esade
RAMON LLULL UNIVERSITY

EsadeGeo-Center
for Global Economy
and Geopolitics

repsol fundación

EsadeGeo DECEMBER 2025

Carbon Capture and Storage in the Race to Net Zero: The Path to a Functional Single Market

Introduction

Carbon capture and storage (CCS) has emerged as a central tool for Europe through its increasingly promising role in the path to climate neutrality. That is because it directly addresses a structural challenge of the clean transition: some emissions cannot be easily eliminated through renewable energy, electrification, or efficiency alone. These hard-to-abate emissions are deeply embedded in the chemistry of industrial processes producing essential goods such as cement, lime, chemicals, and certain steel products. In these sectors, CCS offers something unique: instead of relying on cleaner fuels or altered energy systems, it captures the CO_2 generated during production and prevents it from entering the atmosphere. For this reason, CCS was for years discussed as a potential complement to Europe's decarbonisation portfolio, and the technology has now begun to operate at commercial scale.

The possible applications and limitations of CCS derive from the way the technology works. First, it must be noted that CCS is most effective when CO_2 is captured at the point of emission, not from the atmosphere, so that industrial exhaust gases are passed through solvents or separation units that extract CO_2 from the rest of the flue gas. Second, the purified CO_2 is transported. After compression, it can move through pipelines or be loaded onto specialised ships designed to carry liquefied CO_2 to designated and well-prepared sites. Third, it is permanently stored. The transported CO_2 is injected several kilometres underground into geological formations, such as depleted oil and gas fields or deep saline aquifers, where impermeable rock layers keep it trapped. These sites are also monitored for decades to ensure that the CO_2 remains contained for a prolonged period and is not ultimately released into the atmosphere.

As it exists, this technology is already in use. In August 2025, Europe reached a turning point with the first full industrial CCS chain procedure operating across borders and starting at the Brevik cement plant in Norway, where CO_2 from clinker production is captured at the source. This CO_2 is then transported by ship to Northern Lights, a storage system located on the Norwegian coast and the world's first open-access CO_2 storage service. This means that, instead of serving as a single industrial facility, it is designed as shared infrastructure that multiple European emitters can use. Once received, the CO_2 is injected into a certified offshore reservoir under the North Sea, where it will remain permanently stored.

The Brevik-Northern Lights chain demonstrates not only the technical feasibility of CCS, but also the emergence of a new model in which storage capacity becomes a tradable service fostering its usability in competitive economies.

European policymakers are now attempting to scale this model. The EU's Net-Zero Industry Act introduced a binding target of at least 50 million tonnes of annual CO_2 storage capacity by 2030, signalling that CCS is expected to play a relevant role in the continent's industrial transition. Several Member States have begun reforming their regulatory frameworks to allow CO_2 pipeline development and offshore storage, with Germany's 2025 legal changes standing out as major breakthroughs. Together, these developments indicate a broader recognition: CCS is becoming a realistic, durable, and increasingly central instrument for decarbonising European industry while keeping essential production on the continent and combatting climate dumping.

1. The Origin and Rise of CCS

CCS is not a new concept; CO_2 has been injected underground since the 1970s, albeit not for climate purposes, but to increase oil production by pushing additional hydrocarbons toward a well. Although storage permanence was not the objective, these early operations demonstrated that CO_2 could be handled, transported, and injected at large scale. This did propel storage permanence to emerge as a goal in the 1990s, when the climate science for using geological formations to permanently store CO_2 advanced; Norway became a pioneer with the Sleipner project in 1996, which began capturing CO_2 from natural gas production and injecting it into a deep saline aquifer below the North Sea. This was significant because it demonstrated that permanent CO_2 storage could be carried out safely and monitored effectively, and it introduced the practice of treating storage as a climate mitigation possibility, and not just an industrial by-product.

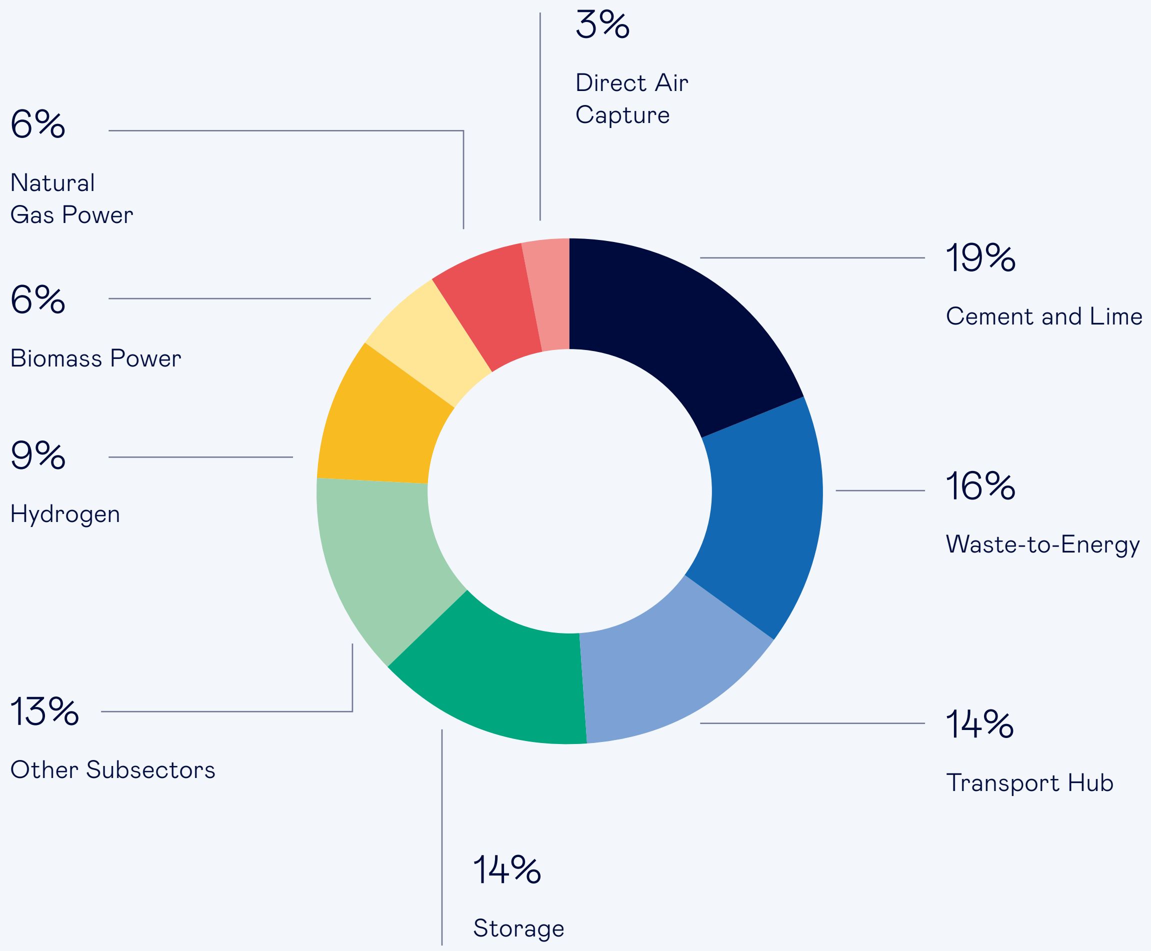
In 2005, the Intergovernmental Panel on Climate Change published its Special Report on CCS, assessing not only the technical feasibility but also the geological conditions and the monitoring techniques and long-term behaviour of CO_2 underground. Showing increased scientific consensus, the report concluded that properly selected and carefully managed storage sites were likely to retain CO_2 for extremely long timeframes. This further helped shift CCS from an experimental option to a possible mitigation tool, and the following decade saw the first commercial power-plant applications, as in 2014 the Boundary Dam project in Canada became the first coal power plant to operate with large-scale post-combustion capture. Similarly, Petra Nova in the United States added another CCS project in 2017. While both demonstrated technical feasibility, they also revealed challenges: costs, integration into power systems, and economic sensitivity to electricity prices were still prevalent in CCS technology.

Europe's trajectory was different. While the EU created a regulatory framework for CCS through the CCS Directive, most investment flowed not into power generation but into industrial sectors such as cement, chemicals, and refining, which produce emissions that are difficult or impossible to eliminate through renewable electricity alone. By the early 2020s, several European countries converged on a communal approach: multiple emitters would share common pipelines and offshore storage, with some central projects such as Norway's Longship and its Northern Lights storage system, the Porthos project in the Netherlands which connects Rotterdam industries to offshore reservoirs, and HyNet in the United Kingdom. With the EU storage target, this culminated in a slow but steady CCS shift from unconnected national initiatives to coordinated EU industrial strategy.

2. The applicability of CCS: Strengths and Gaps

CCS has strong value in specific industrial contexts where other technologies are not as effective. Its primary strength lies in capturing intensive emissions that cannot otherwise be avoided: cement production is a prime example. These “process emissions” represent most of the sector’s climate footprint and cannot be eliminated by electrifying heat or switching to renewable energy alone. At Brevik, CCS directly addresses this inherent chemical source of emissions, and similar conditions exist in lime production, fertilizer manufacturing, certain chemical processes, and parts of steelmaking. In these sectors, CCS offers a way to reduce emissions without shutting down or completely redesigning industrial plants, which is key to keep these industries competitive while meeting climate goals.

Figure 1. CCS Projects in Europe by Sector (CATF, 2025)



A second strength is the emergence of real, operational CO_2 storage services. Of these, Northern Lights is the first fully developed example, as it is designed to accept CO_2 from various customers, regardless of the country where emissions originate, and store it in a secure offshore reservoir. This open access model is new; previously, storage was tied to a single industrial source. Now, multiple companies can share one system, reducing costs and enabling countries without suitable geological formations to still decarbonise their industry. Its success is also notable: Northern Lights' initial capacity is fully contracted, and further expansion is planned. A third strength is regulatory alignment. Under the EU Emissions Trading System, permanently stored CO_2 is exempt from carbon pricing obligations, providing a direct financial incentive for CCS deployment. The EU's legally binding storage target for 2030 signals long-term direction to investors, and several Member States are updating legal frameworks to permit CO_2 pipelines, offshore storage, and in some cases onshore storage under defined conditions.

However, CCS also faces serious challenges. The first major gap is infrastructure. Europe's best geological storage formations are in the North Sea, but many emitters are inland. Building pipelines, terminals, and shipping systems to connect these regions requires long-term planning, high upfront investment, and complex permitting; studies suggest that by 2030 Europe may need around 7,000 kilometres of CO_2 transport infrastructure, expanding to more than 15,000 kilometres by mid-century. Without coordinated planning and deepening integration, the risk is a costly patchwork of disconnected projects with low reliability across scattered, not always aligned states. Indeed, a second gap concerns cross-border rules, as countries must align customs procedures, safety requirements, liability frameworks, and accounting for emissions for CO_2 transport to be easy and effective. For example, a 2019 decision by the parties to the London Protocol provisionally removed the legal prohibition on transboundary CO_2 transport, enabling projects such as Northern Lights to operate. In this regard, coordination with the United Kingdom is particularly relevant, because UK offshore storage sites are among the most advanced in Europe and could significantly reduce continental storage costs if access were standardized.

A third challenge is the business model itself. Capturing CO_2 is relatively well understood, but building and operating large-scale transport and storage networks requires stable revenue and clear allocation of risks. The United Kingdom has advanced the furthest by developing standardised long-term contracts that guarantee payment for CO_2 stored and define responsibilities among emitters, network operators, and states. In contrast, contractual frameworks across the EU differ across countries, which causes financing costs to remain high for investors. Public acceptance is another factor. Although scientific evidence shows that well-selected storage sites are highly secure, public perception is often cautious, especially for onshore storage. Strong regulatory oversight, transparent monitoring data, and clear communication are therefore essential. Germany's recent reform, which allows offshore storage while letting regional governments opt into onshore storage, shows a balanced approach that prioritises industrial decarbonisation while addressing societal concerns.

Finally, CCS must be used where it is strategically more impactful, as it should complement, not replace, renewable energy and efficiency measures. Direct air capture is promising but expensive and comparatively less effective than capture within industrial processes, so priority should remain on implementation in industries with high embedded CO_2 concentration. Used appropriately, CCS is a tool for residual emissions; used poorly, it risks falling into performative climate action.

3. The Future of CCS

A coherent European CCS strategy requires a more ambitious approach; the first step is to complete the EU regulatory framework for CO_2 transport and storage. The upcoming Transport and Storage Package should define uniform rules on access, pricing, CO_2 purity requirements, monitoring obligations, and infrastructure planning. Without common rules, Europe cannot build the predictable environment needed to attract private investment; a harmonised system would allow companies in one Member State to contract storage in another, creating an integrated market. Second, the EU must ensure that cross-border CO_2 movement is legally robust. Bilateral agreements between countries should formalise procedures for shipping or pipelining CO_2, including customs, safety protocols, and responsibilities in case of incidents. Coordination with the United Kingdom deserves special priority as UK storage sites, including those linked to the HyNet cluster, are among the most advanced in the European neighbourhood. Allowing EU industries to access these sites would reduce storage bottlenecks in the 2020s, but to do so, both regulatory systems must recognise each other's monitoring and emissions accounting rules.

Third, CCS must be integrated with Europe's broader climate architecture. The EU Emissions Trading System already recognises stored CO_2, but negative emissions from biogenic sources or direct air capture will need clear integration pathways through the Carbon Removal Certification Framework. Planning should also be coordinated across borders and across sectors, as joint projects could reduce costs, accelerate permitting and minimise local disruption. For that, the EU and national regulators should designate priority corridors for CCS projects where benefits are higher, and early demand must be created for low-carbon materials produced using CCS. Public procurement standards for cement, concrete, and steel can guarantee markets for the first generations of captured CO_2 products, helping companies recover costs. Finally, awareness and clarity over the benefits of CCS must be purposefully promoted in European societies. Communities need transparent information about geological storage, monitoring systems, and long-term safety, for which successful early projects should share data widely and independent verification should be promoted.

4. Conclusions

By 2025, Europe has entered a new phase in industrial decarbonisation. CCS is no longer an ambitious idea but an operating system that can capture emissions, move them across borders, and store them securely. The Brevik-Northern Lights chain demonstrates the model for a new European infrastructure: shared, cross-border, and open-access. EU law now provides direction through a binding storage target, and Member States such as Germany are updating regulations to enable transport and storage networks.

Yet these achievements remain fragile without a unified European framework. The next few years will determine whether CCS becomes an efficient single market or remains a set of disconnected national projects. Completing the Transport and Storage Package, harmonising cross-border rules, developing bankable business models, and integrating CCS with Europe's carbon markets will be decisive. If these foundations are laid, CCS can help Europe decarbonise heavy industry without sacrificing competitiveness. If not, Europe risks slower progress, higher costs, and greater reliance on external producers for the clean transition.

References

Buli, N. (2025, June 18). *Heidelberg sells out of net-zero cement from Norway plant, CEO says. Reuters*. https://www.reuters.com/sustainability/climate-energy/heidelberg-sells-out-net-zero-cement-norway-plant-ceo-says-2025-06-18/

Clean Air Task Force. (2025, November 26). *Carbon capture and storage in Europe: Slow but significant progress in 2025*. https://www.catf.us/2025/11/carbon-capture-storage-europe-slow-but-significant-progress-2025/

Clean Energy Wire. (2025, August 6). Government cabinet paves way for carbon capture and storage in Germany. https://www.cleanenergywire.org/news/government-cabinet-paves-way-carbon-capture-and-storage-germany

Clean Energy Wire. (2025, November 7). German parliament adopts law reform to pave the way for carbon capture and storage. https://www.cleanenergywire.org/news/german-parliament-adopts-law-reform-pave-way-carbon-capture-and-storage

Equinor. (2025, August 25). First CO_2 volumes stored at Northern Lights. https://www.equinor.com/news/20250825-first-co2-volumes-stored-at-northern-lights

Equinor. (2025). Northern Lights. https://www.equinor.com/energy/northern-lights

EsadeGeo. (2025). Webinar: Carbon Capture and Storage.

EsadeGeo. (2025). Podcast: CCS in the race to Net Zero with Samantha Gross.

European Commission. (2024, February 7). Q&A: The EU Industrial Carbon Management Strategy. https://ec.europa.eu/commission/presscorner/detail/en/qanda_24_586

European Commission. (2024). Shaping the future CO_2 transport network for Europe (JRC136709, highlights). Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC136833/JRC136833_01.pdf

European Commission. (2025, May 22). Commission identifies the EU oil and gas producers to provide new CO_2 storage solutions. https://climate.ec.europa.eu/news-other-reads/news/commission-identifies-eu-oil-and-gas-producers-provide-new-co2-storage-solutions-hard-abate-2025-05-22_en

European Commission. (n.d.). The EU's 2030 carbon storage target. https://climate.ec.europa.eu/eu-action/industrial-carbon-management/eus-2030-carbon-storage-target_en

International Energy Agency. (2025, October 27). Driving down the cost of carbon removal: Why innovation matters. https://www.iea.org/commentaries/driving-down-the-cost-of-carbon-removal-why-innovation-matters

International Maritime Organization. (n.d.). Carbon capture and sequestration. https://www.imo.org/en/OurWork/Environment/Pages/CCS-Default.aspx

Low Carbon Contracts Company. (2025, September 25). LCCC signs first industrial carbon capture contracts. https://www.lowcarboncontracts.uk/news/lccc-signs-first-industrial-carbon-capture-contracts/

Northern Lights partners. (2025, August 25). Norway: First CO_2 storage in Northern Lights [Press release]. TotalEnergies. https://totalenergies.com/news/press-releases/norway-first-co2-storage-northern-lights

UK Department for Energy Security and Net Zero. (2025, September 25). Pioneering carbon capture projects ready for construction. https://www.gov.uk/government/news/pioneering-carbon-capture-projects-ready-for-construction

UK Department for Energy Security and Net Zero. (2025, August 5). HyNet Track-1 expansion: Selected projects. https://www.gov.uk/government/publications/hynet-track-1-expansion-selected-projects

United Nations IPCC. (2005). Special report on carbon dioxide capture and storage, Chapter 5: Underground geological storage. https://archive.ipcc.ch/pdf/special-reports/srccs/srccs_chapter5.pdf

Washington Post. (2025, July 21). To combat climate change, Norway wants to be Europe's carbon dump. https://www.washingtonpost.com/climate-solutions/2025/07/21/carbon-capture-northern-lights-terminal/