Commodities Committee

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White Paper

Energy Transition Commodities: Carbon Capture Storage and Utilisation

TIC Council is the global trade association representing the independent third-party Testing, Inspection and Certification (TIC) industry which brings together about 100-member companies and organizations from around the world to speak with one voice. Its members provide services across a wide range of sectors: consumer products, medical devices, petroleum, mining and metals, food, and agriculture among others. Through provision of these services, TIC Council members assure that not only regulatory requirements are met, but also that reliability, economic value, and sustainability are enhanced. TIC Council's members are present in more than 160 countries and the wider TIC sector currently employs more than 1 million people across the globe.

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Abstract

Governments, businesses, and consumers around the world are navigating the complexities of the Energy Transition, surrounded by a flood of new products, technologies, and commodities—all promising to drive a sustainable, green economy. However, amid these numerous offerings and ambitious claims, the challenge remains: how can we ensure that these emerging solutions genuinely contribute to a transparent, reliable, and robust energy transition?

This series of White Papers provides an in-depth analysis of green commodities and their value chains. It explores the challenges faced by economic operators in the commercialization of these products, while also highlighting how independent ESG Verification and Certification services play a crucial role in ensuring quality, transparency, safety, and trust.

This White Paper examines the critical role of **Carbon Capture and Storage (CCS) and Carbon Capture and Utilization (CCU)** technologies in global decarbonization efforts, particularly for hard-to-abate industries with significant CO_2 emissions. CCS focuses on permanently storing CO_2 in geological formations, while CCU repurposes captured CO_2 for industrial applications. Both technologies are essential to achieving emissions reductions across various sectors, including waste treatment and CO_2 removal processes.

The paper addresses the full CCS/CCU value chain, exploring CO_2 capture, transportation, and geological storage methods, along with the key challenges these technologies face, such as project financing, ensuring mechanical integrity, regulatory gaps, and the risks of greenwashing.

The Testing, Inspection, and Certification (TIC) industry plays a vital role in overcoming these challenges by providing independent assessments throughout the project lifecycle. TIC companies ensure compliance with evolving standards, validate the mechanical integrity of assets, and promote ethical and sustainable practices. By offering technical expertise and supporting the development of industry regulations, TIC companies help safeguard the transparency, safety, and long-term viability of CCS/CCU projects, fostering genuine contributions to global decarbonization efforts.

1. Introduction / Executive Summary

Carbon Capture and Storage (CCS) refers to various technologies which capture CO_2 emissions for storage deep underground. Carbon Capture and Utilisation (CCU) is a related process whereby CO_2 emissions are captured, and the CO_2 subsequently used, either in its existing form (e.g. for Enhanced Oil Recovery) or transformed to produce chemical feedstocks, synthetic fuels or building aggregates.

CCS is considered an essential means to achieving decarbonisation targets, particularly for hard-to-abate industry sectors such as cement and steel production, as well as for regions where fossil fuels are likely to remain a significant source of energy generation for some time. Benefits of CCU are likely to be economic, rather than environmental – production of building aggregates is the only application of CCU which is equivalent to permanent CO_2 sequestration, as of now.

CCS can be implemented across a wide range of essential industries to reduce their carbon footprint, including inter alia cement, steel, paper production, power generation, natural gas processing, and the production of decarbonised (blue) hydrogen and derivatives.

The regulatory framework for CCS/CCU remains under development. The ISO TC265 (Carbon Dioxide Capture, Transportation and Geological Storage) working group is currently developing a set of standards covering the applications of CCS and CCU. For operators attempting to navigate this emerging and fast-changing regulatory system, the Testing, Inspection and Certification (TIC) industry offers an excellent source of expertise and guidance.

In addition to providing regulatory counsel, the TIC industry can support CCS/CCU operators with the following:

- Feasibility / RAM studies
- Technology Risk Assessment
- Design Reviews
- Risk and Safety Studies
- Flow Assurance
- Carbon Footprint and Life Cycle Assessments
- Guarantee of Origin and Quantification of CO_2
- ESG / CSRD Certification

The engagement of TIC companies throughout the CCS/CCU value chain provides trustworthy assurance for all stakeholders. Certification by an independent third party can prove to potential investors and the wider community the viability of a project, the expertise of the project's operators and the ongoing compliance of the project's processes with the most up-to-date regulations and standards. With our global ability to provide in-person & on-site inspections rather than remote, paper-based audits, our industry is the best choice for companies looking to demonstrate their ESG credentials and contribute in a truly responsible and sustainable way to reducing the world's carbon emissions.

2. What is CCS/CCU value chain?

CCS stands for Carbon Capture and Storage, while CCU stands for Carbon Capture and Utilisation. Both are technologies aimed at reducing carbon dioxide emissions and mitigating climate change. The first step for capturing fossil-based CO_2 involves capturing carbon dioxide emissions produced from industrial processes, power plants or other sources before they are released into the atmosphere. There are various capture technologies, including post-combustion capture, pre-combustion capture, and oxy-fuel combustion. Once captured, the carbon dioxide needs to be transported to a suitable site for geological storage. This can involve pipelines, ships or trucks, depending on the distance and the form in which the carbon dioxide is stored.

For CCS, the captured carbon dioxide is injected and stored in geological formations using either depleted oil and gas fields, which are repurposed for CO_2 storage, or saline aquifers developed for this purpose. In order to be used for geological storage of CO_2, each site must be evaluated and characterised to provide assurance on storage integrity and to determine the rate at which CO_2 can be injected and the amount of CO_2 that can be safely stored. Assurance on the integrity of the storage during injection operations is provided by undertaking the actions described within the site-specific Measurement, Monitoring and Verification plan. The MMV plan specifies the actions required and information to be collected in order to evidence storage containment and to provide confidence that the store is providing long-term containment of carbon dioxide, with the ability to detect and quantify any CO_2 migrating from storage into the atmosphere.

Instead of storing the captured carbon dioxide underground, CCU involves finding beneficial applications for the captured carbon. This can include transforming carbon dioxide into valuable products, chemicals and materials. For each CCU project, it needs to be assessed how related products are used in order to verify net reduction in CO_2 emissions into the atmosphere.

a) The need to remove CO_2

Carbon dioxide emissions refer to the release of carbon dioxide into the atmosphere, primarily as a result of human activities. The main sources of carbon dioxide emissions are burning fossil fuels and certain industrial processes. The combustion of fossil fuels, such as coal, gas oil, gasoline, residual oil and natural gas for energy production, is a major contributor to carbon dioxide emissions from power generation, heating and transportation. In addition, industrial activities, such as cement and steel production, release carbon dioxide as a by-product.

Carbon dioxide is a greenhouse gas that contributes to climate change by trapping heat in the Earth's atmosphere. Increasing the carbon dioxide concentration in the Earth's atmosphere therefore contributes to a corresponding increase in temperature. The elevated temperature can significantly impact our Earth and its residents, through extreme weather events, rising sea levels, the extinction of species and threats to human health. The Paris Agreement is an international treaty that aims to address climate change by limiting global warming to well below 2˚C above pre-industrial levels, with efforts to limit the increase to 1,5˚C[1].

Carbon Capture and Storage (CCS) can be integrated into power plants and industrial facilities that use fossil fuels, allowing for the continued use of these energy sources with reduced environmental impact. This is particularly relevant since renewable energy sources may not yet fully replace fossil fuels in certain sectors.

1 Paris Agreement. United Nations framework convention on climate change; 2015

Many countries and regions have set targets for reducing greenhouse gas emissions to combat climate change. Carbon capture technologies can play a crucial role in achieving these targets by capturing carbon dioxide emissions from industries that are challenging to decarbonise, such as cement and steel production. In some regions, fossil fuels remain a significant part of the energy mix. Capturing carbon from these sources can help maintain energy security, all the while minimising the environmental impact on the journey towards creating a more sustainable and low-carbon future.

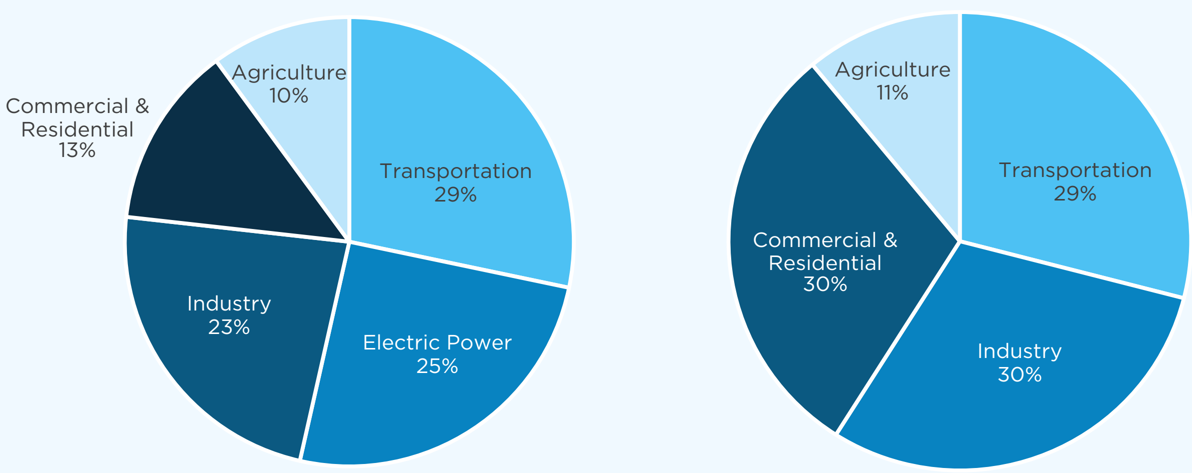
While carbon capture is considered a valuable tool in the fight against climate change, it is important to note that it is not a standalone solution. It is part of a broader strategy that includes transitioning to renewable energy sources, improving energy efficiency, afforestation or reforestation and implementing other sustainable practices to achieve meaningful and lasting reductions in greenhouse gas emissions[2].

b) What industries are at stake?

To reduce net emissions of CO_2, several industrial sectors are planning and developing Carbon Capture and Storage or Carbon Capture, Utilisation and Storage as an integral part of their decarbonisation strategies.

The International Energy Agency, and other organisations looking at ways to reach net zero, have identified Carbon Capture, Utilisation and Storage (CCS/CCU) as necessary for reaching net zero emissions. There are countless places around the world that emit waste gas streams into the atmosphere at varying flow rates and pressures, and with various concentrations of CO_2. In general, the higher the concentration of CO_2 and pressure of the gas stream, the easier it is to capture CO_2 before it is emitted into atmosphere.

Figure 1 – Left: Total U.S. Greenhouse Gas Emissions by Economic Sector in 2021. Right: Total U.S. Greenhouse Gas Emissions by Economic Sector Including Electricity End-Use Indirect Emissions[3]



2 Further relevant information in: JRC Report EUR 31707 EN – JRC134999 – Carbon Capture Utilization and Storage in the European Union – Status report on technology development, trends, value chains & markets

3 United States Environmental Protection Agency – Sources of Green House Gas Emissions: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

CCS/CCU is expected to be implemented by several industry sectors:

i. Industrial emitters

Industrial processing and manufacturing industries are responsible for approximately a quarter of global CO_2 emissions and are often referred to as hard–to-abate, since they cannot reach net zero emissions simply by switching to renewable power or other low-carbon energy sources. These sectors have consequently identified a range of actions to reduce emissions, including implementing CO_2 capture and geological storage across several sectors such as cement, iron, steel, petrochemicals, pulp and paper production.

In order to appreciate the importance of CCS to decarbonising industry, we can consider the cement industry – which is thought to be responsible for approximately 5-8% of global CO_2 emissions. The industry body, the Global Cement and Concrete Association, has set out a road map for reaching net zero by 2050. It has identified the role of Carbon Capture and Storage in 36% of the overall reduction in emissions.

The cost and difficulty of implementing CO_2 capture processes will vary between industries, as will the extent to which CCS/CCU can contribute to reaching net zero goals. The opportunity which CCS represents for industrial emitters is to significantly reduce the carbon intensity of products and meet the anticipated future demand for green products.

ii. Power generation

CCS/CCU has the potential to reduce emissions by being retrofitted to current fossil fuel power generation, and being deployed with a future generation of low-carbon dispatchable power plants.

Retrofitting CCS/CCU to conventional fossil fuelled power plants provides a means by which existing power generation emissions can be reduced. It is unlikely that much of the global fossil fuel power fleet will be shut down in time to meet climate targets. A significant number of fossil-fuel power plants have been commissioned in the last decade, with almost one-third of all coal-fired power capacity being less than ten years old.

Due to the age of a significant number of existing fossil fuelled power fleets, and growing pressure for emission reduction, CCS/CCU retrofits offer asset owners a way of continuing operations at existing plants while meeting carbon reduction targets.

As investment continues in renewable sources of energy, there is a need– due to the intermittent nature of renewable sources – for dispatchable power generation. To ensure the stability of power grids and the availability of electricity for meeting end user demand, dispatchable power plants can go from standby to full power in a relatively short period of time and will normally use fossil fuels such as natural gas, fuel oil and coal. In order for such dispatchable generation to be low emission it will need to be operated on low-carbon fuels or be coupled with CCS.

Several new, low-carbon dispatchable power generation plants are being developed which combine natural gas CCGT with CO_2 Capture and Storage. When completed, they will provide low-carbon power, as and when needed, to meet the intermittency of renewable power sources.

In addition, it is expected that CCS will be retrofitted to quite a few existing gas and coal-fired power plants, providing base load generation in order to reduce the emissions associated with such power generation. This approach may be particularly applicable in regions which rely on coal and gas for power generation.

The same principles can be applied for capturing carbon dioxide emissions produced by the ship's engines for delivering power on board ships. In addition to the carbon capture facilities on the ship, infrastructure ashore for discharging the captured CO_2 and transporting it to storage or utilisation sites is needed. On-board carbon capture technology can potentially allow for the use of non-carbon-neutral or non-zero-carbon fuels while still achieving maritime greenhouse gas emissions targets.

iii. Fuel transformation

Although there is a significant and sustained move towards electrical vehicles for transportation, it is expected that petroleum fuels will continue to provide a significant and vital part of energy for transportation. In order to reduce emissions associated with refining, it is expected that Carbon Capture will be installed on existing oil refineries with captured CO_2 being moved to geological storage via proximity transport and storage infrastructure.

In addition, CO_2 capture and storage is expected to become a key technology used in producing low-carbon hydrogen from natural gas. Although the CO_2 intensity of so-called blue hydrogen is higher than that of hydrogen produced from renewable energy and electrolysis of water (green hydrogen), it is considered that this method may be scaled up more quickly, enabling industrial users of blue hydrogen to reduce their emissions by switching to the fuel.

iv. Waste treatment

Waste incineration is a process for dealing with Municipal Solid Waste (MSW) by combusting the waste stream under strictly controlled conditions to minimise resulting waste products and ensure that the resulting atmospheric emissions, such as sulphur dioxides, nitrous oxides, heavy metals and dioxins, are maintained within the limits set by relevant environmental authorities. This process of handling municipal waste can also be used to generate electricity in Waste-to-Energy (WtE) plants. Although waste incineration and WtE plants are exempt from many of the largest emissions trading schemes, they produce almost a tonne of CO_2 for every tonne of MSW; it seems likely that, by 2028, waste incineration will be included within emissions trading schemes such as the EU ETS and the UK equivalent.

Although adding CO_2 Capture to WtE plants reduces electrical power output, it is considered that adding CCS/CCU to such plants can provide an effective means of reducing overall associated emissions. Accordingly, several projects in Europe are moving forward with applying CCS/CCU to waste incineration facilities.

v. CO_2 Removal

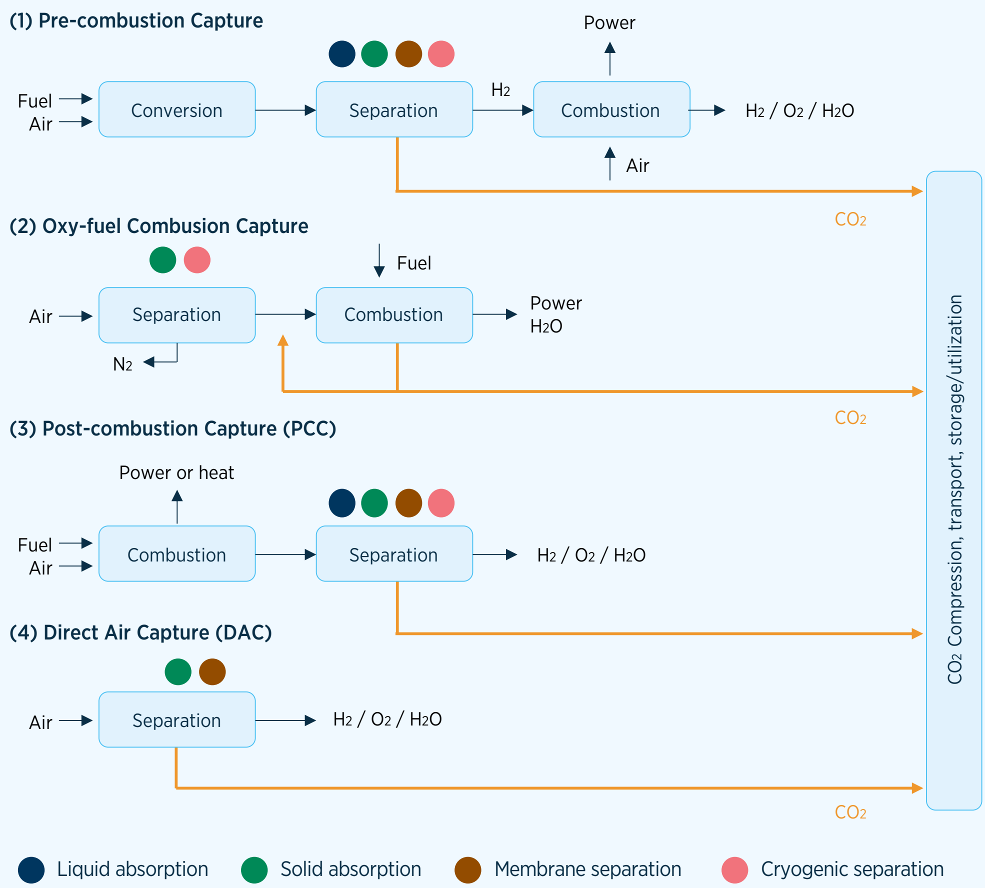
Although CCS will also be applied to Bioenergy and Direct Air Capture plants, production of such negative emissions (i.e. sequestration of atmospheric CO_2) are out-with the scope of this white paper.

c) When can CO_2 be captured?

Carbon dioxide capture can be classified into four main procedures which have a direct impact on the captured carbon dioxide quality[4]. These are pre-combustion, oxy-fuel combustion, post-combustion and direct air capture, as shown below. Post-combustion capture systems are the most mature and popular as they can be retrofitted to existing power plants and industrial facilities.

4 Paola A. Saenz Cavazos, Elwin Hunter-Sellars, Paul Iacomi, Sean R. McIntyre, David Danaci and Daryl R. William. Evaluating solid sorbents for carbon dioxide capture: linking material properties and process efficiency via adsorption performance; 2023.

Figure 2 - Carbon dioxide capture system technologies[4]



Pre-combustion capture involves capturing carbon dioxide before the combustion of fossil fuels. This is typically done by converting fossil fuels into synthesis gas (syngas), separating out the carbon dioxide, and then burning the remaining hydrogen. It is often integrated into new power plants or facilities designed for gasification processes. The concentration of carbon dioxide in syngas is higher than in flue gas, making capture more energy efficient. The carbon dioxide captured from pre-combustion processes tends to have a higher concentration and may require less purification compared to post-combustion capture.

Oxy-combustion involves burning fossil fuels in an oxygen-rich environment, resulting in a flue gas with a high concentration of carbon dioxide, which simplifies the capture process. It can be applied to both new and existing power plants by modifying combustion systems. The flue gas from oxy-combustion is mainly carbon dioxide and water vapour, making separation easier and potentially more cost-effective. The higher concentration of carbon dioxide in the flue gas simplifies the capture process, and the captured carbon dioxide may require less purification.

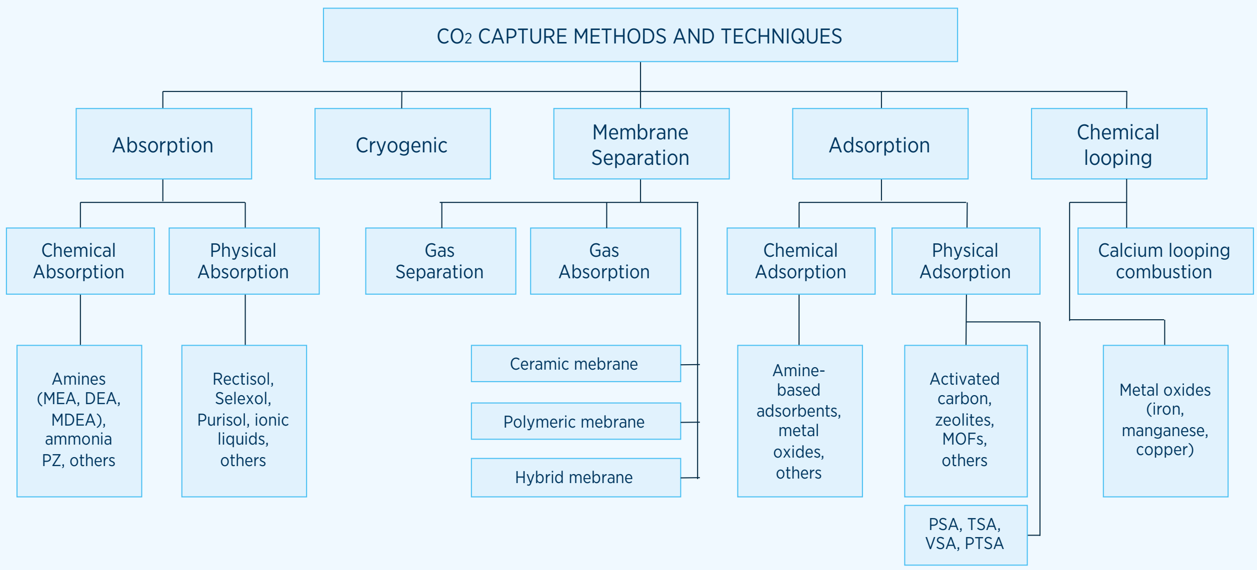
Post-combustion capture involves capturing carbon dioxide from the flue gas produced after the combustion of fossil fuels in power plants or industrial facilities. The concentration of carbon dioxide in flue gas is relatively low, requiring efficient separation technologies. The captured carbon dioxide may need additional purification steps to meet specific quality requirements, especially if it is intended for use in applications such as enhanced oil recovery (EOR) or for direct use in certain industrial processes.

Direct air capture involves extracting carbon dioxide directly from the ambient air using chemical processes or sorbents. It can be deployed anywhere, regardless of the emission source, and is not tied to specific industrial processes. However, it is generally more energy-intensive and currently more expensive than capture methods applied directly to concentrated sources. The captured carbon dioxide is purified if it is intended for applications with strict quality requirements.

d) Processes used for CO_2 Capture

As shown below there are different types for the capture process itself. Each of these methods has its own advantages and challenges, and the choice of a specific carbon capture type depends on factors such as the source of emissions, the purity required for storage or utilization, and economic considerations. Ongoing research and development aim to improve the efficiency and cost-effectiveness of these methods to make carbon capture more widely applicable and scalable. Other methods may also be invented in the future.

Figure 3 - Carbon dioxide capture types[5]



e) CO_2 transportation

Most carbon dioxide capture processes produce gaseous carbon dioxide at atmospheric or slightly elevated pressure. Liquid carbon dioxide cannot be obtained only by cooling at atmospheric pressure. In fact, if a carbon dioxide plant is built close to a port, the carbon dioxide would be fed directly to a liquefaction plant, where it would be compressed, cooled using an external refrigeration circuit and then partially depressurized to provide final cooling. If the capture plant is remote from a port, the carbon dioxide must be compressed and transported to the liquefaction plant by a high-pressure pipeline. Refer to below table for typical conditions of transport.

5 Methods and Techniques for CO2 Capture: Review of Potential Solutions and Applications in Modern Energy Technologies by Paweł Madejski, Karolina Chmiel, Navaneethan Subramanian and Tomasz Kus

Table 1 - Conditions for different carbon dioxide phases

	Pressure / MPa	Temperature / ˚C	Phase	Example for density in kg/m3 at stated pressure in MPa and temperature in ˚C
Source	0.1 to 1	(*)	Gas	1.815 kg/m3 at 0.1 MPa and 20 ˚C
Pipeline	8.5 to 15	13 to 44	Liquid / Supercritical	622.64 kg/m3 at 10 MPa and 40 ˚C
Ship	0.6 to 1.5	-30 to -57	Liquid	1155.755 kg/m3 at 0.7 MPa and -50 ˚C

(*) Depends on capture system (from industry, post-combustion, pre-combustion or oxy-fuel combustion) and technology used (sorbets/solvents, membranes or cryogenic).

Differences in conditions and concentrations of carbon dioxide emitted at source are illustrated below.

Table 2 - Typical carbon dioxide composition and conditions for different industries[4]

Industrial Process	CO_2 concentration in feed (vol%)	Main impurities (vol%)	Typical conditions
Power generation	5% - 15%	70%-75% N_2, 6%-18% H_2O, 6%-14% O_2, trace SO_x, H_sS, NO_x	1 bar, 40°C – 90°C
Cement industry	14% - 33%	50%-75% N_2, 6%-12% H_2O, 2%-5% O_2	1 bar, 40°C – 75°C
Steel industry	20% - 22%	5%-46% N_2, 4%-54% CO, 3%-6% H_2, 4% H_2O, 1% CH_4	1 bar, 30°C
Air	0.04%	78% N_4, 20% O_2, 1% Ar	1 bar, location dependent

Supercritical phase is more expensive than gas phase due to the high pressure but it also has a lower friction along the pipe per unit mass of carbon dioxide compared to gas or a gas liquid phase and has greater transport capacity to transport larger volumes through smaller pipe diameters. This is not normally used for ships due to costs associated with ships being capable of withstanding such high pressures.

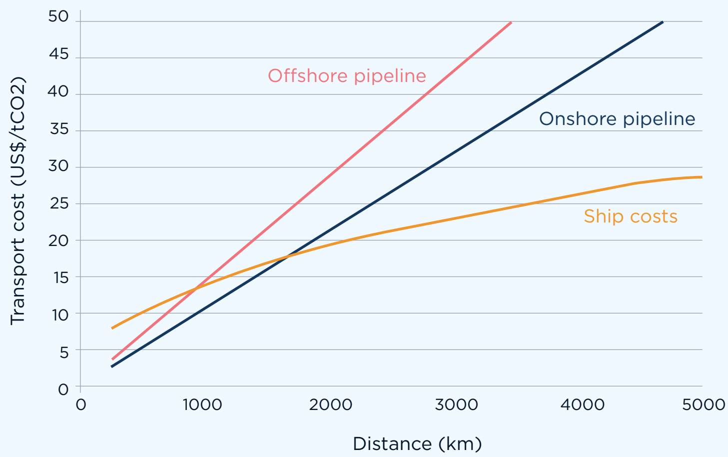
Ultimately the choice of transportation phase will be dictated by cost. The diagram below illustrates the cost differentials between pipeline and marine transportation, displaying the break-even distance[6]. When the marine alternative is feasible, it generally proves more cost-effective than pipelines for distances exceeding approximately 1000 km and for quantities below a few million tonnes of carbon dioxide per year.

Establishing a comprehensive infrastructure for transporting carbon dioxide will require significant investment. This includes the construction of specialized pipelines, vessels and the development of loading and unloading facilities, which could pose challenges in terms of cost and regulatory compliance.

6 Working Group III of the Intergovernmental Panel on Climate Change. Carbon dioxide capture and storage. Cambridge University press; 2005.

Repurposing natural gas pipelines for carbon dioxide also comes with specific challenges such as materials resistant to corrosion and ability to withstand higher pressures than natural gas. Modifications may be needed to adapt the pipeline for the requirements of carbon dioxide transport. Repurposing pipelines for carbon dioxide transport may also require regulatory approvals and compliance with safety and environmental standards. Regulations may vary depending on the jurisdiction, and stakeholders must navigate the legal aspects associated with repurposing existing infrastructure. Thus, while repurposing natural gas pipelines for carbon dioxide transport is technically possible, it requires careful engineering, compliance with regulations, and considerations of the specific properties of carbon dioxide.

Figure 4 - Carbon dioxide transportation costs[6]



f) Geological storage

Geological storage integrity is critically important for CCS in depleted reservoirs, aquifers, and salt caverns. This ensures that the carbon dioxide remains contained within the designated storage site, preventing leaks that could harm the environment or human health. Maintaining integrity is essential for the long-term success and safety of CCS projects.

Crucial components of a comprehensive well integrity and reservoir evaluation program for CCS in accordance with ISO 27914 are as follows:

Site Screening and selection

- Confirm criteria are met (technical, legal & regulatory)
- Assess capacity & injectivity and assess risks
- Both surface and subsurface

Site characterization

- Geological and hydrogeological characterization
- Overburden (sealing capacity of the storage)
- Baseline Geophysical
- Baseline geochemical (CO_2 /rock or CO_2 / fluid reactions)
- Baseline geomechanical
- Well

Design & development Modelling (geostatic, dynamic)

- Geochemical assessment
- Geomechanical assessment
- Risk management
- Well infrastructure

Post injection & termination

- Project termination criteria
- Project termination plan
- Project termination qualification process
- Monitoring and verification (M&V)

Operation

- Design of Site and CO_2 injection operations
- Develop operation and maintenance procedures
- Metering
- Well Integrity monitoring
- Well testing
- Corrosion control
- Well intervention
- Monitoring and verification (M&V)
- Quantification and verification

Each of these processes plays a role in ensuring the well and reservoir can effectively and safely store carbon dioxide over the long term. Proper evaluation and integration of these disciplines help in selecting, designing, monitoring, and maintaining geological storage sites that are robust against potential integrity issues, such as leaks or structural failures. This integrated approach is vital for the success and safety of CCS projects.

3. What are the challenges?

Carbon Capture, Utilization, and Storage (CCS/CCU) technologies face several challenges that need to be addressed for widespread adoption. For instance, there is a need for continued research and development to advance existing CCS/CCU capture technologies and transportation techniques to obtain more cost-effective methods. Establishing a comprehensive infrastructure for transporting and storing captured carbon dioxide is also a significant challenge. This includes the development of pipelines and storage sites, which requires substantial investment and regulatory approvals. Finally, to ensure operation to be as per expectation by measuring actual efficiency and be in a situation to mitigate derives.

In general, operators will be confronted with several challenges when they want to initiate their project. At this moment in time, they can require certification of their project or part of it to access the following:

- Financing of the project (de-risking, access public fundings, demonstrate viability of the project on long-term basis, access to credits…).
- Demonstration of conformity to the regulation or policies in place at the moment the project is initiated.
- Prove and ensure that asset is properly operated and maintained through relevant asset integrity management program and verification of its performance.
- Be transparent with regards to any party and demonstrate sustainable approach.

The regulatory context accompanying CCS/CCU is under development. The main initiative lays down with the set of ISO standards under revision / creation by Working Group TC265[7].

ISO TC265 (Carbon dioxide capture, transportation, and geological storage) working group is currently working on development of set of standards to provide appropriate framework for the development of CCS/CCU.

Scope is Standardization of design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities in the field of carbon dioxide capture, transportation, and geological storage (CCS) including EOR (Enhanced Oil Recovery).

The set of ISO standard covers the CCS value chain as follows[8]:

General	Carbon Capture	Transportation	Storage	Utilization
ISO 27912	ISO 27919-1	ISO 27913	ISO 27914	Not covered at
ISO 27915	ISO 27919-2	ISO 27925	ISO 27916	the moment in
ISO 20917	ISO 27927	ISO 27929	ISO 27923	the framework
ISO 27918	ISO 27928		ISO 27926	of TC265
ISO 27921				

CCU has not yet been covered but some specific reference documents may be soon developed to accompany development of this path.

In addition to this international development and to support local context, several reference documents are already setting the landscape to accompany CCS and CCU development:

- CCS Directive in Europe
- Several tax mechanisms supporting the development of CO_2 sequestration (USA, Australia, Canada…)
- There are also cross-boarders protocol signed between countries to permit the transfer of CO_2 from one country to another one (CO_2 being considered as a waste)

In parallel to this regulatory context applicable to CCUS, it shall be accounted for the following:

- Development of framework for decarbonized product (hydrogen, ammonia) in connection with CCS (IRA, UK Standard for Low Carbon Hydrogen, Japan subsidies to low carbon hydrogen – contract for difference, several voluntary certification schemes.)
- Area-based taxing system on some products in association with their carbon intensity: CBAM, ETS, International Maritime Organization Decarbonization trajectory, FuelEU Maritime initiative, and soon equivalent mechanisms elsewhere (Border Carbon Adjustments – BCAs, etc)

As this is a rapidly evolving regulatory system, it is encouraged to keep up to date with the latest developments in the industry. The TIC industry is well placed to provide support on regulatory watch[9].

7 Further information on ISO/TC 265 can be found in the following website: https://www.iso.org/committee/648607.html

8 See Appendix 1 for a list of standards referenced

9 A good way to start looking at the different regulations is provided by the IEA in the following website: https://www.iea.org/policies?topic%5B0%5D=Carbon%20Capture%20Utilisation%20and%20Storage

a) Financing CCS/CCU projects

TIC companies can assist the CCS/CCU industry in financing projects by providing essential documentation for demonstrating risk acceptance, supporting requests for public fundings, offering insights into project viability, accessing carbon credits or initiating claims.

TIC companies can perform comprehensive risk assessments and due diligence evaluations of CCS/CCU projects to identify potential financial, technical and regulatory risks. By offering insights into project viability and resilience, these assessments help investors make informed decisions and allocate capital more effectively. Risks associated with non-compliance are mitigated by conducting thorough inspections and audits, thus instilling confidence among financiers and stakeholders.

There are different conditions to be fulfilled for a project receiving fundings: this could be funding associated to sequestration of CO_2, decarbonization of a facility (reduction of GHG), a key infrastructure project (e.g.: project of common interest (PCI) or project of mutual interest (PMI)), actions on product carbon footprint.

One major lever for getting the fundings is associated to the quantification of carbon dioxide emissions: it is a crucial step in the process of carbon credit trading and environmental accounting. Carbon credits are a key component of emissions trading schemes and other mechanisms aimed at mitigating climate change[10]. This includes Emissions Trading Systems (ETS are in force in various jurisdictions such as EU, UK, China, Canada and US) where companies that capture carbon dioxide from their emissions can generate carbon credits called Certified Emission Reductions (CERs). These can be used to offset their emissions or sold to other companies that need to offset their emissions. To be eligible for CERs, the carbon dioxide must be captured and stored in accordance with EU regulations, and the storage site must be verified and monitored to ensure that the carbon dioxide remains stored over the long term.

In addition to ETS schemes, various jurisdictions are also planning to introduce a carbon emission pricing system for importation of goods. An example is the carbon border adjustment mechanism (CBAM) which equalises the price of carbon between domestic products and imports by requiring certain goods imported to EU (including aluminium, steel, fertilisers, hydrogen and cement) to have their carbon emissions certified. This implies that TIC services will be required at the manufacturing countries if these are intended to be exported.

TIC companies can offer services to accurately measure the amount of carbon dioxide captured and stored by CCS/CCU projects. Through precise monitoring and verification processes, TIC companies provide credible documentation that validates the emission reductions achieved by the projects, which is essential for generating carbon credits. Quantifying carbon dioxide emissions helps organizations and industries be accountable for their environmental impact.

b) Mechanical integrity of the asset

Mechanical integrity of CCS/CCU assets considers the operation of all equipment and materials used across the CCS/CCU value chain including capture plant, chemical handling, pipeline, marine and other transportation systems, CO_2 processing for Utilisation projects and facilities, pipelines and wells used for geological storage of CO_2.

10 Dr Norman Glen and Lynn Hunter. Measurement challenges for carbon capture and storage. Measurement and control; 2011.

The design process addresses process and operational hazards including how mechanical integrity or equipment and materials will be assured.

Material selection is one of the key design processes undertaken to ensure safety, reliability, durability and cost-efficiency of the CCS/CCU infrastructure. The process of selecting materials requires knowledge of fluid compositions and the process conditions under which they will be processed, transported and stored. CO_2 gas streams will differ depending on the source of emission and technology to be used for CO_2 capture. Steady state conditions of operation should be considered together with conditions during process start-up, shutdown and non-routine operations. Consideration must be given to fluid mixing and the full range of composition which may be present in shared transportation and handling systems in addition to considering changes in composition and process conditions which may take place over the life of the project.

Material selection is also critical when considering repurposing infrastructure such as pipelines and storage tanks for CO_2 duty.

TIC companies have an important role to play inspecting and testing existing equipment and materials where repurposing is being considered and in undertaking activities to verify that the supply chain delivers materials in accordance with specifications provided by the project.

Carbon steel is currently the most common material used due to cost and availability[11]. Even though this type of steel is much stronger than mild steel due to a higher carbon content, carbon steel is also more susceptible to corrosion than stainless steel. The latter contains chromium which gives it a higher corrosion resistance. The higher the amount of chromium used in the steel used the more corrosion resistant it is but also more expensive. The steel grade needed to safely process and transport carbon dioxide can only be determined if impurities are measured.

For successful operations it is important that a mechanical integrity assurance plan is drawn up and implemented.

TIC companies can play an important role by inspecting and testing during operations to verify the condition of equipment and materials exposed to process fluids and operating conditions. Note that impurities directly affect the physical properties of carbon dioxide. In addition, TIC companies can provide an essential service measuring and verifying the composition of fluid streams in the value chain to ensure that process fluids are maintained within the CO_2 composition specified by the projects. It is, for example, important to verify that impurities – such as SO_x, NO_x and H_2S which form acids in the presence of water – are not present in concentrations higher than allowed by the project CO_2 quality specification.

c) Transparency: Preventing greenwashing and ensuring ethical & sustainable practices[12]

In a general manner, the TIC sector will accompany independently in assessing and providing detailed outputs to support transparent communication on sustainability targets. This could cover the following:

11 Bjørn H. Morland, Gaute Svenningsen and Arne Dugstad. The Challenge of Monitoring Impurity Content of CO_2 Streams. MDPI; 2021.

12 ISO Standards mentioned in this section:
ISO 14001:2015 – Environmental management systems – Requirements with guidance for use.
ISO 14040:2006 - Environmental management – life cycle assessment – principles and framework.
ISO 14044:2006 - Environmental management – Life cycle assessment – requirements and guidelines .
ISO 14067:2018 - Greenhouse gases – Carbon footprint of products – requirements and guidelines for quantification.
ISO 19870:2023 - Hydrogen technologies — Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen to consumption gate.

- Quantification of carbon footprint of organisations, products, processes and supply chains (refer to ISO 14067).
- Life Cycle Assessment (LCA) to assess the environmental performance of products, identify hotspots for improvement, and support sustainable decision-making applying principles of ISO 14040 to ISO 14044 and ISO 19870.
- Monitoring and reporting services to help organisations comply with emissions regulations and reporting requirements.
- Certification for organisations' environmental management systems against international standards such as ISO 14001.
- Certification schemes for sustainable practices, such as energy efficiency, renewable energy use, waste reduction, and water conservation providing recognition for organisations' sustainability efforts.
- Facilitate transparency and disclosure by providing independent verification and assurance of sustainability performance data.
- Verification of compliance to Measuring Reporting and Verification over time (base line versus operations), in accordance with regional / local regulations, but also bringing global best practices.

Specifically, TIC companies can:

- Validate the accuracy and reliability of data collected from CCS/CCU projects, ensuring that emissions measurements, carbon capture rates, and storage volumes are reported accurately. By implementing robust data validation and quality assurance processes, TIC companies enhance transparency and credibility in carbon accounting practices.
- Conduct regular on-site inspections and audits of CCS/CCU facilities to verify compliance with environmental regulations, operational standards, and carbon accounting methodologies. These physical inspections provide assurance that projects are actively implementing carbon capture and storage measures, rather than relying solely on self-reported data. By certifying adherence to recognized standards and best practices, these audits help prevent greenwashing and ensure transparency in carbon accounting and reporting.
- Engage with stakeholders, including local communities, environmental organisations, and regulatory authorities, to solicit feedback, address concerns, and promote transparency in CCS/CCU projects. By facilitating open dialogue and transparency, these companies help build trust and credibility within the communities affected by CCS/CCU activities. This helps with the companies' CSRD, which is the practice of companies disclosing information about their social impact.
- Incorporate environmental, social and governance (ESG) criteria into their assessment frameworks for CCS/CCU projects, considering factors such as community impacts, stakeholder engagement, and ethical business practices. By evaluating projects against comprehensive ESG criteria, sustainable development and responsible investment in the CCS/CCU sector is promoted.
- Ensure well integrity for CCS/CCU projects through a comprehensive approach that includes rigorous testing, continuous monitoring, regular inspections, proactive maintenance, and strict adherence to regulatory standards. By leveraging advanced technologies and expert knowledge, the TIC industry helps to maintain the safety, reliability, and environmental sustainability of CCS/CCU operations.

d) Lack of regulation

CCS/CCU has been recently qualified as an acceptable path for reduction of emissions in addition to the shift from fossil sources to renewable sources. In this context, the ecosystem for developing these kinds of projects is still under development: regulation and policies are under construction and are unequally developed worldwide.

From an operator perspective, that may raise some concerns to initiate any formal projects as there is a risk of discovering a new constraint during or after project development. In this context, loads of operators need to be properly informed about what is going on (regulatory watch) and how to discuss with their local / national governmental entity to initiate any investment. TIC companies are well placed and recognized to accompany operators present and discuss their project with any type of authorities to track any risk of deviations.

TIC companies also advocate for the development of appropriate regulations and standards within the CCS/CCU industry. TIC companies contribute valuable insights to policymakers and industry stakeholders, helping to shape effective regulatory frameworks that promote safety, sustainability, and innovation.

It may be valid to discuss grandfather clause with authority to set up the basic rules for initiating a project prior to any specific laws or rules being developed. In this context, monitoring of what is going on and anticipation of future change in regulation is key: TIC companies could support operators in being well prepared.

TIC companies can establish standards and protocols for CCS/CCU projects to ensure that a minimum level of standard is achieved, even in the absence of formal regulations. By providing thorough testing and inspection services, TIC companies can help verify that CCS/CCU facilities are built and operated safely and efficiently. This includes assessing environmental risks, health and safety concerns, and technological risks related to carbon capture and storage.

Moreover, part of the validation for the methodologies and specifications used is to ensure they are adequate for the purposes for which they are to be used. TIC companies can perform gap analysis to ensure suitable implementation to any type of guidance and standards.

Grandfathering[13] is a provision that grants specific allowances to actors already engaged in a particular industry when new regulations are introduced, allowing them to bypass newly introduced requirements and/or restrictions. Under a grandfather clause, existing industry actors might receive free allowances and exceptions from new carbon emission regulations based on their historical emissions over a specified period. These exemptions are often temporary and can be revoked under certain conditions.

e) Commodities testing

When a carbon capture installation is first built, it undergoes rigorous testing and commissioning to ensure that all components are functioning properly and that the capture process meets specified performance targets, emissions reduction goals, and other regulatory obligations. This includes testing individual components, such as the capture mediums (as amine or potassium carbonate composition), gas composition before and after the capture process, capture rate and storage facilities quantification to keep leakages to a minimum.

Once the carbon capture installation is operational, ongoing performance maintenance and monitoring are essential to ensure that the installation continues to operate efficiently and

13 Granfathering clause: https://www.iea.org/reports/implementing-effective-emissions-trading-systems/ets-in-industry, and https://www.encyclopedia.com/history/united-states-and-canada/us-history/grandfather-clause

effectively. In addition to ongoing monitoring by the carbon capture installation itself, periodic testing and verification services offered by the TIC industry are essential to confirm that performance is still as expected. This can involve conducting performance tests, audits, and compliance assessments to ensure that the installation remains in conformance with regulatory requirements and industry standards.

TIC industry services provide an independent assessment of the performance of carbon capture installations in time. This independence is crucial for ensuring the credibility and reliability of the performance data, as it helps build trust and confidence among stakeholders, including regulators, investors and the general public. It eliminates potential conflicts of interest that may arise if the assessment were conducted solely by the entity operating the installation.

f) Risks mitigation

Risks require careful management and mitigation to ensure the overall safety and success of CCS projects. Effective risk assessment, monitoring, and response strategies are essential to address these risks promptly and minimize any potential impacts.

The TIC industry plays a crucial role in evaluating the risk mitigation plan, in the verification of data quality and transparency, and in ensuring that the mitigation is being performed in accordance with the MRV plan.

4. TIC role in this value chain

The mission of the Testing, Inspection and Certification (TIC) sector is to offer independent conformity assessment services, either for regulatory purposes or to promote good practice, in order to protect people and the environment. Our activities can include supply chain certifications, industrial site inspections, management system auditing and certification, pre-shipment inspections and many other services. The TIC industry is a major contributor to the global economy and quality of daily life around the world, since it provides a guarantee that products and services are safe, secure, effective, reliable, of quality, and sustainable.

We are expertly qualified to prepare and facilitate CCS/CCU value chains from end to end in a variety of ways. From the earliest stage of project conception, the TIC industry can provide design review services for CCS/CCU projects, evaluating safety, feasibility, and environmental impact. The independent reviews and assessments that we can perform provide operators with a means of satisfying authorities, local communities, investors, and all other stakeholders of the viability, safety, and sustainability of the CCS/CCU project on its entire value chain.

TIC firms are a valuable source of regulatory insight and can provide technical expertise to assist in navigating an evolving framework of standards, codes, and regulations. Further than this TIC companies also advocate for the development of appropriate regulations and standards within the CCS/CCU industry. We can contribute important insights to policymakers and industry stakeholders, helping to shape effective regulatory frameworks that promote safety, sustainability and innovation.

TIC company experts can conduct risk and industrial safety assessments, to ensure staff, equipment and assets are protected from injury, damage and accidents. Among our many service offerings to this sector, we can certify production assets, accompany best available technology analysis, and verify that CO_2 transport systems and storage comply with technical and safety standards. We can test and assess material and components of transporting pipelines for suitability and certify according to existing standards, and we can verify that geological sequestration is adequately monitored for valid quantities.

We can support the success of an overall CCS/CCU project or a segment of the value chain (carbon capture, transportation, storage or utilisation) by assisting the operator to continually guarantee performance. Operators will need to demonstrate the environmental impact of their assets, supported by independently verified data. TIC firms can calculate carbon footprints of production assets, perform lifecycle assessments, propose integrity management studies to help prevent leakage from pipelines and measure fugitive emissions. To confirm the quality of the product from an asset where CO_2 is captured, we can provide sampling and analysis services.

The target of installing Carbon Capture to an asset is to produce a more sustainable product, and the resulting challenge is to demonstrate the environmental, social and governance (ESG) credentials of said product to environmentally conscious users. Through voluntary certification schemes, TIC firms can assess, as an example, a decarbonised hydrogen production asset against ESG criteria and issue a decarbonised hydrogen certificate if all requirements are met.

The TIC industry is founded on the principles of independence and impartiality. Through our expertise, worldwide presence, and knowledge of local regulations and requirements, we are dedicated to supporting a just and responsible energy transition and to preventing greenwashing activities. The TIC industry has a singular ability to conduct in person on-site inspections anywhere in the world, which, in contrast to paper-based audits conducted remotely, can provide true confidence to society that CCS/CCU meets the relevant regulatory requirements and standards for safety, security and sustainability.

Appendix 1 Standards by ISO/TC 265: Carbon dioxide capture, transportation, and geological storage

Type	Number	Publication year	Title	Version under review by TC265?
ISO/TR	27912	2016	Carbon dioxide capture — Carbon dioxide capture systems, technologies and processes	-
ISO	27913	2016	Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems	Yes
ISO	27914	2017	Carbon dioxide capture, transportation and geological storage — Geological storage	Yes
ISO/TR	27915	2017	Carbon dioxide capture, transportation and geological storage — Quantification and verification	-
ISO	27916	2019	Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO_2 -EOR)	-
ISO	27917	2017	Carbon dioxide capture, transportation and geological storage — Vocabulary — Cross cutting terms	Yes
ISO/TR	27918	2018	Lifecycle risk management for integrated CCS projects	-
ISO	27919-1	2018	Carbon dioxide capture — Part 1: Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant	Yes
ISO	27919-2	2021	Part 2: Evaluation procedure to assure and maintain stable performance of post-combustion CO2 capture plant integrated with a power plant	-
ISO/TR	27921	2020	Carbon dioxide capture, transportation, and geological storage — Cross Cutting Issues — CO2 stream composition	-
ISO/TR	27923	2022	Carbon dioxide capture, transportation and geological storage — Injection operations, infrastructure and monitoring	-
ISO/TR	27925	2021	Carbon dioxide capture, transportation and geological storage — Cross cutting issues — Flow assurance	-
ISO/CD	27926	-	Carbon dioxide enhanced oil recovery (CO_2 -EOR) - Transitioning from EOR to storage	Under development
ISO/AWI	27927	-	Carbon dioxide capture, transportation and geological storage — Key performance parameters and characterization methods of absorption liquids for post-combustion CO_2 capture	Under development
ISO/AWI	27928	-	Carbon dioxide capture, transportation and geological storage — Performance evaluation methods for CO_2 capture plants connected with CO_2 intensive plants	Under development
ISO/AWI	27929	-	Transportation of CO_2 by ship	Under development

Editor's Note About TIC Council

TIC Council is the global trade association representing the independent third-party Testing, Inspection and Certification (TIC) industry which brings together about 100-member companies and organizations from around the world to speak with one voice. Its members provide services across a wide range of sectors: consumer products, medical devices, petroleum, mining and metals, food, and agriculture among others. Through provision of these services, TIC Council members assure that not only regulatory requirements are met, but also that reliability, economic value, and sustainability are enhanced. TIC Council's members are present in more than 160 countries and the wider TIC sector currently employs more than 1 million people across the globe.

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