per year, while another investment sets to finance a CCS plant which will be part of an ethanol refinery project. This initiative is designed to capture 55,000 tonnes of CO_2 per year which will be transported to depleted gas fields about 40 kilometres away from the site. The CO_2 is transported via existing gas pipelines, while the latter still need to be renovated before being put into use.

Furthermore, **Croatian oil company INA** implemented an enhanced oil recovery (EOR) project, with a total investment amounting to around 69 million euros. A method largely applied on depleted oil reservoirs is carbon dioxide injection. An assessment of the possibility of CO_2 in oil fields was conducted in the last decades of the 20th century. Detailed laboratory research determined thermodynamic interaction of the injected CO_2 and reservoir fluid and confirmed the effectiveness of the oil displacement process. The best increase in oil recovery was achieved by alternating water injection and gas.

During 2001 – 2006, a pilot project of alternating water and CO_2 injection was performed. The injection of carbon in Ivanić oilfield started in late 2014 and in the northern part of the Zutica oilfields in late 2015. The EOR project considers dehydration, compression and transmission of 600,000 m^3/day of CO_2 by gas pipeline. The outcome of the project was an enhanced recovery for 6% compared to stored oil, prior to production, an additional production of 360.4 tonnes of oil and 55.120 m^3 of gas, and reduced CO_2 emissions permanent disposal of 2.9 billion tonnes m^3 CO_2. The plan is to perform 6 WAG cycles during the next 25 years.

4.2. CCS offshore projects: Norway, Denmark, the Netherlands, UK

Norway case studies

Norway's **Longship full-scale project** remains **the largest integrated CCS initiative** with two capture plants, the Hafslund Oslo Celsio waste-to-energy and Brevik cement and ship based open-access transport and storage provided by Northern Lights. The project has the potential capture and storage capacity of 5 million tonnes of CO_2 per year, while the government provides US $2.3 billion in support.

Northern Lights has finalised well drilling and started production of its ships. The capture facilities of the longship project are expected to be operational as of 2024, at least at the Heidelberg Materials Brevik plant. This initiative is about to become the world's first cement factory equipped with a CO_2 capture plant. However, given an updated cost estimate indicating larger expenses than initially planned, Celsio Oslo is currently considering pausing CCS instalment operations at its waste-to-energy Klemetsrud plant[25].

24 https://www.terega.fr/en/lab/does-terega-practise-co2-capture

25 NTB (2023) Hafslund Olso Celsio: The carbon capture project at Klemetsrud is carrying out a cost-reducing phase, 26 April 2023. Available at: https:// kommunikasjon.ntb.no/pressemelding/karbonfangstprosjektet-pa-klemetsrud-gjennomforer-en-kostnadsreduserende-fase?publisherId=17848166&releaseId=179643 54&lang=no

Additionally, Northern Lights has signed another international agreement, with Ørsted, for the commercial transport and storage of 430,000 tonnes of biogenic CO_2 per year for a decade. The Northern Lights capacity is fully booked for this project.

Furthermore, **Norway has already started awarding other exploration and storage licences to expand its CO_2 storage capacity.** Other **storage initiatives in preparation** include Poseidon (exploration licence stage), Luna, Smeaheia and Havstjerne (storage licence stage). Equinor is leading the planning process behind a wider project covering the entire CCS value chain known as the EU2NSEA project. This initiative aims to connect CO_2 emitters in Europe with storage sites in the North Sea by pipeline, with an expected capacity to transport and store up to 40 million tonnes of CO_2 per year. It is worth noting that **the Norwegian government has committed to using financial measures to support CCS initiatives through a mix of state aid and a national carbon tax.** This tax is expected to rise from NOK 952 (EUR 84) per tonne currently to NOK 2,000 (EUR 176) per tonne of CO_2 in 2030.

The Norwegian company **Removr,** which removes CO_2 directly from the atmosphere, has received NOK 36.3 million in government support for an industrial scale pilot project. This represents the first ever Direct Air Capture pilot developed in Norway, at the Technology Centre Mongstad, the world's leading carbon capture technology test centre.

Denmark case study

The Danish Ministry of Climate, Energy and Utilities has awarded the first three exclusive licences for exploration for the development of **full-scale CO_2 storage projects in the North Sea.** The government supports CO_2 storage and capture development through subsidies. €5 billion is expected to be distributed to store an estimated 3.2 million tonnes of CO_2 per year from 2030 through CCS projects in Denmark, with €500 million allocated in 2023 alone.

The Danish government awarded three full-scale exploration permits for offshore storage in February 2023. The expected storage capacity is two to three million tonnes per year in 2029 and 10 – 15 million tonnes per year in 2030 – 2032. An INEOS consortium, including Maersk drilling, GEUS and Wintershall DEA, was awarded both a pilot storage permit and a full-scale exploration permit. The expected storage capacity amounts to 1.5 million tonnes per year in 2025 and to 8 million tonnes per year by 2030.

Onshore storage is also under consideration, at least in a temporary form before CO_2 is transported for permanent storage in the Danish North Sea. In preparation for this, a geological survey of Denmark and Greenland has launched seismic preliminary studies of possible storage structures on land and near the coast. Concurrently, the Danish Energy Authority has started an environmental impact assessment.

Gas Storage Denmark and Fidelis New Energy are collaborating to develop the **Norne Carbon Storage Hub,** a large onshore carbon storage facility in Denmark. This initiative will include two CO_2 port reception facility sites, pipelines and wells designed to store CO_2 in existing natural reservoirs, with an expected storage capacity of 2.3 million tonnes per year in 2026 and 18.7 million tonnes annually by the end of this decade.

The Danish scheme is expected to stimulate investments in the CCS sector, cut down costs for future applications and facilitate the development of a commercial CCS market in Denmark. The European Commission has already approved €1.1 billion for a Danish scheme dedicated to carbon capture and storage technologies across the country.

The Netherlands case study

The country's highest administrative court ruled that the nitrogen oxide emissions during construction of the **Porthos[26] Project** would not have a significant impact on nearby natural areas. The project includes transportation of CO_2 from industrial sites in Rotterdam port and storage in empty gas fields underneath the North Sea. Entities capturing the carbon will further supply it to a collective pipeline running through Rotterdam port area. The CO_2 will be then pressurised in a compressor station and transported through an offshore pipeline to a platform in the North Sea, around 20 km off the coast. From there, the carbon will be pumped in an empty gas field. Porthos will store around 37 million tonnes of CO_2, around 2.5 million tonnes CO_2 per year for 15 years.

The construction of the project infrastructure will start this year (2024), with the system being expected to be operational from 2026 onwards.

26 https://www.porthosco2.nl/en/project/

Separately, the **Aramis[27] Project** will provide CO_2 transport infrastructure from Rotterdam to various storage fields in the North Sea. The project is expected to provide 22 million tonnes per year capacity for CO_2 transport and offshore storage, contributing to cuts in CO_2 emissions for hard-to-abate industries. CO_2 will be stored in depleted offshore gas fields, under the North Seabed. The project's location makes CO_2 transport and storage services accessible to various industrial clusters. The project is due to be operational in 2028, with further expansion starting in 2030.

The UK case study

The UK government in March 2023 announced it aimed to invest £20 billion for the early development of CCUS technology, as part of its broader target to reach net zero by 2050, which was signed into law in 2019. The objective is to capture 20 – 30 million tonnes of CO_2 per year. In 2022, the UK launched its first ever carbon storage licensing round, finalised with the receipt of 26 bids for 13 areas offered. In May 2023, the offer of awards for 20 carbon storage licences were made to 12 different companies. If accepted, these new carbon storage areas, could significantly support the aim of storing 20 – 30 million tonnes of CO_2 per year by 2030.

Pilot projects include **Oxycoal2[28],** located in Renfrew, Scotland, aiming to test a facility for oxyfuel combustion of pulverised coal. The initial test programme was finalised in 2011, with an estimated cost of £8.2 million, out of which £1.6 million from the government. Another pilot project is underway in Edinburgh, representing a research partnership between the British Geological Survey and several UK-based universities. The project aims to support the development and commercialisation of CCS technology as a climate mitigation means.

Denmark, Norway, the UK and the Netherlands lead the way in the CCS sector. Denmark and the UK recently launched their first tenders for CO_2 storage licences in the North Sea, including in both saline formations and depleted oil and gas fields. These countries also lead the way in developing and implementing **rules for CO_2 storage and transport licences.**

27 https://www.aramis-ccs.com/project/
28 https://www.geos.ed.ac.uk/sccs/project-info/99

5. Regulatory mapping

5.1. EU framework for the development of the market for CO_2

In 2009, the EU adopted the Directive regulating the safe and environmentally sound geological storage of CO_2 - **the CCS Directive.** Directive 2009/31/CE provides a regulatory framework for permitting the exploration of potential CO2 storage sites and storage operations. It covers the legal requirements for operation, closure and post closure obligations. The document also requires Member States to report to the Commission any updates relating to the implementation of the Directive every four years.

The Directive is accompanied by four nonbinding **Guidance Documents (GDs)** which were released in 2011 and are currently subject to updates:

- GD1 - CO_2 Storage Life Cycle Risk Management Framework;
- GD2 - Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures;
- GD3 - Criteria for Transfer of Responsibility to the Competent Authority; and
- GD4 - Financial Security and Financial Mechanism.

Operators are included in the **Emissions Trading System,** which ensures that in case of leakage they must surrender emission allowances for any resulting emissions. Emissions captured, transported and stored according to this Directive will be considered as not emitted. In the context of CCS, the **Environmental Liability Directive** complements these rules. Operators of CCS storage sites are obliged to prevent and remedy environmental damage associated with those sites (Articles 5, 6). Member States are required to take measures to develop financial security instruments and markets to enable operators to use financial guarantees to cover their environmental liability responsibilities (Article 14).

The CCU technology is regulated in **Directive (EU) 2018/2001**[29] on the promotion of the use of energy from renewable sources, which promotes renewable fuel of non-biological origin, and among others, fuels produced from captured CO_2. In December 2021, the Commission adopted a Communication on Sustainable Carbon Cycles[30] that aims to establish sustainable and climate-resilient carbon cycles. The document mentions key actions to support industrial capture, use and storage of CO_2, including the assessment of cross-border CO_2 infrastructure deployment needs at EU, regional and national levels until 2030 and beyond.

On 16th March 2023, the Commission put forward a proposal for a **'net-zero industry act'** that aims to expand the manufacturing capacity of net-zero technologies in the EU. The concept of 'net-zero technologies' includes carbon capture, transport, and storage technologies. As stimulating the geological storage of carbon dioxide is considered an essential element in the energy transition process of the European and Romanian economies, the NZIA Regulation also sets up an EU-level target for CO_2 injection capacity: the EU would have to reach an annual injection capacity of at least 50 million tonnes of CO_2 by 2030. Licensees of oil and gas production across the EU shall contribute to this objective on a pro rata basis of their oil and gas production over the period 2020 to 2023. Net zero strategic project status will be determined by Member States upon request from project promoters, with fast-track permitting procedures available. For instance, permits for operating a storage site will be granted within 18 months, in line with Directive 2009/31/EC.

5.1.1. Net Zero Industry Act - injection capacity obligation for oil and gas producers

Recently, the EU Council and the European Parliament reached a political agreement on the Net Zero Industry Act. The COREPER endorsed the agreement on 16th February 2024 and ITRE Committee from the European Parliament approved the agreement on 22nd February. A substantial market intervention was enacted through introduction of injection capacity obligations for oil and gas producers distributed pro-rata based on crude oil and gas production volumes between 1st January 2020 - 31st December 2023, with entities below a certain production threshold excluded (to be defined in a separate Delegated Act). The provisions leave room for an unbalanced interpretation of the manner in which the quota is assigned to Member States. Thus, the way in which this quota is conceived and applied presents several significant disadvantages for the new Member States, which are major gas producers. Based on provisional estimates of the European Commission, this will translate into approx. 9 Mtpa for Romania, the second biggest share in the EU following The Netherlands.

29 https://energy.ec.europa.eu/topics/oil-gas-and-coal/carbon-capture-storage-and-utilisation_en
30 https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

In line with the document, Member States are responsible for identifying and transmitting to the European Commission the relevant entities as well as their volumes in crude oil and natural gas production from 1st January 2020 to 31st December 2023. After receiving these reports, the Commission will consult the Member States and relevant parties and allocate the quotas.

Also, according to the provisions, within a year after the entry into force of the Regulation, the entities mentioned above are expected to submit to the Commission a plan presenting how they intend to meet their contribution requirement. These plans are expected to: (1) confirm the entity's contribution, expressed in terms of targeted volume of new CO_2 storage and injection capacity commissioned by 2030; (2) detail the means and milestones for reaching the targeted volume.

To meet the expected volumes of available injection capacity, relevant entities should:

- Develop or invest in CCS storage initiatives;
- Conclude agreements with other entities;
- Conclude agreements with third party storage project developers or investors to ensure they fulfil their contribution.

Two years after the entry into force of the Regulation, the entities mentioned should report to the Commission their progress.

The proposal notes that a value-chain approach should be encouraged through both EU and national measures. The text also points out that investments should be made while also paying attention to the development of "viable business models for the entire carbon dioxide value chain".

According to the proposal, in cases where joint ventures have been established before the entry into force of this Regulation, the full injection capacity of relevant joint CO_2 storage projects can be used to meet the requirements of the parties that need to fulfil this obligation. Also, to ensure that storage sites are developed under robust market conditions, the European Commission will conduct an assessment exploring the relationship between the concrete demand for injection capacity from CO_2 capture projects and the main infrastructure needed for the transportation of CO_2 under development or planned to be operational by 2030. Nevertheless, it is to be underlined that the 2028 deadline for the assessment exercise risks to undermine the very scope of it, as it will happen too close to the compliance deadline of 2030. Details and terms concerning these derogations will be provided in a Delegated Act.

Furthermore, additional policy steps are needed to ensure the deployment of cross-border infrastructure planning, in the case of projects involving collaboration between entities located in different member states. Accessibility and connectivity across the full spectrum of CO_2 transportation arrangements "play a critical role" for the deployment of CCS and CCUS initiatives.

These arrangements include ship, barge, train and trucks as well as fixed facilities for connecting purposes, liquefaction, buffer storage and converters of CO_2, considering their further transportation through pipelines.

Furthermore, based on the progress concerning CO_2 market developments assessed by the EC, no later than 31st December 2028, a new legislative proposal may be presented, defining new injection capacity targets. Although the current text does not clarify if this would be also based on obligations of oil and gas producers, the prospects of further market interventions can harm the overall investment climate.

With respect to sanctions applicable to operators failing to comply with CO_2 injection and storage requirements, the proposal sets out that member states should establish penalties, through administrative procedures or legal proceedings, for infringements involving entities mentioned in Article 18 (1), no later than 24 months after the entry into force of the Regulation. Under this proposal, the penalties should be "effective, proportionate and dissuasive". It is to be noted that this provision will result in different implementation across the various member states with relevant challenges attached to it.

5.1.2. Challenges linked to implementation

According to the agreement, "Member States should take the necessary measures to facilitate and incentivise the deployment of carbon capture and storage projects"'. These measures should include steps aiming to stimulate emitters to capture emissions, including through investments designed to support investments in CO_2 transport infrastructures to transport CO_2 to storage sites.

The proposal notes that the reduction of the regulatory burden on operators is "particularly important for industries to adjust effectively to the climate and energy transitions". Thus, the EU should aim to achieve by the end of this decade a significant reduction in the general regulatory burden on the industry. To support this objective, the EU has set up a Net-Zero Regulatory Burden Scientific Advisory Group, tasked with elaborating science-informed advice on the impact of the regulatory burden in the EU on net-zero industries.

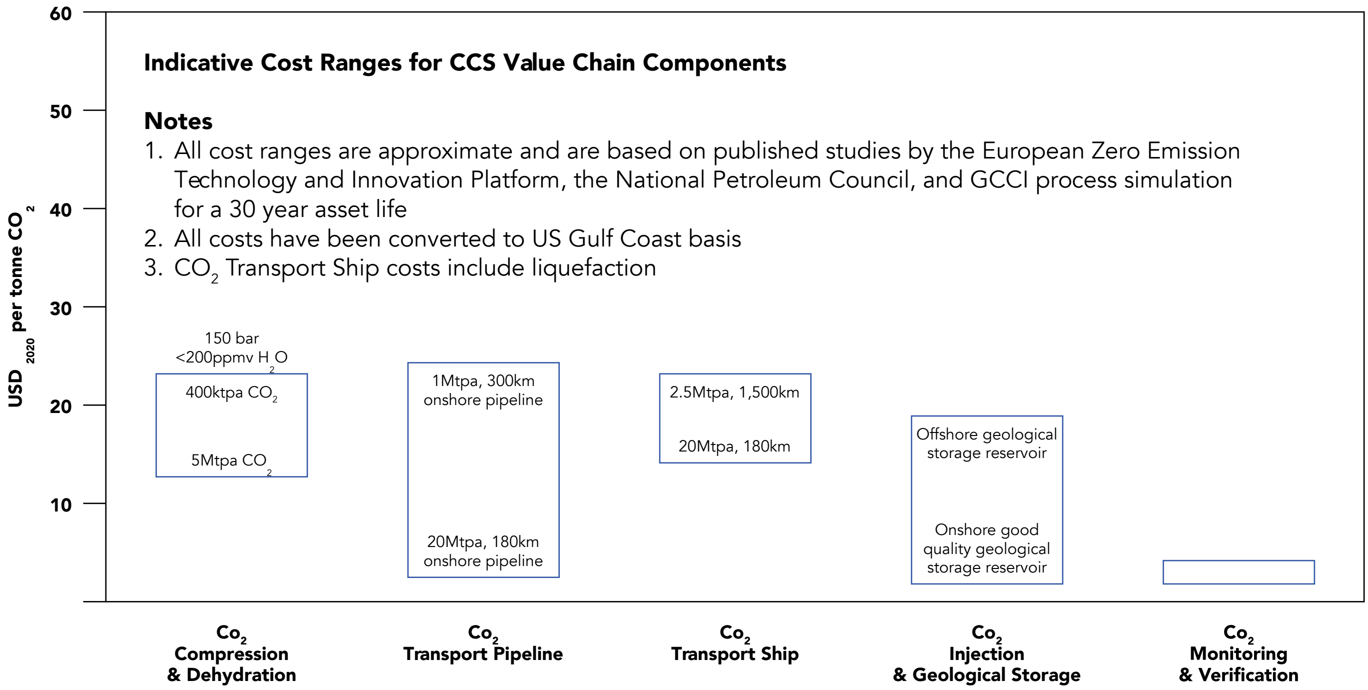
Romanian oil and gas operators have highlighted the fact that before any decision is taken with respect to the implementation of CCS projects at the national level, **it is necessary to conduct environmental impact studies,** to validate that it is safe to undertake such projects, in relation to local communities. The responsibility for such environmental impact assessments should be clearly assumed at the national level by authorities with attributions in this sector. It should not be up to operators to conduct these assessments, particularly since there are several member states which have formally prohibited the underground storage of CO_2, and others are about to do so.

The oil and gas industry has increasingly signalled the need for the Romanian state to assume an active role **providing access to public funding or other financing support schemes** being essential for CO_2 storage projects, due to:

- Capital intensive investments;
- Long project development periods (8-10years) with uncertain CO2 ETS price as cost avoidance along the full value chain for such long period and long payback period for the investments due to longevity of operations;
- Longevity of environmental liabilities risk.

Considering that authorities do not offer any guarantees with respect to assuming firm contracts in relation to emitters for at least a decade, able to justify alternative funding from external loans for such investments. If authorities do not succeed to grant support in this respect to the industry, there is a risk that targeted entities face significant negative financial impact on their business, particularly small and medium-sized operators.

Indicative cost ranges for CCS value chain components are shown in the figure below, calculated in USD for 2020.



Source: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf

Addressing carbon capture, transport and storage presents a complex challenge, particularly when it comes to capturing investment commitments from emitters while simultaneously imposing storage capacity obligations, as proposed by the Net Zero Industry Act (NZIA) on the oil and gas industry. This dual requirement necessitates careful balancing to ensure that emitters are incentivized to invest in capture technologies while also ensuring that sufficient storage capacity is available to accommodate captured CO_2. The potential imposition of storage capacity obligations adds an additional layer of complexity, as it requires precise estimation of future storage needs and coordination between industry stakeholders. Failure to effectively manage these commitments could result in bottlenecks within the CCS value chain, hindering progress towards emissions reduction goals and creating uncertainty for both investors and policymakers.

Moreover, Romania faces significant challenges related to the lack of CO_2 transport infrastructure, further exacerbating the bottleneck within the CCS value chain. Despite the country's potential for CCS deployment, including ample geological storage sites, the absence of an adequate transport network limits the feasibility of large-scale CCS projects. Without the necessary infrastructure to transport captured CO_2 from emitters to storage sites, the potential benefits of CCS technology cannot be fully realized. Overcoming this challenge requires substantial investment in building CO_2 transport infrastructure, along with coordination among government agencies, industry stakeholders, and financial institutions to ensure the timely development of a comprehensive and efficient transportation network. Failure to address this infrastructure gap not only hampers Romania's ability to reduce emissions but also impedes its competitiveness in transitioning towards a low-carbon economy.

5.2. National legislative and non-legislative framework

5.2.1. Missing elements and recommendations for legislative update to reflect the requirements of the CCUS technology

The CCS Directive had to be transposed into national law by June 2011. In the Romanian national legislation this happened through Emergency Ordinance 64/2011. It was meant to facilitate the implementation of the Getica CCS project, this largescale demo project with storage in deep saline geological formations with the capacity of 1,5 Mtpa.

Primary regulatory adjustments as well as elaboration of related secondary legislation (technical norms) are prerequisites for a successful deployment of this technology at the national level.

However, although GEO 64/2011 has been approved in due time, it lacks the administrative and procedural aspects. Also, no support schemes have been introduced so far to encourage the development of CCS projects on the local market. This state of facts is also highlighted in the latest version of the National Integrated Plan in the field of Energy and Climate Change 2021 - 2030 (PNIESC), currently under public consultation, and in Romania's Long-Term Strategy for reducing greenhouse gas emissions.

The proper implementation of a fit for purpose regulatory framework should be ensured by institutional knowledge and capacity building, which is of key importance.

5.2.2. Need for national strategy for successful deployment of CCUS technology

In order to enable the CCS technology to live up to its full potential a holistic approach is needed, involving all relevant parties across the value chain. The development of specific infrastructure and storage projects is crucial to attain the climate change objectives. It is crucial also to consider the national specific limitations at the level of each Member State, which are beyond the scope of action of the companies required to take steps in this sector.

All entities participating in the value chains of CO_2 injection activities should be stimulated to consider whether the carbon to be stored could be permanently stored in new products. Innovation will play an important role in ensuring the Union's competitiveness, as well as reaching the net-zero objectives as soon as possible.

Formulating a national CCS strategy ensuring a roadmap for implementation based on trilateral work of the Ministry of Economy, Energy and Environment should ensure the long-term vision and stability for investors. In this sense the following key elements should be considered:

- Mapping potential storage sites, involving the NAMR and operators;
- Mapping potential emitters;
- Mapping transport routes, with pipelines across existing routes and new routes which can be created;
- Necessary normative acts;
- Communication strategy, both at the national and local level, in relation to local authorities and wider audience;
- Funding;
- Necessity to have a platform accommodating the entire value chain.

5.2.3. Social acceptance of the CCUS technology - potential showstopper

Recent analysis and research conducted by leading think tanks experts indicate that wider commitments from governments are required to ensure alignment with the Paris Agreement goals. Concurrently, such commitments need to be correlated with the development and adoption of adequate communication strategies and policy measures, including information to wider audiences about the technologies used or planned to be used, the types of technical standards relating to the operations involved, the relevant entities and the CCS sector's role in combating climate change.

Information for the wider public should also present the key benefits and challenges involved by the implementation of the CCS technology, to prevent misinterpretations. In this context, it is important for both member states and operators to develop and use adequate communication and engagement strategies in relation to the local communities where they plan to develop CCS projects.

The Global CCS Institute has developed a **Communication and Engagement Toolkit for CCS Projects[31].** The toolkit focuses on identifying the relevant stakeholders, elaborating SWOT analyses, as well as establishing **a suitable communication and engagement plan.** According to the global CCS institute, the stakeholders' identification process involves assessing the attitudes of stakeholders in relation to the proposed project. Assessing these attitudes will help establish the level of interest and influence these stakeholders may have on the proposed CCS initiative.

More importantly, the document notes that stakeholders' attitudes may change throughout the course of the project. As a result, it is important to monitor these attitudes in order to adequately identify ways to effectively manage any challenges. **The identification of the relevant stakeholders and their attitudes towards the proposed project** will serve as an important tool in establishing where the greatest and least efforts are likely to be required when developing a communication strategy. Particular attention should be paid to the academic community, whose interest and commitment to the CCS sector may be significant. Experts such as scientists, researchers and academics with knowledge about the CCS sector "are often trusted sources of information" and can be involved in formal engagement activities with the aim of disseminating information across all levels of society.

Another important recommendation is that open communication with key stakeholder groups such as groups or people holding lands nearby a site suitable for CCS projects should take place as early as possible in the process. Important issues include **access to land, benefits and compensation.** In this process, neighbouring communities along the transportation routes or where seismic testing may needs to occur are equally important.

Financial groups and investors require specific engagement because of the size of investments required for CCS projects. In this case, it is essential that relevant financial representatives adequately understand the nature of the business or of the project. In several cases, the nature of the risks identified, or the level of uncertainty was considered so high that the market could not bear the costs and the investment would not occur at any level of return. Another significant factor to be considered is the policy uncertainty. **Policy uncertainty** may be regarded as a risk that could prevent investment unless it is addressed.

31 https://www.globalccsinstitute.com/archive/hub/publications/13571/publication-20110601-communication-engagement-toolkit.pdf.

Conclusions

According to recent analysis by Kearney[32], the capture capacity of the current pipeline projects needs to be multiplied nearly four times by 2030, to achieve the International Energy Agency's objectives and the UN's sustainable development scenario.

The reduction of CO_2 emissions and increased resilience to climate change are possible, provided that a set of significant social, economic and technological conditions are in place to allow the implementation of the CCS technology. The dissemination of comprehensive information to the general public about the technology is also a major factor to be considered as a key element for public acceptance. Equally important is to engage early in the process with all relevant stakeholders and potentially impacted communities, as well as engaging with the academic community, which is an important resource of knowledge and expertise in this sector.

In Romania, a country with extensive experience, human capital and know-how specialised in oil and gas exploration and exploitation, which can be easily transferred to the CCS sector, the existence of significant industrial sites such as those in the southwest part of the country, present significant opportunities to implement the CCS technology. For the successful deployment of the CCS technology first and foremost a fit for purpose legislative framework is needed with the relevant technical norms also in place.

Exchanging best practices and looking at other European states with interest and experience in developing CCS systems, (for example Denmark, France, and Norway) with CCS projects in various stages of development underway, both onshore and offshore would come with an added value.

From an investor perspective, current **barriers** limiting the development and use of the CCS technology are linked to the considerable **upfront capital costs** involved in the initial development stages, characterised by high uncertainty with respect to the success of the project. In addition, the entire CCS value chain needs to be considered, to ensure the financial feasibility of the project. Also, particular attention should be paid to ensuring that comprehensive information about the CCS technology reaches the general public as well as national decision-makers with attributions in this sector, to prevent counterproductive reactions.

Additionally, it is critical to ensure that CCS initiatives in development stage proceed efficiently to the final investment decision, construction and operation. The formulation of policies which facilitate transport and storage sites, attracting more local capture projects, would contribute to an increasing number of CCS projects which can be developed. Such actions can also be coupled with the support for initiatives which encourage cross learning between projects, thus leading to an improved understanding of the CCS technology and its benefits across wider audiences and decision makers alike.

CCS is expected to generate new investments, and as a result produce revenues for the state budget, while preserving workplaces in the oil and gas sector which would otherwise disappear, in the context of the energy transition. Several schemes have been set in place by the European Commission to support CCS projects, including the Innovation Fund (with over 25 billion euros allocated for CCS initiatives), the Connecting Europe Facility (for cross-border CO_2 transport networks), and the Recovery and Resilience Fund (for projects included in national plans), the Just Transition Fund, and the Modernisation Fund.

In the context of the ongoing approval of the Net Zero Industry Act, and the importance of ensuring projects' economic feasibility, it is important to monitor the form in which the derogatory mechanism based on a demand and offer analysis of the injection capacity will be defined.

More importantly, taking into consideration the natural decline specific for Romania's overall oil and gas resources, as well as the potential reduction in the related production in the context of the decreasing financing for oil and gas projects in the context of the energy transition, the potential to implement CCS projects, as a secondary activity to oil and gas operations, remains very significant.

32 Carbon Capture Utilization and Storage - Kearney - https://www.kearney.com/documents/17779499/17781864/CCUS-2021+FactBook.pdf/718e94af-1536-b23e-1ac9-a4de74ffef25?t=1623398953000