GLOBAL STATUS OF CCS 2023

SCALING UP THROUGH 2030

GLOBAL CCS INSTITUTE

ABOUT THE REPORT

This report documents the milestones for carbon capture and storage over the past 12 months, as it is increasingly adopted globally, and defines the key opportunities and challenges for the coming years.

The data is provided to inform and help accelerate deployment of this proven emissions reduction technology as an integral part of meeting global climate targets. We hope it will be read and used by governments, policymakers, academics, media commentators and the millions of people who care about our climate.

About us

The Global CCS Institute is a leading international carbon capture and storage (CCS) think tank. Our mission is to accelerate the global deployment of CCS as an integral part of tackling climate change and delivering climate neutrality.

Our more than 200 international members include governments, companies, research bodies and NGOs, all with a commitment to CCS as part of achieving a net-zero future. We have resources in Washington DC, New York, Houston, London, Paris, Brussels, Abu Dhabi, Beijing, Kuala Lumpur, Melbourne, Perth, Brisbane and Tokyo.

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1.0 FROM THE CEO

The climate math is clear: carbon capture and storage (CCS) and carbon dioxide removal (CDR) must scale up to gigatonnes per annum to mitigate climate change and reach net-zero emissions.

The growing urgency to address climate change felt by policy makers, industry leaders, investors and the general public is now accelerating CCS deployment in many regions around the globe. World-leading climate and energy analysts maintain CCS and CDR are key pillars needed this decade to keep within reach the Paris Agreement's target of pursuing efforts to limiting the global temperature rise to 1.5 °C.

We have seen significant progress on CCS since last year's 2022 Global Status of CCS report, spurred by government policies in North America and Europe set forward to catalyse all forms of climate change mitigation.

In the United States alone, federal policy is unlocking the potential for hundreds of million tonnes per annum (Mtpa) of CCS deployment this decade. Support for CCS in Denmark is an example of how quickly and strongly enabling policies can be developed and implemented with strong public support.

The Global CCS Institute is now tracking 41 projects in operation and 351 in development globally, with new projects being announced weekly. The growing interest from CCS project developers is now palpable in many regions, across industries and in diverse applications.

It is exciting to see so many projects progressing in many regions around the globe, including major projects in North America, the Jubail hub in Saudi Arabia with the first phase operational by 2027, and the first major CO_2 pipeline in China. We are seeing accelerating progress at a project level in the Middle East and North Africa, Australia and Asia.

CCS networks (sometimes also referred to as hubs and clusters) are growing and we are tracking approximately 115 networks globally. Shared common infrastructure can provide economies of scale and leverage synergies between point source carbon capture and carbon dioxide removal. It can shorten permitting timelines and create efficiencies during both development and operation.

> The Global CCS Institute is now tracking 41 projects in operation and 351 in development globally, with new projects being announced weekly.

The financial sector and investors are actively looking to include CCS in their sustainable development portfolios and investments. We are working with the financial community to include CCS in regulatory and reporting requirements to address this growing interest.

Global collaboration on CCS has never been stronger. We support the Carbon Management Challenge championed by the United States and a growing coalition of countries, which aims to deliver gigatonne scale CCS by 2030 – consistent with the climate math and models. On behalf of our Members, the Global CCS Institute is working hard to help speed deployment of this critical climate change mitigation technology through our advocacy, thought leadership, and knowledge-sharing efforts.

I am encouraged by the exponential growth of enabling policies, projects, and collaborative activities we are witnessing on CCS globally.

With public-private collaboration across government and industry and multi-lateral collaboration across many regions, we can accelerate CCS.

Jarad Daniels

2.0 SCALING UP THROUGH 2030

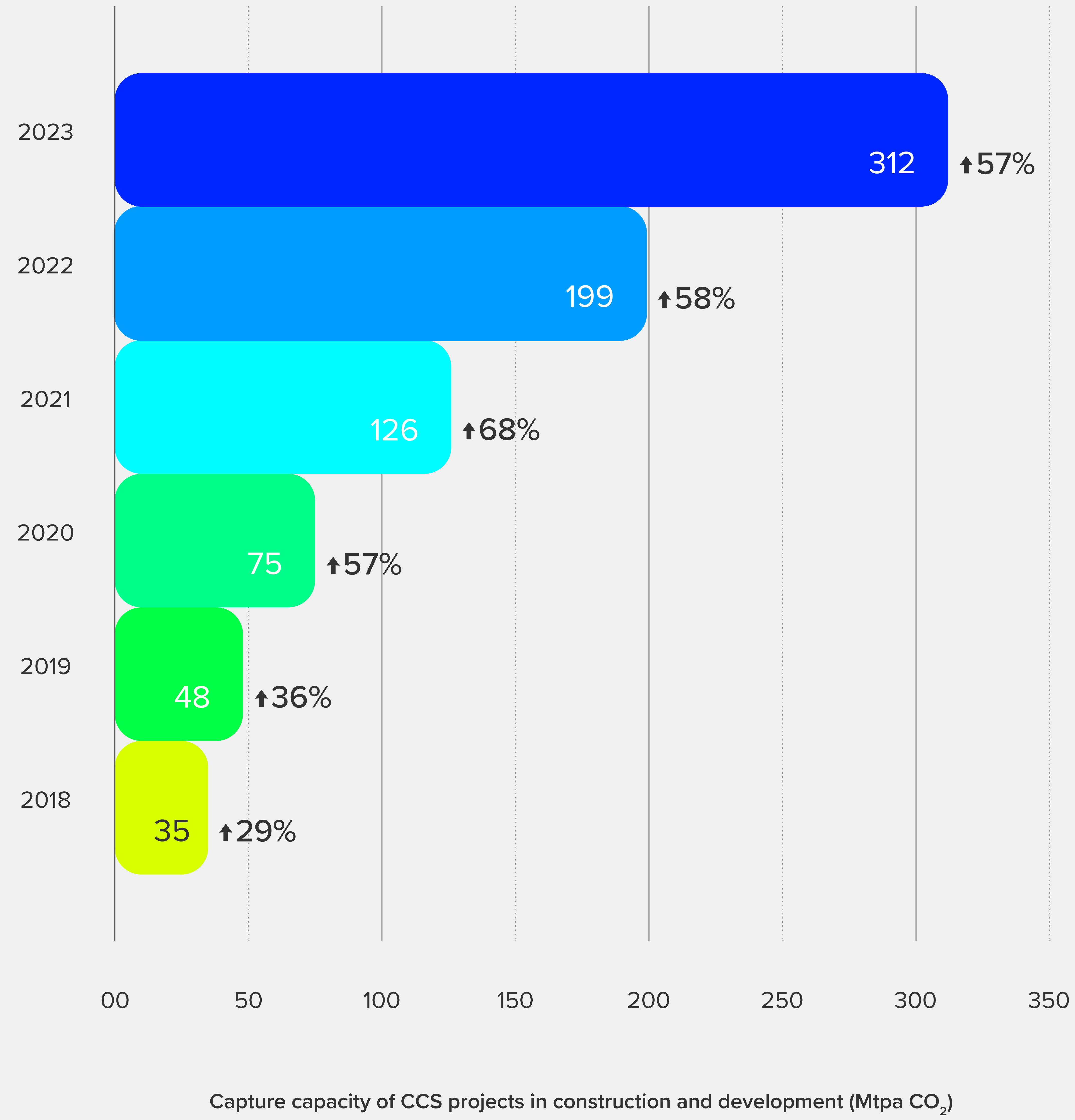
2.1 SCALING UP THROUGH 2030

Carbon capture and storage is beginning to scale up, and the CCS project pipeline has reached an unprecedented capacity. As of 31 July 2023, the total CO_2 capture capacity of CCS projects (in the public domain) in development, construction and operation was 361 Mtpa, an increase of almost 50% compared to that reported in the 2022 Global Status of CCS report.

Considering just CCS projects in construction and development, the rate of growth has remained high, as shown in Figure 2.1–1.

In addition to the headline statistics noted in Figure 2.1–1, the diversity of industries to which CCS is being applied has increased significantly over the past several years, demonstrating its role in supporting net-zero ambitions.

Figure 2.1–1: Year-on-year growth in capture capacity of CCS projects in construction and development (excludes capacity in operation).



The last 12 months have seen a significant increase in equity financing and interest in project finance for CCS projects. Many businesses seeking to profit from the provision of CCS services, especially in the transport and/or storage of CO_2, are now emerging on the back of decades of government-sponsored research, development, and deployment, industry net-zero commitments, and expectations of more stringent climate policy.

CCS is also becoming a more prominent feature of public policy, from inclusion in a growing number of countries' Nationally Determined Contributions (NDCs) to the provision of targeted policy to drive deployment and the drafting of appropriate regulations. International CCS business models are being developed, with the first transboundary movement of CO_2 by ship for geological storage completed between Belgium and Denmark in 2023.

There have been very significant policy developments in the last few years that have enabled the potential of CCS project investment to accelerate.

These are all encouraging indicators of progress. However authoritative analysis by the International Energy Agency, the Intergovernmental Panel on Climate Change, and others consistently indicates that achieving global climate targets will require annual CO_2 storage rates of approximately 1 Gtpa by 2030, growing to around 10 Gtpa by 2050. A critical question given where we are today is: Is this level of scale-up feasible?

Analysis from the Institute and other organisations demonstrate that whilst there are credible pathways for scaling up CCS deployment to keep the world on track for the goals of the Paris Agreement, this will require an ongoing and expanded commitment from governments and project developers, adoption of policy measures, and platforms that expand the CCS knowledge base to a wider audience of key stakeholders. Continued growth of the facility development pipeline, and ensuring projects in development proceed efficiently to final investment decision, construction and operation, are critical in the path to achieving the rates of deployment needed.

Supportive policies that underpin more robust carbon values, compelling and complementary tax incentives, and facilitating CO_2 transport and storage hubs to attract more local capture projects would help maximise the number of CCS projects entering the development pipeline.

In parallel, encouraging improved cross-learnings between projects, creating more support for CCS amongst the financing community, facilitating closer interaction between capture customers and infrastructure providers and enhancing public and community engagement, education, and communication would ensure projects successfully progress through FID and construction.

Thankfully, there have been very significant policy developments in the last few years that have enabled the potential of CCS project investment to accelerate, as described in the regional sections of this report. For example:

- In the EU, the Net-Zero Industry Act aims to have 50 Mtpa of CO_2 storage developed by 2030.
- The UK's CCUS Net Zero Investment Roadmap foresees 20 to 30 Mtpa of CCS capacity installed by 2030.
- Analysis of the impact of the US Inflation Reduction Act concludes that it could increase CCS deployment in the US by 200 to 250 Mtpa of CO_2 by 2030.
- Japan's CCS Long-Term Roadmap announced in January 2023 sets a target for the first commercial facilities to commence operation by 2030 on a trajectory towards 240 Mtpa CO_2 stored by 2050.
- Saudi Arabia has announced a target of capturing and storing 44 Mtpa CO_2 by 2035.

In addition, more stringent general climate policy and regulation is sending a very clear signal that the world is looking to expeditiously decarbonise across all sectors. The entry into force of the European Carbon Border Adjustment Mechanism and reform of the EU Emissions Trading System (EU ETS) to achieve a 55% reduction in emissions by 2030, and the commencement of the reforms to the Australian Safeguard Mechanism, requiring 4.9% year on year reduction in emissions from covered facilities over the next 5 years, are examples.

We are now seeing a rapid escalation in the development of new CCS projects, although relatively few have yet advanced to operation. Given projects typically take 7 years or more to develop, the lag between projects in development and projects entering operation is not surprising.

The impact of these recent developments is expected to be a sustained increase in the number of CCS projects in development, and a greater proportion of them successfully progressing to construction, especially when compared with the decade between 2010 and 2020. That decade was characterised by cost discovery through studies and the subsequent cancellation or delay in project developments due to economic non-viability. Now there are far fewer cost surprises and policy drivers are much stronger. The game has changed.

However, recent growth in CCS project capacity has been concentrated in North America and Europe where supportive policy and/or carbon pricing is the strongest. These jurisdictions have also promulgated comprehensive CCS regulation. Together, they have demonstrated how sound policy and regulation can rapidly increase investment in CCS. Growing the CCS project pipeline to the level required to capture 10 Gtpa CO_2 per year by the middle of this century will require strong growth in all jurisdictions, not just Europe and North America.

This, in turn, will require similar policies and regulation to those in place in Europe and North America to be commonplace around the world. Further, the rate of development of geological storage resources is not keeping pace with potential future demand, even in leading jurisdictions and especially in Europe. Unless dedicated programs are put in place to identify and appraise geological storage, sufficient capacity may not be available when required.

Stronger policy, targeted programs to develop storage resources and the promulgation of fit-for-purpose regulation of CCS in more jurisdictions including the Global South are essential within the next decade to ensure that CCS can scale up though 2030 to 2050 and beyond.

3.0 GLOBAL STATUS OF CCS

3.1 GLOBAL FACILITIES AND TRENDS

The number of CCS facilities in the development pipeline has increased significantly in 2023, with 11 new facilities commencing operations and 15 new projects in construction. As of July 2023, there are 392 projects in the pipeline, representing a 102% year-on-year increase.

The project pipeline in terms of facility numbers and capacity is at an all-time high. Since 2017, capture capacity has grown at a compound rate of more than 35% per annum. This has accelerated in the last 12 months; capture capacity increased 50% from 2022 – the highest increase since the upward momentum started in 2018.

102%

year-on-year increase in number of CCS facilities in development pipeline.

Figure 3.1–1 shows the increase in capacity from 2010 to 31 July 2023. This figure, and the capture capacity reported in Figure 3.1–1, do not include the capacity of CO_2 transport and/or storage projects, to avoid double counting. However, the number of facilities in Figure 3.1–1 does include CO_2 transport and/or storage facilities that do not have their own CO_2 capture source. As of 31 July 2023, 101 transport and/or storage projects were in the deployment pipeline, in construction or operational.

Capture capacity in all stages of project development has increased significantly, including a 47% increase in both Advanced Development and Early Development projects. Projects that have received significant funds for engineering development, are demonstrating a higher level of commitment, and have a higher probability of moving to funding approval and construction are included in "Advanced Development". In light of this, an increase of 47% is significant.

Figure 3.1–1: Capacity of commercial facility pipeline since 2010

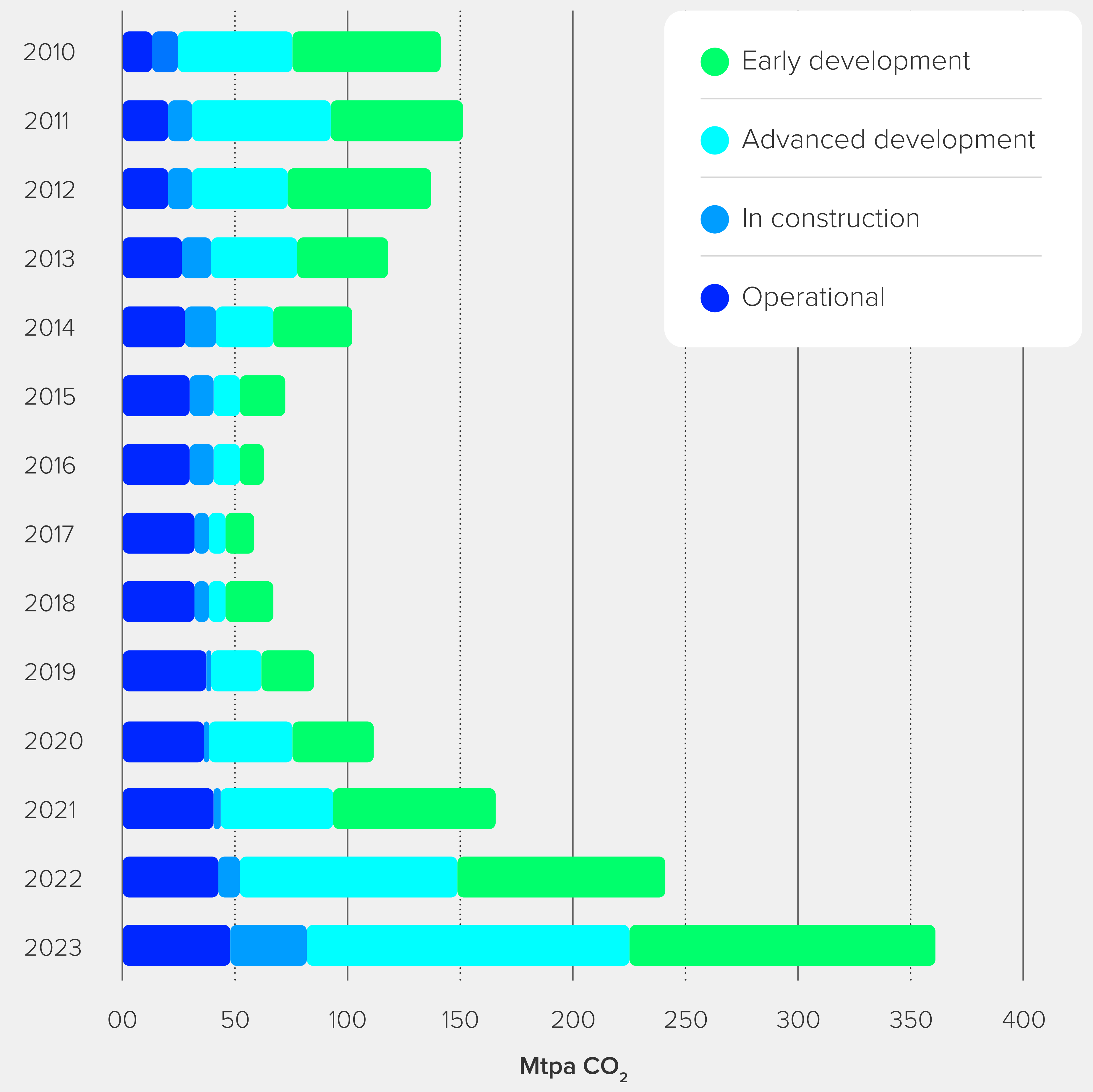
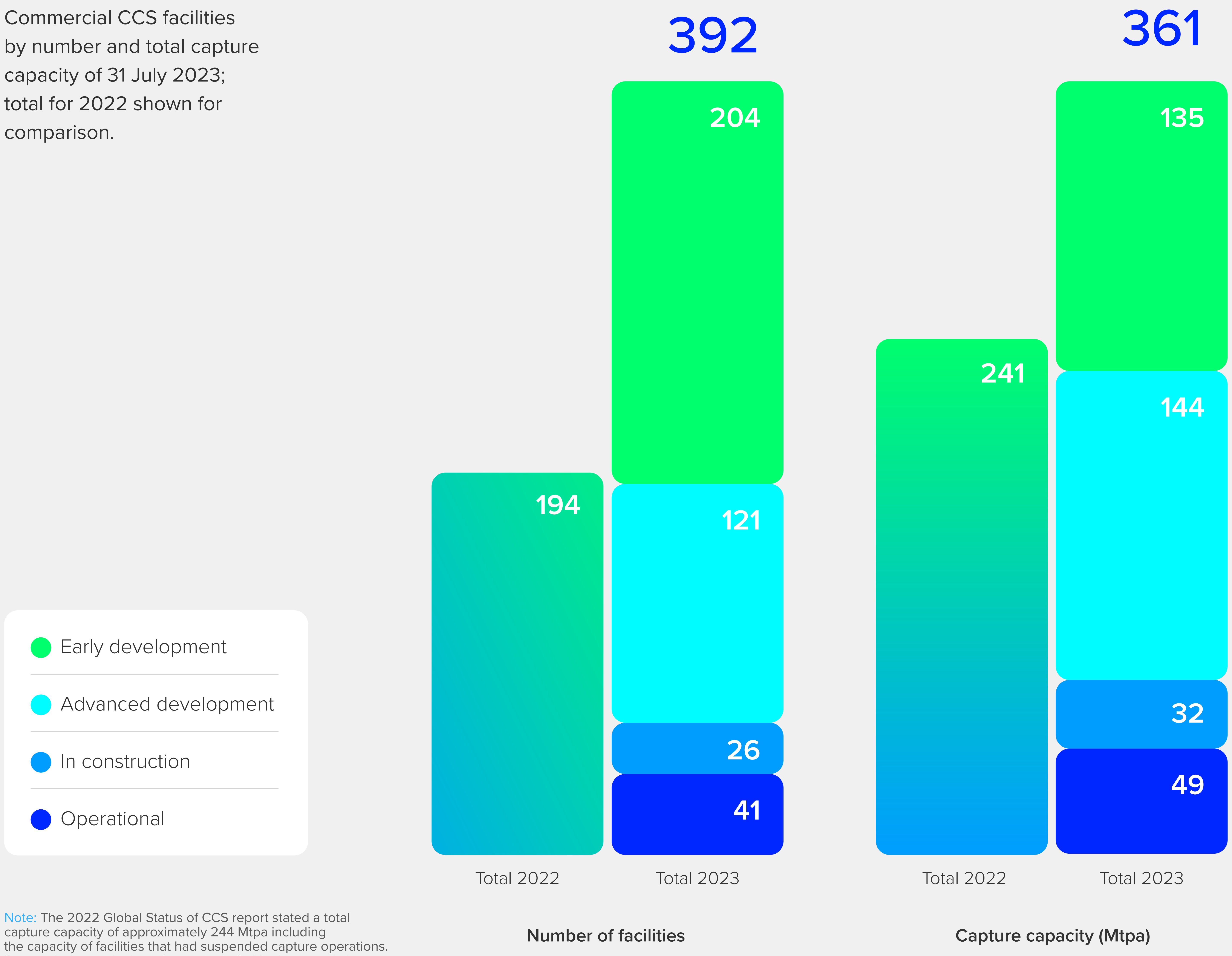


Figure 3.1–2:
Commercial CCS facilities by number and total capture capacity of 31 July 2023; total for 2022 shown for comparison.



Note: The 2022 Global Status of CCS report stated a total capture capacity of approximately 244 Mtpa including the capacity of facilities that had suspended capture operations. Suspended capacity is no longer included in these statistics and thus the 2022 capacity has been revised down slightly.

Historically, a CCS facility was vertically integrated – a single CO_2 capture plant with dedicated CO_2 compression, pipeline and storage systems. However, CCS networks are becoming the dominant mode of CCS deployment.

CCS networks involve capture plants utilising shared transport and storage infrastructure. Many CO_2 transport and storage facilities in the deployment pipeline are not associated with a specific CO_2 capture source. However, those same CO_2 transport and storage facilities still have a design capacity. For example, a storage site will announce its maximum annual injection rate, which will be reported as its capacity. Including the CO_2 flow capacity of these CO_2 transport and storage facilities along with the capacity of the CO_2 capture plants that will utilise them would result in double counting of CO_2 capture and storage capacity.

Since 2022, the Global Status of CCS reports have used only the maximum CO_2 capture design capacity in their reporting. This method avoids double counting while ensuring compatibility with our historical capacity statistics. Facility pipeline charts and figures are now explicitly referred to by "Capture Capacity", a change from the pre-2022 title of "Capacity of CCS Facilities". Dedicated CO_2 transport and storage facilities are still counted in total facility numbers but will not contribute to global CCS capacity.

The CCS facilities' capture, transport and storage capacity is detailed in Section 6.

Industry developments

Transport and storage networks

CCS deployment through networks has become the dominant pathway as networks deliver economies of scale that reduce cost and business model synergies that reduce risk. Capture hubs and transport networks are being developed to service regional CO_2 sources. These sources are typically less than 1,000 km from the storage resource but may be significantly further where the scale and project economics allow, particularly where the main transport mode is by ship.

These hubs and networks establish shared CO_2 storage infrastructure for permanent CO_2 storage. Modelling suggests that up to 4.2 Gtpa of CO_2 could be captured and stored by establishing 160 hubs globally at costs of less than $85 per tonne of CO_2. It is clear the development of CCS networks and hubs is critical, since storage of around 10 Gtpa of CO_2 is required to achieve net zero emission targets by mid-century.

As global CCS policy and regulation develop and funding support increases, companies can be expected to build positions in CCS networks to take advantage of economies of scale and reduced cost. To date in 2023, there have been three key CCS merger and acquisition transactions – the Chevron-Talos-Carbonvert deal in the US; E.ON-Horisont's Energi deal in Europe and ExxonMobil Corporation acquiring Denbury Inc. for its CO_2 transport and storage facilities.

There has seen the proliferation of CCS networks in 2023. The ongoing development of CCS networks has resulted in a new industry category of "CO_2 transport and storage" facilities. In 2023, 101 of these facilities were identified globally.

These stand-alone facilities represent a new CCS industry model. The facilities are not aligned to any other industries, which to date were defined by their capture source. Examples of these multi-user, multi-industry CO_2 transport and storage facilities include:

- Wolf 's Alberta Carbon Trunk Line CO_2 compression and pipeline in Canada, operating since 2020.
- CarbonNet in Australia, a CO_2 storage-focused facility.
- CarbFix CODA CO_2 transport and storage, shipping CO_2 from across Europe before storing the CO_2 through mineral carbonation.
- The Northern Lights open-source transport and storage network in Norway, aiming to be operational in 2024 and storing 0.8 Mtpa of CO_2 from a cement plant in Brevik and a waste plant in Oslo (phase 1) deep under the seabed in the North Sea. In May 2023, the project signed another cross-border deal with Ørsted to transport and store a further 430,000 tpa from two power plants in Denmark.

Industries hosting CCS facilities

Focussing on the capture source of emissions, the ethanol industry has the second largest number of facilities at 70. Two major US ethanol-focused CCS networks are Summit's Mid West Express with 36 plants and Navigator's Heartland Greenway with 18 plants.

Power generation and heat is the third largest count of facilities by industry at 53, followed by hydrogen/ammonia/fertiliser (50). Natural gas processing, which historically was a primary industry for CCS, completes the 2023 top five industries with 45 facilities.

Away from these five industries, cement was the fastest-growing industry at 22 facilities, dominated by European plants. Finally, there are now six commercial direct air capture plants in the pipeline.

CCS development highlights

10.6 Mtpa

The world's largest operating project, Petrobras Santos Basin Pre-Salt Oil Field, has a capture capacity of 10.6 Mtpa dedicated CO_2

5

New facilities in operation in China

7

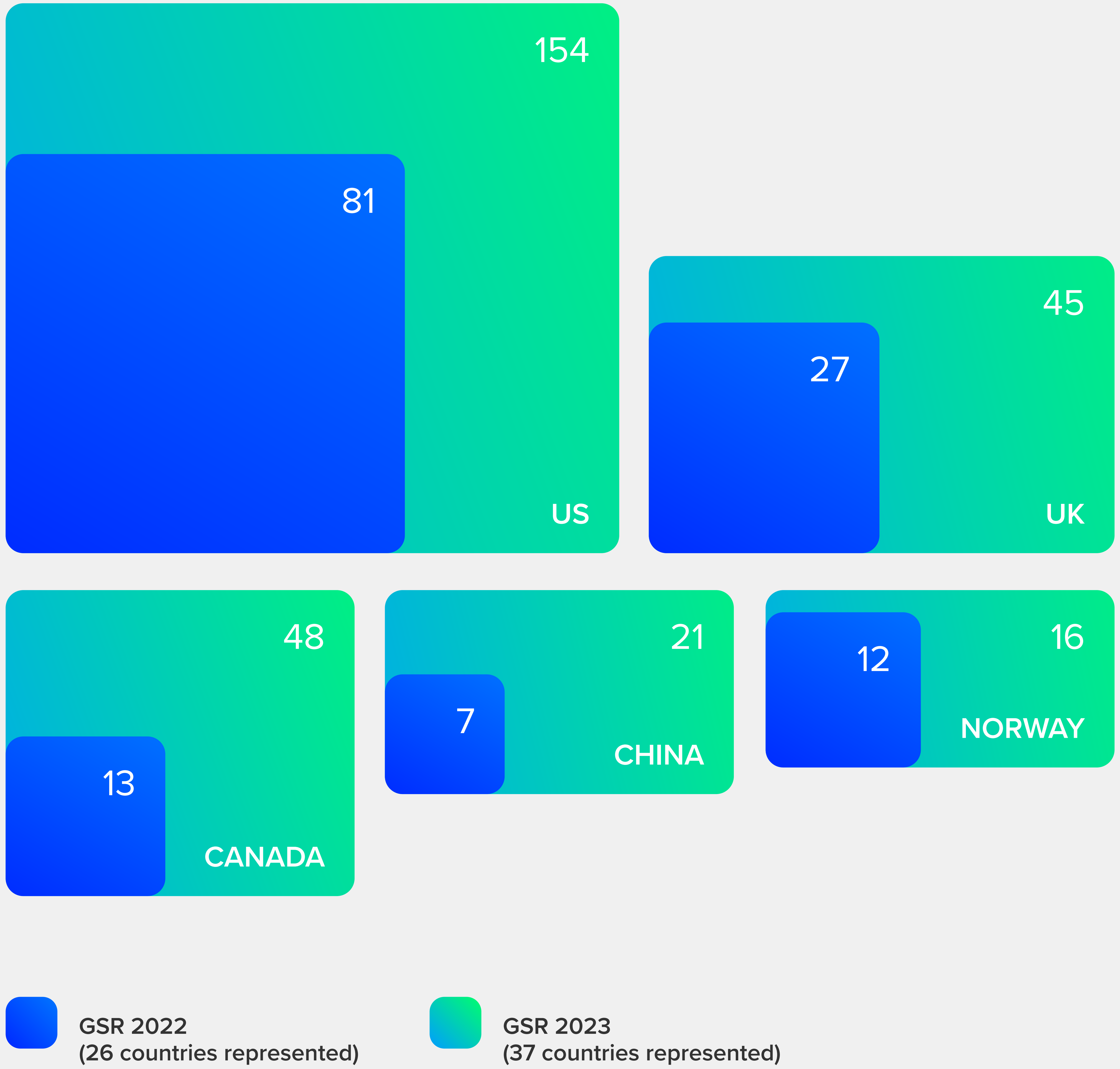
New funding for seven CCS networks in Japan

2

Top 2 applications by the number of facilities – ethanol, power generation and heat

Figure 3.1–3:
CCS project pipeline by industry and year of operational commencement.

Figure 3.1–4:
Top five countries with CCS projects in the pipeline in 2023 vs 2022; the US, UK, Canada, China and Norway



Country and regional developments

The CCS facility developments over the past year are far too numerous to summarise here. However some examples are mentioned below to illustrate the broad scope and scale of CCS projects in development:

- Saudi Arabia: Jubail Industrial City, one of the world's largest CCUS hubs, will start operating by 2027 with a capacity of up to 9 Mtpa of CO_2 in its first phase, supporting Saudi Arabia's aim to extract, use and store 44 Mtpa of CO_2 by 2035.
- China: Three projects became operational in 2023 – Asia's largest coal-power plant CCS facility, the first offshore CO_2 storage facility, and carbon capture at an oil refinery. China now hosts 11 operating facilities including its first commercial-scale CO_2 transport pipeline (part of the Sinopec Qilu-Shengli facility).
- The US: Construction commenced on the first large-scale DAC project, STRATOS, and operations are planned to start in 2025. The project aims to capture up to 500,000 tonnes of CO_2 per year.
- Japan: Announced support for seven CCS networks that will capture CO_2 in Japan for storage in the offshore waters off Japan and in the wider Asia-Pacific region.
- Greece: Announced five facilities as part of the Prinos CCS network with natural gas, cement and hydrogen plants to access their CO_2 transport and storage infrastructure.

The growth in the number of CCS facilities announced and in development worldwide indicates that the technology is becoming attractive as countries and companies work to achieve their climate commitments on a shrinking carbon budget.

Between 2022 and 2023, 11 new countries registered CCS facilities in various stages of development. The US still dominates CCS deployment, with 73 new facilities entering the pipeline in 2023. The UK, Canada and China increased their facility counts and remained in the top five CCS deployment countries. The Netherlands has been replaced by Australia, which now has 12 facilities in development. In 2022, Japan and Greece had no commercial facilities but now host seven and five, respectively in 2023.

Middle East and Africa

Three CCS facilities are operational in the Middle East, with three in construction, and three in advanced development. Six CCS facilities in this region are associated with the natural gas processing industry.

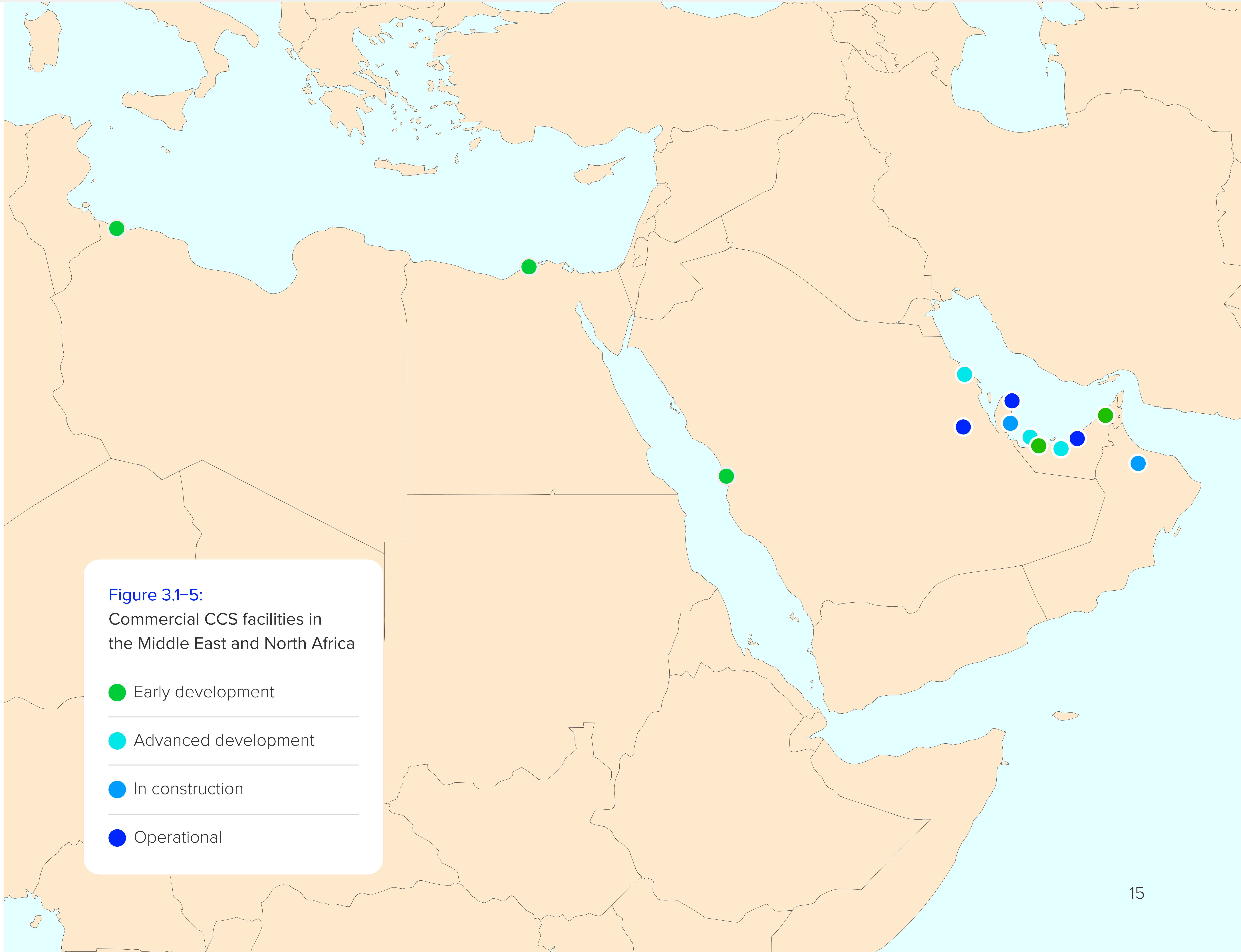


Figure 3.1–5:
Commercial CCS facilities in the Middle East and North Africa

- Early development
- Advanced development
- In construction
- Operational

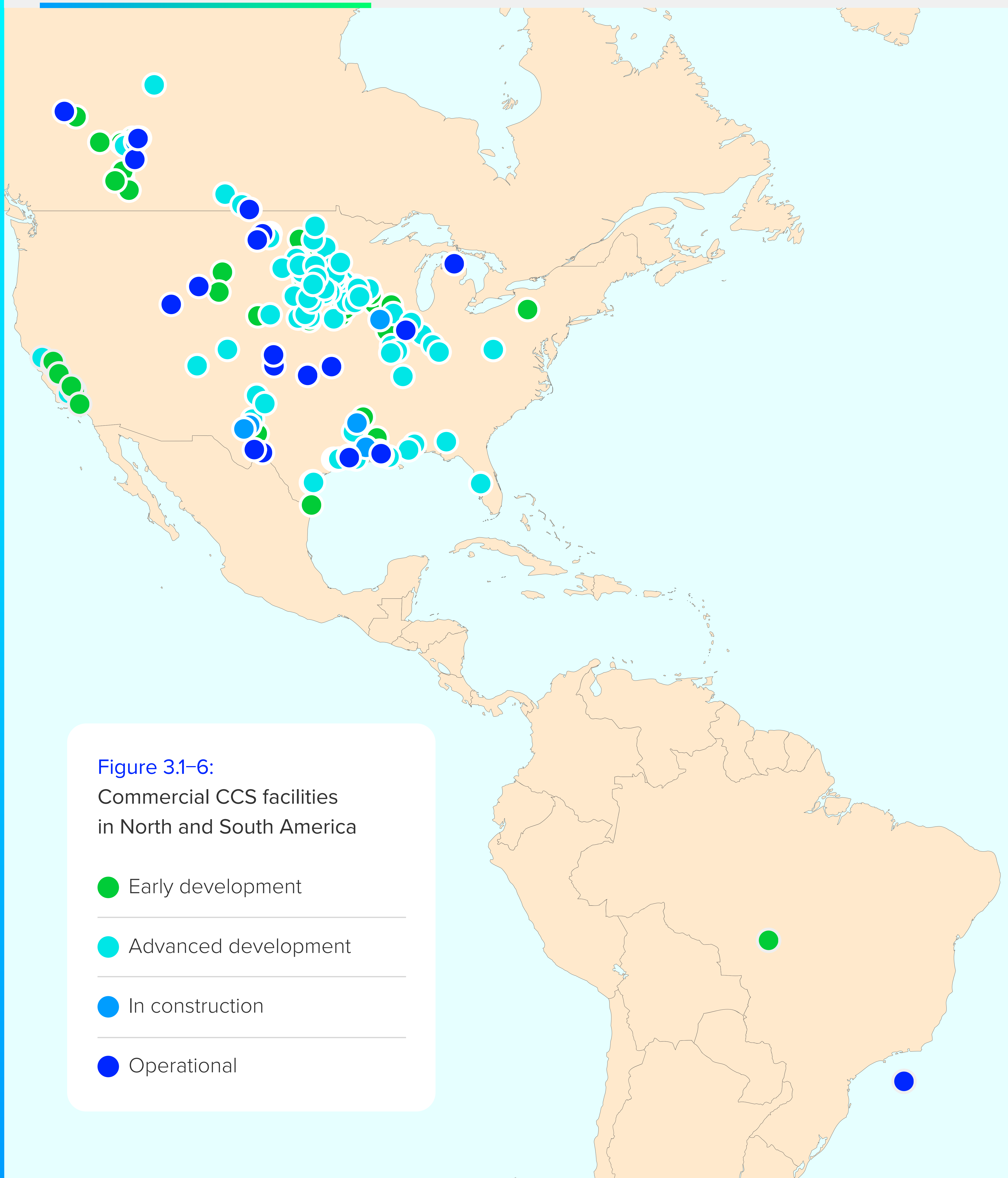


Figure 3.1–6:
Commercial CCS facilities in North and South America

North America

In the US and Canada, the ethanol industry hosts the most carbon capture facilities (69) in operation, construction or development. CO_2 transport and storage facilities are the second most prolific
industry with 48 facilities in the pipeline. CCS is gaining momentum in ammonia, hydrogen and fertiliser production, as well as power generation and heat, with 25 and 28 projects respectively across the project pipeline or in operation. Natural gas processing accounts for 16 CCS projects. Overall, 21 CCS facilities are operational in this region, nine in construction, 80 in advanced development and an additional 92 in early development.

South America

The world's largest operating CCS facility is in the natural gas processing industry; the Petrobras Santos Basin Pre-Salt in Brazil. Operating in over 2,000 m water depth, the facility is currently capturing 10.6 Mtpa and re-injecting the CO_2 for enhanced oil recovery. In 2022, 40.8 Mt of CO_2 had been cumulatively reinjected.

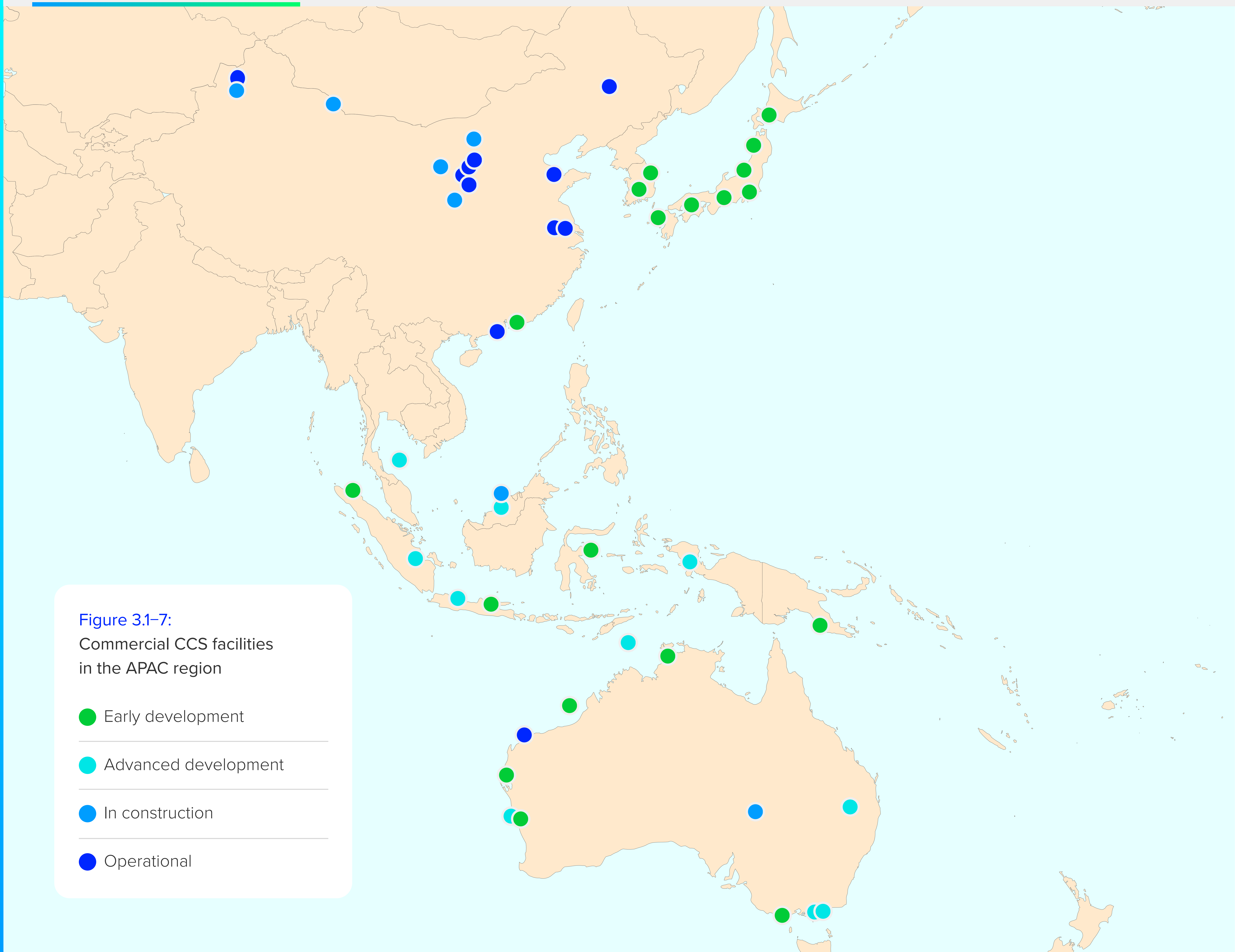


Figure 3.1–7:
Commercial CCS facilities in the APAC region

Asia Pacific

CO_2 transport and storage facilities under development (17) make up the largest category of facilities in the Asia Pacific region, followed by natural gas processing and chemical manufacturing – 15 and 10 facilities respectively. A total of 12 facilities are operational (five facilities commencing operations in 2022/23 in China), eight in construction, and 34 in advanced or early development.

Europe

In Europe, 35 CO_2 transport and storage networks are in development. Other industries where CCS features prominently include hydrogen, ammonia and fertiliser facilities (20), power generation and heat (19 facilities), cement (17 facilities), and biomass to power/heat (15 facilities). Four facilities are operational, with six in construction and 109 in early or advanced development.

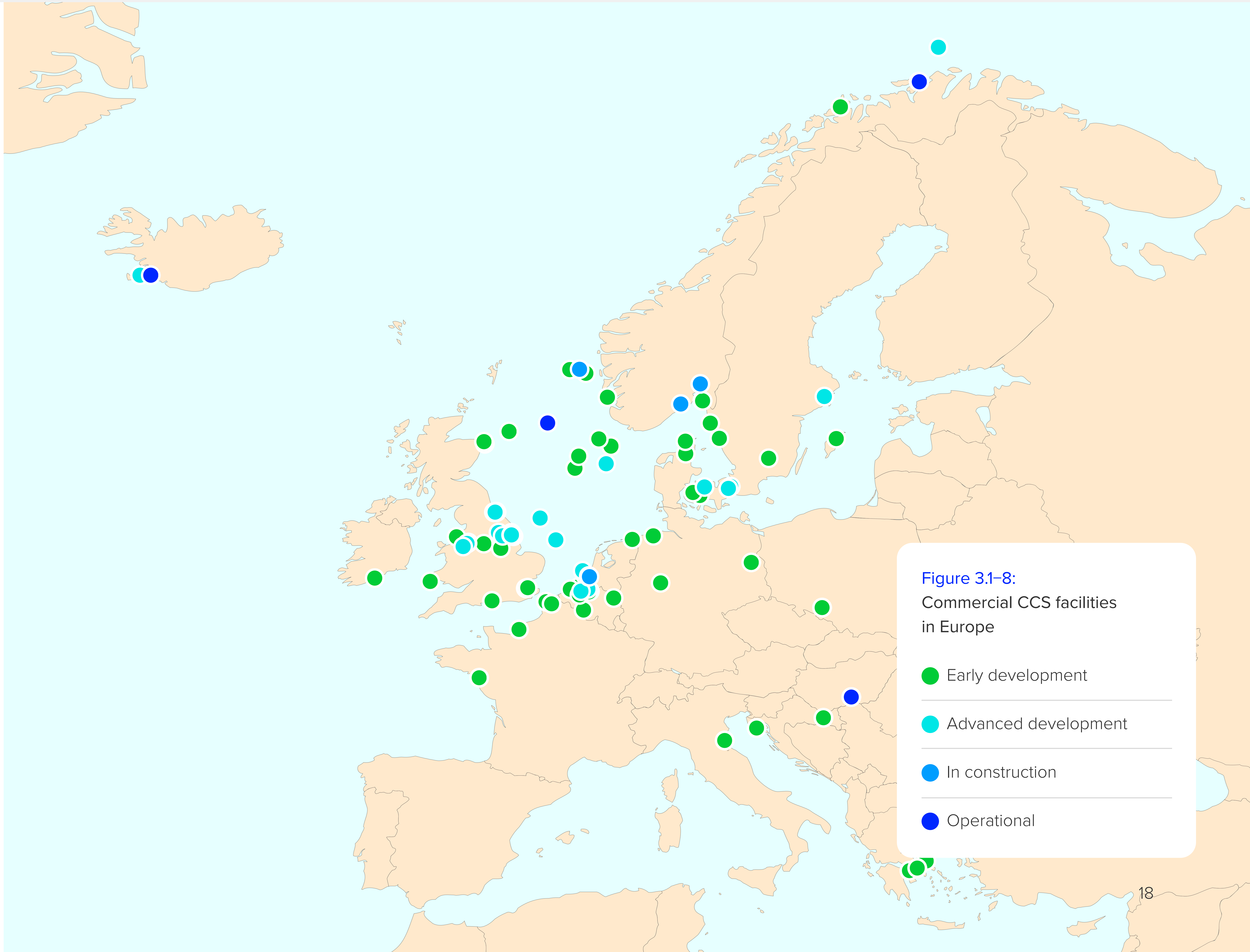
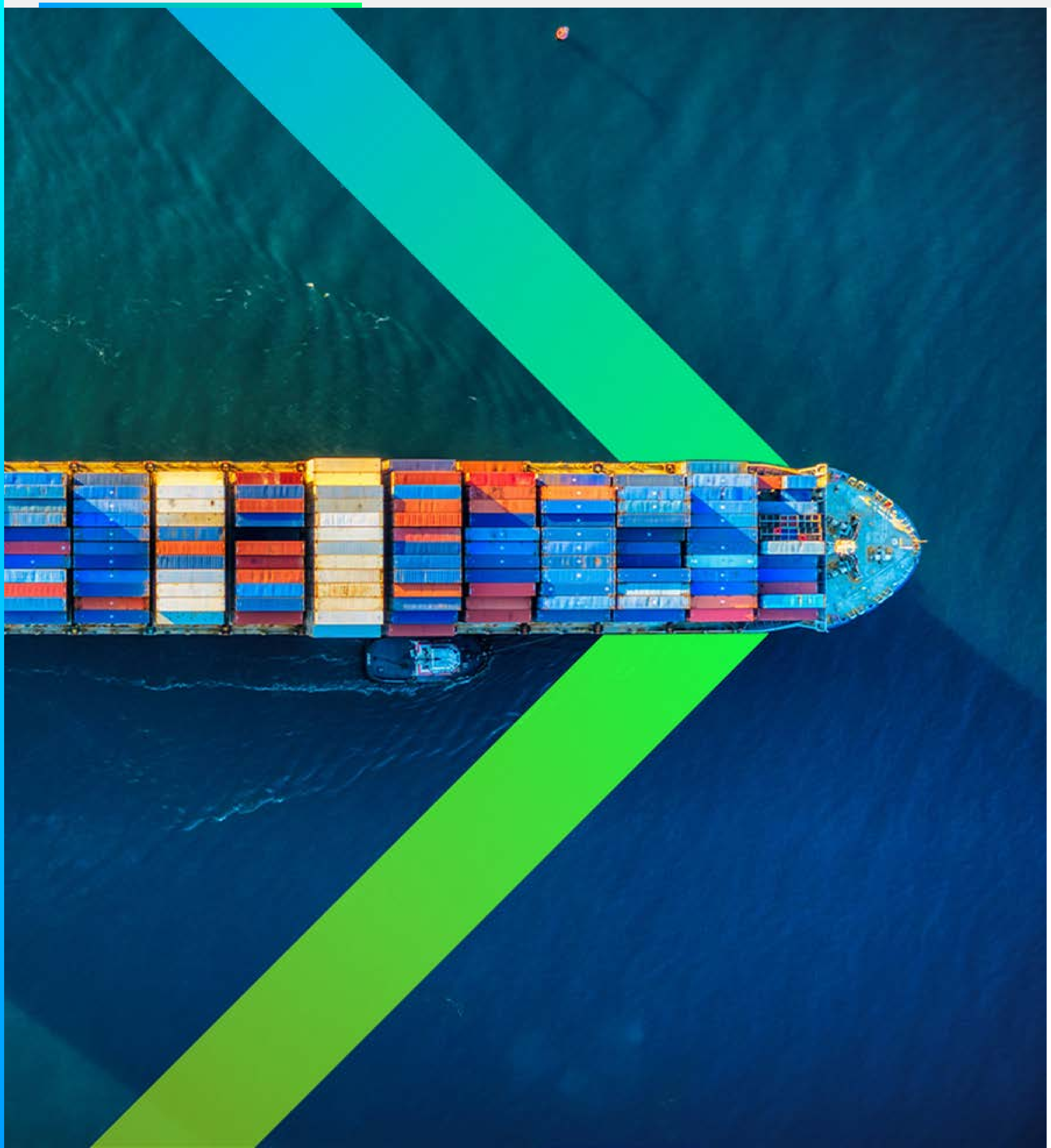


Figure 3.1–8:
Commercial CCS facilities in Europe



Developments in the shipping of liquified CO_2

As CO_2 networks gain momentum, CO_2 transport mechanisms are developing and maturing, including technologies for shipping liquefied CO_2 (LCO_2). Shipping companies are actively expanding their services into the shipping of LCO_2. Key activities over the past 12 months include:

- The Northern Lights project will be the first to transport LCO_2 by ship. In December 2022, Kawasaki Kisen Kaisha, Ltd. ("K" Line) signed long-term charter contracts with Northern Lights JV DA for two 7,500 m^3 LCO_2 vessels. These vessels will start transporting LCO_2 from several CO_2 capture facilities, including Norcem Brevik and Hafslund Oslo Celsio, to the Northern Lights CO_2 receiving terminal in Øygarden, Norway in 2024.
- In June 2023, Knutsen NYK Carbon Carriers AS (KNCC), an affiliate of NYK, received the maritime industry's first General Approval for Ship Application (GASA) for an ambient temperature and elevated pressure containment system (the LCO_2-EP system) which can be fitted or retrofitted on vessels for transport of LCO_2.
- In June 2023, Mitsui O.S.K. Lines, Ltd. (MOL), Malaysian state oil company PETRONAS and the Shanghai Merchant Ship Design & Research Institute (SDARI) acquired approval in principle from ship classification societies Det Norsk Veritas and the American Bureau of Shipping (ABS) for a jointly developed LCO_2 carrier. ABS also granted approval in principle for the companies' jointly developed floating storage and offloading unit.
- Also in June 2023, Mitsubishi Shipbuilding Co., Ltd. and Nippon Yusen Kabushiki Kaisha (NYK Line) were granted approval in principle from Japan's classification society, ClassNK, for the development of a ship that can simultaneously transport ammonia and LCO_2.
- In July 2023, South Korea's HD Hyundai, through its Korea Shipbuilding & Marine Engineering arm, received its first order to build the largest LCO_2 carriers for Greece's Capital Maritime Group. The two vessels will each carry 22,000 m^3 of LCO_2 and the first delivery will be in 2025.

3.2 INTERNATIONAL POLICY, LEGAL AND REGULATORY DEVELOPMENTS

Momentum grows for collective global action on CCS

The first half of 2023 saw significant strides toward global action on CCS. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Synthesis report re-stated the need for CCS to achieve the Paris climate goals.

The report concludes the 6-7 year reporting cycle and highlights CCS as a clear option in modelled pathways to limit global warming 1.5˚C, with carbon dioxide removal from the atmosphere (CDR) to counterbalance residual emissions from the hard-to-abate sector. With the next report scheduled to be published around 2030, the timing of IPCC AR6 is crucial for this critical decade for climate action.

Significantly, the report will inform the world's first Global Stocktake (GST) at the 28th Conference of the Parties (COP28) hosted by the UAE in Dubai from 30 November. The GST is designed to lay the foundation for countries to update their national climate action plans known as Nationally Determined Contributions (NDCs).

A highlight in global CCS collaboration was when the US announced the Carbon Management Challenge at the Major Economies Forum (MEF) in April, inviting other countries to join the challenge towards a collective CCS/CDR target by 2030, with the aim of unveiling at COP28 a suite of concrete announcements and goals.

At the MEF meeting, leaders from Australia, Canada, Egypt, the European Union, Japan, Saudi Arabia, the UAE, Norway and Denmark joined in supporting the launch of this call to action. Sweden and Brazil joined the initiative in July during the 14th Clean Energy Ministerial in Goa, and more countries are expected to join. In tandem came the International Energy Agency (IEA) Credible Pathways to 1.5˚ report, which features carbon management as the fourth of the four pillars outlined for action this decade, with a 1.2 Gt of CO_2 storage target by 2030.

Shortly after the MEF meeting, the Group of 7 Summit in Hiroshima Leaders' Communiqué heralded the most detail on CCS ever featured in a G7 leaders document, acknowledging that the technology is an important part of the broad portfolio of decarbonisation solutions to reduce emissions that cannot be avoided otherwise, with CDR to counterbalance residual emissions.

At the Bonn Climate Change Conference in June, the Global CCS Institute led the conversation as a technical expert on CCS with IEA GHG at the first Global Dialogue and Investment-focused event under the accelerated mitigation ambition and implementation work programme established at COP27.

This involved day-long discussions that brought to light shifting country perspectives on CCS, such as from small island nations, which despite having no CCS opportunities within their borders see the value of it in the implementation of the Paris Agreement.

At the third and final technical dialogue of the GST diverging views on CCS were more pronounced, with countries with strong views for or against the technology speaking up in their interventions.

Latest NDC updates as of July find newcomers Andorra, Singapore, Türkiye, Turkmenistan, the UK and Vietnam including CCS in their NDCs. Furthermore, at the Katowice Committee of Experts on the Impacts of Implementation of Response Measures, CCS is found in Activity 5 of its current work plan, providing an opportunity for countries to discuss aspects in relation to capacity building and socio-economic impacts of the technology in a United Nations setting.

As the world anticipates the operationalisation of the new international carbon market under Article 6, the year saw contentious discussions surrounding key documents that will dictate how CDR is handled under the mechanism.

The views expressed in these documents on engineered removals (ie direct air capture and storage – DACCS and bioenergy carbon capture and storage – BECCS) and consequently CCS, subsequently led to a significant response from the CCS/CDR community through a series of official submissions to the process.

Looking at the wider picture for Article 6, projects are indeed underway for the bilateral segment of Article 6.2, with an interim platform online as negotiations continue on various administrative elements, with technical capacity building being set up for certain countries in need.

For the global market (Article 6.4), under which the current CDR debate falls, further fundamental differences overshadow the progress necessary to begin trading, as any mechanism put in place under Article 6.4 would be perceived as the 'gold standard' for the oversight for compliance and voluntary carbon markets.

Expectations are high for the UAE's COP28 presidency to deliver on the global energy transition towards net-zero, where there is an opportunity to advance CCS.

With a global target on the horizon, global ambition on CCS deployment this decade needs to become clearer. With such momentum, it is also imperative that "how", and not just "how much", is being addressed.

With a global target on the horizon, global ambition on CCS deployment this decade needs to become clearer.

Preliminary work on the Global Sustainable Development Goals (SDGs) and how they relate to CCS is demonstrated in IPCC AR6, in tandem with the global focus on just energy transition pathways. Indeed, the mobilisation of the international community towards the technical capacity building and financial needs of the Global South is a critical lever to ensure deep decarbonisation through the use of CCS technologies this decade.

Role of policy

The past year has seen significant policy, legal and regulatory intervention in many jurisdictions around the world, which in turn has resulted in a strengthening of support for CCS and in some instances further commitments to commercial deployment. While there are noteworthy examples of developments in jurisdictions with a history of support for CCS, it is positive to see a wider group of nations now focused on fostering a supportive environment for deployment.

The impact of strong policy intervention is particularly evident in the US, with federal and state level initiatives affording strong incentives and support for projects. At the federal level, the Inflation Reduction Act and Bipartisan Infrastructure Law have had an undeniable impact upon project commercialication and their package of programs, funding and strong ambition has led to a rapid expansion in project announcements nationwide.

State level regulatory activity, for permitting geological storage as well as other issues such as pore space acquisition or long-term stewardship, may offer further support for those seeking to develop projects in several states across the US.

Coordination between federal and state regulatory authorities and technical capacity building across all jurisdictions may ultimately lead to more efficient regulatory timelines.

In Europe, the Commission's proposed Net Zero Industry Act offers further support for the EU's clean energy transition. With a focus on scaling up decarbonisation technologies and a clear commitment to enhancing storage opportunities and increasing injection capacity by 2030, the Act further bolsters the strong Union-wide policy and regulatory environment for the technology.

The development of CCS-specific policy and legislation is also proving important for nations in the nascent stages of formulating a national approach to the technology. The recent development of CCS-specific laws and regulations in Indonesia and a state in Malaysia, for example, have addressed a significant barrier to more widespread deployment in both nations. These early frameworks offer an important foundation and provide confidence for investors and the operators of the newly-announced projects in both jurisdictions.

Importance of frameworks

Notwithstanding the significant developments in several jurisdictions over the past year, the scale and urgency of the policy and legislative task remains significant. Examination of national frameworks in even the most advanced jurisdictions indicates that further action is required.

In Europe, where some of the world's first CCS-specific policies and legislation were developed, work remains underway to complete and strengthen these early frameworks. In addition to the policy development highlighted previously, the Commission is supporting the revision of its Guidance Documents, a key tool for supporting operators and authorities in their domestic implementation and interpretation of permitting procedures under the EUCCS Directive. The latest version will reflect the significant developments that have been made in Europe, including project-level experience and feedback from policymakers and regulators in the member states.

Permitting is now an acute issue in the US, where there is suddenly a sizeable number of permit applications for CO_2 storage.

The Commission's work will also provide important support to national authorities focusing on the permitting of new projects and address the newer technical applications of the technology that were not conceived when the original policy and regulation was developed. The timeliness of this is particularly noteworthy as several member states are currently in the process of reviewing domestic legislation to enhance regulatory frameworks.

Delays in implementing legislation will have a profound impact on project deployment, an issue that has proven particularly significant for those seeking to invest in or develop projects in several regions around the world. Many nations have yet to develop CCS-specific frameworks and a significant number have yet to begin even preparatory studies or assessments of existing capacity to regulate the technology.

In Southeast Asia, project proponents continue to voice concern that existing frameworks will not support commercial-scale deployment and cite many critical issues that remain unaddressed by national legislation. Although there have been some noteworthy developments in the region over the past year, the absence of CCS-specific legislation remains a significant barrier that must be overcome for countries and industries to meet their commitments to both deployment and emissions reduction. Timely action is essential in this regard, and the consequences of further delay are likely to prove significant.

Permitting is now an acute issue in the US, where there is suddenly a sizeable number of permit applications for CO_2 storage. The US EPA has recently provided more details on the status of each permit, but many questions remain regarding the timing of these permits and the EPA process to grant primacy to states. State primacy is important because it can help expand the CCS regulatory and permitting capacity in the US.

Transboundary issues

The emergence of new markets and applications for CCS technologies, enhanced or revised national commitments to achieving net-zero and wider commercial opportunities afforded by CCS networks has led to greater scrutiny of CCS project opportunities beyond national boundaries.

This focus has been strengthened further by the development of several regional cooperation initiatives aimed at advancing deployment of the technology in recent years. Consequently, project proponents, policymakers and regulators have also had to consider the legal implications of transporting captured CO_2 across territorial boundaries, including between nations.

The most significant of these considerations was in Article 6 of the London Protocol, which prohibited "the export of wastes or other matter to other countries for dumping or incineration at sea" and was determined to similarly prohibit the transboundary transportation of CO_2 for geological storage.

Amendments to the Protocol in 2009 addressed this obstacle and a more recent decision by the Protocol's parties removed a final barrier by enabling the provisional application of the amendment.

For some nations, however, uncertainty remains as governments have yet to commit to the adoption of the Protocol's amendments or enter into formal agreements with other nations to enable transboundary movement.

While several European parties have entered into these agreements to facilitate projects in the North Sea, formal adoption and agreement has been slower in other parts of the world where transboundary operations are proposed.

The recent recommendation by the Australian government's House Standing Committee on Climate Change, Energy, Environment and Water to ratify the 2009 amendment is an important step in recognising both the significance of the agreement and the role of CCS in the region.

In addition to international marine agreements, focus must also turn to the wider body of domestic and international law that will apply to operations of this nature. Analysis suggests a variety of laws will apply and policymakers and regulators must ensure these will not present further barriers to deployment.

3.3 STATUS OF CCS FINANCING

Financing prospects have improved substantially in the past year in key jurisdictions due to increased policy support and other factors, including price signals, and there is every indication that the momentum will continue.

This has precipitated a substantial increase in CCS investment, however the increase is mostly in equity funding in developed economies benefiting from multiple revenue streams. For CCS to scale up to reach climate goals, debt finance and rapid deployment in the developing world are necessary.

Table 3.3–1 represents the Global CCS Institute's high-level assessment of how changes in key factors have affected the finance-ability of CCS projects over the past year in leading jurisdictions.

The net result of the improvement of the factors listed in the table is a significant increase in investment to develop CCS facilities. The total capacity of CCS projects in development, construction or operation has increased from 244 Mtpa CO_2 in September 2022 to 361 Mtpa CO_2 in July 2023, an increase of 47%.

Table 3.3–1: High level assessment of factors impacting potential financing of CCS in leading jurisdictions

Factor	Change*	Drivers
Expected Return on Investment	Improved	Stronger policy support, higher C pricing, tax credits, more commercial/offtake agreements
Predictability of revenues	Improved	Stronger policy support, higher C pricing, Carbon Contract for Difference (CCfD) instruments, tax credits, more commercial/offtake agreements
Maturity of technology	Improved	Accumulation of operational experience, many more feasibility studies/Front End Engineering & Design (FEED) studies
Experience of developers	Improved	Accumulation of operational experience, many more feasibility studies/FEED studies
Political risk	Improved	Where policy support has increased, political risk is generally lower
Interest rates	Deteriorated	Rising interest rates increase the overall cost of capital
Permitting	Unchanged risk of deterioration in permitting times in the US	Timing uncertainty due to strong growth in the number of permit applications requiring assessment. Permitting requirements/Regulation materially unchanged
Liability risk	Improved	Risks are better understood/Insurance companies are beginning to price risks

* Change since release of 2022 Global Status of CCS report

Equity financing:

Busy and accelerating

Debt financing:

No firm commitments yet, but momentum growing

Government finance:

Governments are putting significant financial resources into CCS projects and infrastructure through loans, guarantees, or grants

Balance sheet/cash flow:

This is the main source of finance currently, but project finance is needed to reach ambitious targets

Equity investment in companies

Equity finance is a high-risk high-return investment provided in return for share ownership. The equity flow to climate technology, including CCS which accounts for only a small share, reached $196 billion in 2022, an increase of 6.6% over 2021.

The increase contrasts with a slump in venture capital, private equity, and environmental, social and governance (ESG) investing. To provide context, overall venture capital funding decreased by 37% in 2022 to $420 billion and ESG inflows dropped to $155 billion in 2022 from $650 billion in 2021.

Table 3.3–2 lists some notable deals of relevance to CCS in 2022 and the first half of 2023.

Table 3.3–2: Recent notable deals

Deal	Description	Investors	Investor type	Size $US mil	Date
Climeworks	Direct Air Capture	Swiss Re Partners Group M&G GIC Baille Gifford	Insurer Private Equity Private Equity Singapore Wealth Fund Pension Fund	646	April 2022
Svante	CO_2 Capture	Chevron Ventures United Airlines Samsung Ventures OGCI M&G Japan Energy Fund GE Vernova 3M Hesta AG	VC arm of Chevron Airline VC arm of Samsung Growth Capital Private Equity Private Equity Decarbonised power technology supplier Diversified conglomerate Family office	324	May 2022
Summit carbon solutions	CCS as a Service	TPG Infrastructure Tiger Infrastructure Continental SK	Private Equity Private Equity Oil and Gas Diversified conglomerate	1,000+	May 2022
Amogy	Near-zero emissions ammonia as a fuel	SK Innovation Temasek Aramco Ventures Korea Zinc MOL+	VC arm of SK Global investment company VC arm of Saudi Aramco Non-ferrous metals & clean energy company VC arm of Mitsui Lines	150	March 2023
Infinium	Synthetic fuel production using captured CO_2 and near-zero emissions hydrogen	SK Innovation Nextera MHI Grantham Foundation	VC arm of SK (Korea) Utility Diversified heavy industry company Foundation	69	October 2021/22
Ion clean energy	CO_2 Capture	SK Materials Denbury	Semiconductor and gas supplier CCS developer / Oil and gas	25	April 2023
Heirloom	Direct Air Capture via accelerated mineralisation, CO_2 liberation and geological storage of CO_2	Carbon Direct Ahren Innovation Breakthrough Microsoft Climate Time Ventures	Venture Capital Venture Capital Venture Capital Venture Capital Venture Capital	53	March 2022

Source: Crunchbase – GCCSI analysis

Equity project finance

In addition to taking equity in companies that are developing CCS, investors may also take equity directly in CCS projects. This is equity project finance. Notable examples of CCS projects that have benefitted from equity project finance include:

- Brookfield Renewables led with a $300 million equity commitment in Entropy in a hybrid structure to fund Glacier phase I and II and a $500 million commitment in California Resources Corporation's Grannus blue ammonia project in California.
- Crescent Midstream, backed by the Carlyle Group, partnered with Repsol and Cox Oil to build a CO_2 pipeline for offshore storage from Geismar to Grand Isle, Louisiana.
- Manulife Investment Management, the largest timberland investor, partnered with Occidental to lease 27,000 acres to develop and operate a geological carbon storage hub.
- Copenhagen Infrastructure Partners (CIP) acquired a majority stake in a blue ammonia project in the Gulf Coast with an annual capacity of 3 million tonnes at an estimated cost of $4.6 billion along with US-based Sustainable Fuel Group. International-Matex Tank Terminals is planning to provide ammonia storage and handling services. CIP made this investment through the CI Energy Transition Fund, which makes investments aligned with the UN Sustainable Development Goals.

As the economics of CCS projects become better understood and the need for infrastructure for the transport and handling of decarbonised fuels and CO_2 increases, private equity investments in CCS are expected to accelerate. This is most obvious in the US, where the policy incentives are the strongest.

Development capital & project debt finance

Development capital is a form of equity finance and is used for engineering and feasibility studies, permitting, and offtake agreement negotiations, etc. Project debt finance is where the project developer borrows money to finance the project, and the lender's claim is limited to project assets and cash flows and not other assets of the borrower, i.e. non-recourse finance. Project finance is crucial in financing infrastructure projects, typically accounting for 70-80% of capital expenditure. It requires a high degree of certainty of project commercial viability and is the last instrument to fall in place as all the operational, regulatory and commercial terms must be determined before or concurrent with the financial closing.

There is limited public data on development capital deals as they are only sometimes publicly announced. That said, the Institute's engagement with project developers and financiers suggests that the change in the policy landscape, especially in the US and the EU, has led to a substantial increase in the demand for and supply of development capital for CCS.

Further, the first project finance deals for CCS projects are now being developed by commercial banks. One example of project debt finance for a CCS project is the Midwest Carbon Express CCS network under development by Summit Carbon Solutions in the US. The emergence of project debt finance for CCS projects is a compelling indicator of the recent rise in the finance-ability of CCS, at least in the US. To reach rates of deployment required to support climate ambitions, project debt finance will need to be as common for CCS projects as it is now for general infrastructure projects around the world.

Government-related finance

Recent enhancements in government support for CCS in the US (e.g. the Inflation Reduction Act) have made unprecedented levels of government financing available to CCS projects in the country. Other nations have also ramped up government finance. Commitments made by governments globally in the past year that have increased financing include:

- In the US, through the Inflation Reduction Act, the federal government provides over $300 billion for projects that support clean energy deployment and infrastructure reinvestment (including CCS) under Title 17 of the Clean Energy Financing Program and $25 billion for Carbon Dioxide Transportation through September 2026 for loans and loan guarantees, in addition to $2.5 billion in grants.
- The EU announced €3 billion in funding for climate technologies, including CCS projects, under the third call of the Innovation Fund.
- The UK government committed to investing £20 billion to scale up CCS projects over a period of 20 years.
- Norway provided 85% of the €400 million cost for Heidelberg subsidiary Norcem's (cement) carbon capture facility. This is in addition to Norway's long-time financial commitment to Northern Lights as part of the greater Norwegian carbon capture and storage initiative, Longship.
- The Dutch government announced €6.7 billion to be allocated to CCS projects, specifically eight projects that use the Aramis project to store CO_2 in depleted natural gas fields in the North Sea.
- In Asia, Japan's JOGMEC selected seven potential CCS projects, five domestic and two involving international CO_2 shipping to support commercialisation, with undisclosed financial terms aiming to store a combined 13 million tonnes per year of CO_2.
- The People's Bank of China provides support through the carbon emission reduction facility (CERF) and has a targeted re-lending quota for the clean, efficient use of coal. The CERF is not capped, while the re-lending quota is currently Yuan 300 billion (US$42 billion).

Green and climate bonds

Green and climate bond standards and certificates have historically omitted CCS technologies. Still, there are examples of more resources being allocated to examining the eligibility of CCS. Given that green bonds offer a lower cost of debt, including CCS may improve the finance-ability of CCS projects.

Corporate finance

Most CCS projects are financed by corporate balance sheets as project finance is not yet widely available; for example Exxon, Occidental and Denbury each financed their CO_2 pipeline and storage networks. Historically, the bulk of corporate finance has been provided by the oil and gas sector, however there is now a greater diversity of industries investing directly in CCS projects. The fertiliser and chemicals sector is now active, with CF, MHI, Linde, OCI and Yara having announced blue hydrogen and ammonia plants in the US Gulf Coast.

Likewise, cement giants like Holcim, Cemex and Heidelberg have announced projects to deploy CCS. Maritime shipping players such as Hafnia-NYK, Knudsen and MOL have announced plans to invest in low-carbon fuel and CO_2 tankers while shifting to low-carbon fuels to decrease their emissions.

Conclusion

The recent increase in finance for CCS projects, now at unprecedented levels, is encouraging and demonstrates how policy can incentivise material private sector investment. Assuming the current global macro-trend of strengthening policy drivers for climate mitigation continues, the Global CCS Institute expects financing of CCS projects to accelerate as the finance sector and project proponents' experience grows, further de-risking the sector.

To achieve global climate goals, these developments that are focused on North America and Europe must further accelerate and be replicated in developing economies, which currently still exhibit the highest rates of growth in greenhouse gas emissions.

4.0 REGIONAL OVERVIEW

+73

US Facility count increased by 73 since GSR 2022*

45Q

Expansion of 45Q production tax credit and other incentives in the Inflation Reduction Act and funding provided under two other acts cultivate robust and attractive business environment for CCS in the US.

Clean ammonia and clean hydrogen production become economically favourable in the US.

✓ H_2

✓ NH_3

19 hubs

Canada's Alberta awards 19 hubs through provincial TIER system – in addition to 6 sequestration hub agreements announced in spring 2022.

40 $MtCO_2$

Brazil's Petrobas injects 10.6 $MtCO_2$ into pre-salt reservoirs in Santos Basin in 2022, yielding a cumulative 40.8 $MtCO_2$ – surpassing its 40 $MtCO_2$ target – and aims to reinject 80 $MtCO_2$ by 2025.

*This excludes "announced" projects.

4.1 AMERICAS

Overview

North America remains the world leader in CCS deployment following substantial policy enhancements, particularly the game-changing US Inflation Reduction Act (IRA). Multiple new CCS projects and networks have been announced in the region since the publication of the 2022 Global Status Report, continuing the established momentum. Moreover, the acceleration in policy and attitudes has brought CCS more directly into decarbonisation conversations and public awareness.

Enabling this positive trend is rising societal expectations to lower emissions and define pathways to net-zero enabled by sustained policy support from federal, state and provincial level governments that create business cases for CCS. Through clear policy set by the Governments of the US and Canada as well as continued acceptance that CCS is necessary for North American decarbonisation, the persistent growth of the project pipeline in this region reflects the bullish trend of CCS across industries.

United States

Policy

The US is leading the global CCS landscape with the largest number of CCS facilities operating, in construction, and in development, which has increased by 73 since the publication of the 2022 Global Status Report. Several projects have cited the Inflation Reduction Act (IRA) as a driving force in accelerating their launch.

The US has a robust and comprehensive policy framework that provides support for all stages of CCS deployment. CCS is a key mitigation tool for reaching federal climate goals, including 50-52% emissions reduction from 2005 levels by 2030 and net-zero emissions by 2050.

The 2021 Bipartisan Infrastructure Law (BIL), the 2022 IRA and the 2022 Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS) provide financial and policy incentives to spur CCS deployment by providing greater financial support mechanisms. This policy framework is critical for reaching the US government's ambitious climate targets and solidifying the US as a leader in decarbonisation, which can help motivate others to deploy necessary resources and join the US in scaling carbon management.

The BIL provides $12 billion for programs such as carbon management, research, demonstration and deployment up to 2026. The funds provide $8.5 billion in supplemental funding for CCS for FY2022-FY2026, including funding for the construction of new carbon capture facilities and commercial carbon storage facilities, and $3.6 billion in supplemental funding for DAC, primarily to support the establishment of four regional direct air capture hubs in the US.

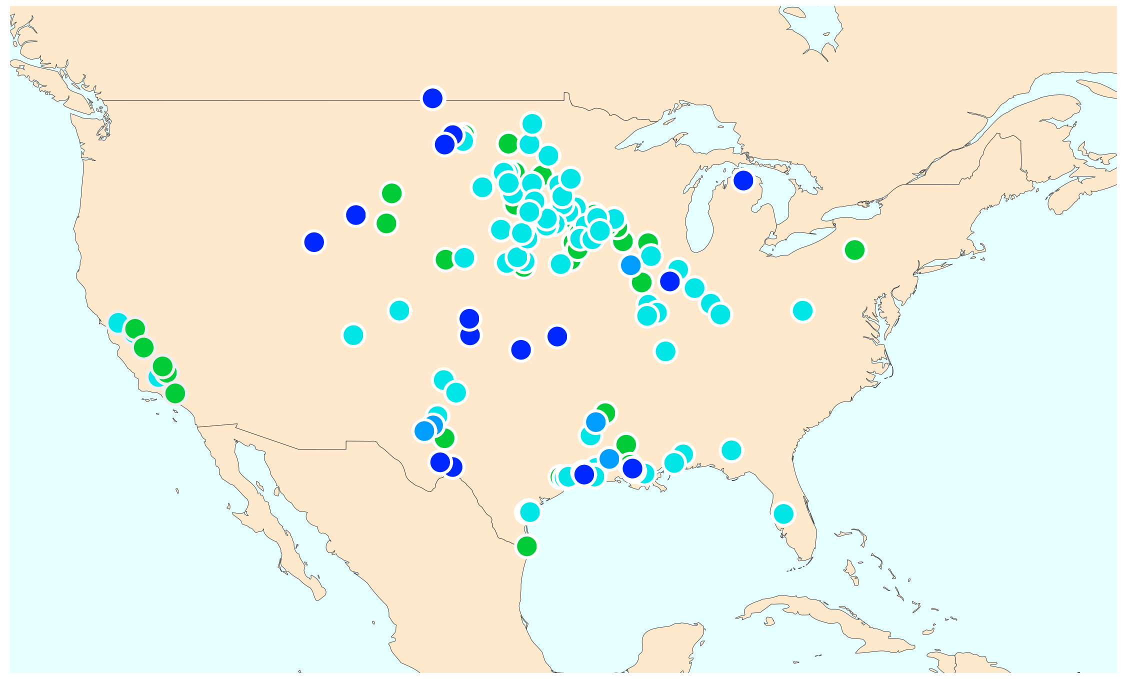
The tax incentives included in the IRA to deploy CCS and direct air capture technologies complement funding in the BIL. The IRA provides billions of dollars to help decarbonise existing industrial facilities and includes an enhanced Internal Revenue Service (IRS) Section 45Q federal corporate income tax credit that lowers carbon capture thresholds, increases the dollar value of tax credits ($85/t$CO_2$ captured from power and industrial sources and stored in dedicated geological storage resources), and adds provisions for direct pay and tax credit transferability.

Analysis suggests the IRA could increase the deployment of carbon capture in the US by as much as 13-fold by 2030.

The CHIPS Act Sec. 10102 authorised the DOE to establish a "Carbon Sequestration Research and Geologic Computational Science Initiative" and at least two carbon storage research and geologic computational science centers to expand the fundamental knowledge, data collection, data analysis, and modelling of subsurface geology for advancing carbon sequestration in geologic formations. Under CHIPS, the US Department of Energy (DOE) will carry out research for the sequestration of carbon in geologic formations.

The Biden Administration continues to drive CCS deployment as a whole-of-government approach, with the executive branch agencies working to advance the deployment and enhance the safety of the entire CCS value chain while addressing the concerns of communities and developers. The BIL established a timeframe for the Department of Interior (DOI) to promulgate regulations for offshore storage of CO_2.

The Department of Transportation's Pipeline and Hazardous Material Safety Administration (PHMSA) continues to work on new rulemaking to update standards for CO_2 pipelines, including requirements related to emergency preparedness and response.



The EPA issued a rule proposal to grant Louisiana primary enforcement authority (primacy) for Class VI wells under the Underground Injection Control program, which is currently progressing through the administrative process. The EPA also issued a proposed rule to reduce carbon dioxide emissions from power plants, expected to be finalised next year.

States are also actively engaged in policy and regulatory actions in the US. The California Air Resources Board approved its climate action plan (scoping plan) to shift the world's 4th largest economy from fossil fuels to clean and renewable energy, in which CCS is one of the mitigation tools. Louisiana has enacted legislation to address various aspects of CCS deployment, while meeting the federal primacy requirements.

Despite significant progress at federal and state levels, several important steps are needed, including community support and permitting. Successful community engagement is critical to deploying CCS projects. In the past, unsuccessful community engagement and local opposition have contributed to cancellation or relocation of some CCS projects, while others were well received. Lack of community support, coupled with permitting challenges, has become a barrier for some early development stage CCS projects in the US.

Permitting, specifically for Class VI wells and pipeline infrastructure, remains a potential bottleneck for CCS deployment, with a rapid influx of permits and need to ramp up federal and state capacity including the technical and regulatory expertise needed to evaluate permits. Congress provided funding via the IRA and the BIL to add staff to the Class VI permitting program at the EPA, which committed to focusing on streamlining the permitting process, performing continuous programmatic evaluations, and increasing public outreach, awareness, and transparency.

Ethanol production projects in the US have progressed to advanced development.

Carbon dioxide pipeline safety and pipeline siting is a concern for developers. While PHMSA regulates pipeline safety, no federal entity regulates pipeline siting in the US. Opposition to CO_2 pipelines is a consideration for developers making community engagement a priority.

Projects

Production of clean hydrogen and ammonia has become economically favourable in the new policy environment and is reflected in several of the projects announced this year. The US Department of Energy's Hydrogen Shot – which seeks to reduce the cost of clean hydrogen by 80% to $1 per kilogram within a decade – is supported by government funding and policy frameworks, including $8 billion to support the development of regional hydrogen hubs.

CCS at coal and gas-based hydrogen production remains the most economic option in regions where both CO_2 storage and low-cost fossil fuel feedstocks are available and offers opportunities to produce clean hydrogen at scale. Since the 2022 Global Status of CCS Report was published, the number of clean hydrogen/ammonia facilities in development, construction or operation has increased by 13 in the US.

Ethanol production has driven a new tranche of announced projects and 40 have progressed into advanced development. Thirty-six of these facilities are part of the Mid West Express CCS network.

The US' goal of carbon-free electricity by 2035 has turned attention to the potential for the scaling-up of CCS at fossil fuel power plants, evidenced in the Environmental Protection Agency's proposed rule issued in May 2023. Development continues at 23 power/heat facilities, more than half of which plan to be operational in the late 2020s.

CCS at current and future fossil fuel power-generating assets offers the benefits of reliable, low-carbon dispatchable electricity without the need for costly energy storage. In addition, CCS can be combined with bioenergy and waste-to-energy to remove carbon dioxide from the atmosphere and deliver net negative emissions. There are now two biomass to power/heat facilities with CCS in early development in the US.

CCS projects in cement, steel and chemical production are also being developed. There are three chemical CCS facilities and three cement CCS facilities in development. The first two steel CCS projects in the US entered early development this year. CCS remains a highly viable technological solution to abate emissions in these industries.

One DAC project is in construction and two more are being developed in the US. DAC projects are supported by the billions of dollars flowing from the US government into research and development, through both the DAC Regional Hubs funding opportunity and the DOE Carbon Negative Shot, which aims to reduce carbon removal costs to $100/net tonne.

Credit: NET Power's La Porte test facility, image courtesy of NET Power

In August, the US Department of Energy announced up to $1.2 billion funding to advance the development of two commercial-scale direct air capture facilities in Texas and Louisiana.

Project developers that offer CCS as a service, or more broadly decarbonisation as a service, are becoming a more common feature in the North American CCS landscape. Entrepreneurs able to manage the value chain for CCS projects and offer flexible business models are seeking to provide a one-stop-shop for emitters looking to decarbonise.

CCS transport and storage hubs remain among the largest projects with the highest potential for emissions mitigation. Capitalising on economies of scale and diverse CO_2 sources, CCS networks offer some of the largest total capacities of capture and storage. The Institute's database records 16 transport and/or storage facilities in the US in development and 1 in construction.

Broader CCS-enabled ecosystems are shaping up as a notable theme across the sector. Multi-party partnerships to develop and deploy complex projects continue to grow, taking advantage of complementary capabilities across the CCS value chain to offer deep emissions reductions across various industries. This past year saw a flurry of partnership announcements between the largest vertically integrated energy companies and emitters, technology providers, and service providers with CCS competencies or regional assets. For example, at the time of writing ExxonMobil was in the process of acquiring Denbury and its significant CO_2 transport and storage assets in a multi-billion dollar deal.

Storage developments

There is considerable geological storage development activity underway in the US. A selection of storage facilities is summarised below.

Carbon Terravault (CTV) & California Direct Air Capture (DAC) Hub Consortium

California Resources Corporation (CRC) was an early CCS mover in California, identifying 1 Gt of CO_2 storage resources at sites across the state. CRC's Class VI well permit applications filed with the US EPA are well advanced, with three having been designated "administratively complete" for its projects in development.

In the southern San Joaquin Basin, CRC estimates 46 Mt of CO_2 storage resources are present in formations of the Elk Hills Field. It refers to this project as Carbon Terravault I (CTVI). CRC is progressing offtake agreements with Lone Cypress Energy Services and InEnTec to store 100,000 tonnes of CO_2 per year from each company for storage in CTVI.

CTVI is also the planned storage site for CO_2 captured from the newly formed California DAC Hub Consortium, which is led by CRC subsidiary CTV Direct, EPRI and Kern County Community College District, but comprises a much broader partnership of organisations across industry, technology, academia, national laboratories, local communities, government, and labour groups. Capture rates for the California DAC Hub have not been released, but the consortium is targeting funding for DAC hubs available through the US Department of Energy.

In the Sacramento Basin, CRC has identified 118 Mt of CO_2 storage resources across three additional sites, which it refers to as CTV II, CTV III and CTV IV and comprise 23, 71, and 24 $MtCO_2$ of storage resources, respectively. CRC is progressing an offtake agreement with Grannus to accept 370,000 tonnes of CO_2 per year from its Grannus Blue Ammonia and Hydrogen Project for storage in CTV III. It is partnering with Yosemite Clean Energy to store 40,000 $MtCO_2$ per year from Yosemite Clean Energy's planned bioenergy plant in Oroville at CTV sites.

Central Louisiana Regional Carbon Storage Hub (CENLA Hub)

CapturePoint in February 2023 approved its final investment decision to develop a CO_2 storage hub comprising 14,000 acres in central Louisiana. It estimates the storage complex contains more than 100 $MtCO_2$ of total CO_2 storage resources, with the potential to inject more than 10 Mtpa and has submitted applications for two US EPA Class VI well permits.

Denbury Orion and Leo Sequestration Sites

Denbury has announced eight projects focused on CO_2 transport and storage, in addition to its vertically integrated project with partner Clean Hydrogen Works, which will sequester CO_2 from their planned Ascension Clean Energy hydrogen-ammonia complex in Ascension Parish, Louisiana. Together, the eight transport and storage-focused projects comprise 1.78 Gt of storage resources. The Orion and Leo sites have matured into early development and are located in Alabama and Mississippi, respectively. Denbury has submitted Class VI permit applications to the EPA for both Orion and Leo and has drilled an initial stratigraphic test well for the Orion site.

100 $MtCO_2$

CENLA Hub's estimated storage resources, with the potential to inject more than 10 Mtpa.

River Bend CCS

Talos Energy (60% share) is also developing the River Bend CCS project in the New Orleans/Baton Rouge region with Storegga (40%). The project comprises more than 620 $MtCO_2$ of CO_2 storage resources across three sites, with 47,000 acres leased by Talos, which has secured the right of first refusal on an additional 63,000 acres in the area for future expansion. First injection is expected in late 2026.

Bayou Bend CCS

The Bayou Bend CCS project is a joint venture between Chevron New Energies (operator, 50%), Talos Low Carbon Solutions (25%) and Carbonvert (25%), which in March 2023 acquired nearly 100,000 acres onshore in Chambers and Jefferson counties, Texas. In August Carbonvert sold their share to Equinor. This acreage adds to the project's previously announced 40,000 acres in state waters offshore Port Arthur/Beaumont, Texas. Bayou Bend's offshore permit was the first offshore storage permit granted by the state. The combined onshore and offshore acreage holds an estimated CO_2 storage resource exceeding 1 $GtCO_2$. First injection is expected in early 2027.

Coastal Bend

In Corpus Christi, Texas, Talos Energy (50%) is partnered with Howard Energy Partners (50%) in developing storage sites across 13,000 acres onshore, comprising 50-75 $MtCO_2$ of CO_2 storage resources. The initial project goal is to store 1-1.5 Mtpa in saline formations, with the capability to increase to 6-10 Mtpa. First injection is expected late 2026.

Canada

Policy

Canada's ambitious climate targets include reducing greenhouse gas emissions at least 40% by 2030 from 2005 levels and reaching net-zero emissions by 2050. Its federal emissions reduction plan expects national CCS capacity to grow significantly, adding facilities to capture and store at least 15 Mtpa by 2030, while a federally mandated carbon price is slated to increase to C$170 per tonne by 2030.

The federal government announced significant support for CCS deployment in its March budget, including an investment tax credit expected to be in place by October following further public consultation that will cover up to 50% of the capital cost of CO_2 capture projects over 2022-2030. There is also a proposal to introduce carbon contracts for difference (CCfDs), which effectively de-risk carbon pricing by eliminating carbon price uncertainties over future prices.

At a provincial level, Alberta continues to advance efforts to be a global leader in emissions reductions, innovation and technology, and the sustainable development of its resources. The Emissions Reduction and Energy Development Plan sets Alberta's course for cutting emissions, attracting investment, working with Indigenous communities and supporting jobs. Leveraging the province's geological advantages enables large-scale emissions mitigation. CCS will be a fundamental piece of the equation.

Projects

Canada has experienced continued growth of CCS, particularly in Alberta and Saskatchewan, since establishing an escalating carbon price that is continuing to drive CCS investments.

In Alberta, in addition to the six sequestration hub agreements announced in the second quarter of 2022, 19 further hubs have been awarded through the provincial Technology Innovation and Emissions Reduction Regulation (TIER) Regulation. These hubs facilitate access to storage resources for emitters undertaking carbon capture and following on from this, networks have become a primary strategy for growing CCS in the province.

The Glacier Gas plant CCS project in Alberta came online in August 2022 and has been successfully storing CO_2 as a first-of-kind application that captures and sequesters CO_2 from the exhaust of a natural gas-fired emission source.

Several projects have been announced since last year and most of the projects in the pipeline are progressing through various stages of development. These projects slated to come online in the coming years span industries including refining, power generation, hydrogen production, and ethanol, pointing towards a growing interest in multiple sectors for CCS as an emission abatement pathway.

Carbon price stability and certainty of business case around CCS are chief concerns among

Credit: Carbon Engineering's Innovation Centre and Research & Development headquarters, image courtesy of Carbon Engineering

Canadian enterprises and as such, CCS project growth in the country is cautiously slow.

Storage developments

Northeast British Columbia (BC) Geological Carbon Capture and Storage Atlas

Geoscience BC in February 2023 published the Northeast BC Geological Carbon Capture and Storage Atlas, the first report in a project aimed at developing a province-wide CCS storage resource atlas. The report estimates 4,230 Mt of combined (depleted gas fields and deep saline formations) CO_2 storage resources are present in the study area.

Table 4.1–1: Proponents and estimated CO_2 storage rates of the first six CCS Hub projects selected by the Government of Alberta to evaluate and explore CO_2 storage site suitability in the Edmonton region

Project	Proponents	Location	Rate
Meadowbrook Carbon Storage Project	Bison Low Carbon Ventures	Morinville, Alberta	3 Mtpa (25 yrs)
Open Access Wabamun Carbon Hub	Enbridge, First Nations Capital Investment Partnership, and Lac Ste. Anne Métis Community	West of Edmonton	4 Mtpa
Origins Project	Enhance Energy	Central Alberta	20 Mtpa
Alberta Carbon Grid (ACG)	Pembina and TC Energy	North of Fort Saskatchewan	10 Mtpa ACG Industrial Heartland Project; 20 Mtpa across several hubs comprising ACG
Atlas Carbon Sequestration Hub (Atlas Hub)	Shell Canada Ltd., ATCO Energy Solutions Ltd., and Suncor Energy Inc.	East of Edmonton	.78-.85 Mtpa in Phase I; Expansion up to 10 Mtpa
Sequestration Hub by Wolf Midstream and Partners	Wolf Midstream (Wolf), Whitecap Resources (Whitecap), the First Nation Capital Investment Partnership and Heart Lake First Nation	Fort Saskatchewan area	2-3 Mtpa initially

Source: Government of Alberta, 2023

Alberta CCS Hubs

Alberta in March 2022 selected six CCS hub project proposals to evaluate and explore CO_2 storage site suitability in the Edmonton region. If these six hub projects proceed and expand to their maximum capacity, they will have a combined estimated annual CO_2 storage rate exceeding 50 Mtpa (Table 4.1–1). A second group of 19 hub proposals were also selected for the same evaluation process in October 2022. When the hub proponents have completed their evaluations, they will be able to apply to provincial government for the right to inject CO_2 at their evaluated sites. The evaluation process is ongoing.

Brazil

Policy

In August, a Bill (PL 1.425/2022) which would establish a legal framework for CCS in Brazil passed the Senate and moved through to the Chamber of Deputies. The law outlines fundamental definitions and regulations for CO_2 storage in Brazilian sedimentary basins, including initial terms for storage and the limits of responsibility for the stored CO_2 over time. If approved by the Chamber of Deputies, the Bill will then progress to the President for sanction.

Projects

Brazil's state-controlled Petrobras operates one of the world's largest CCS projects in the Santos Basin and in its 2023 Climate Change Supplement report says it injected 10.6 $MtCO_2$ into the pre-salt reservoirs in 2022, yielding an accumulated 40.8 $MtCO_2$ injected since operations began. Petrobras has readjusted its target to reinject 80 $MtCO_2$ cumulatively by 2025.

Petrobras is preparing a pilot project for CCS from industrial emissions and is looking to build partnerships for a full-scale CCS hub. This pilot project will serve as a testing ground for developing the geological aspects of carrying out CCS in a saline aquifer environment and will involve geophysical studies, at least one drilling operation, and research on storage sealing. These operations will likely provide not only technical data for the project itself but also information for legislators and regulators to build up the framework for such activities.

+34

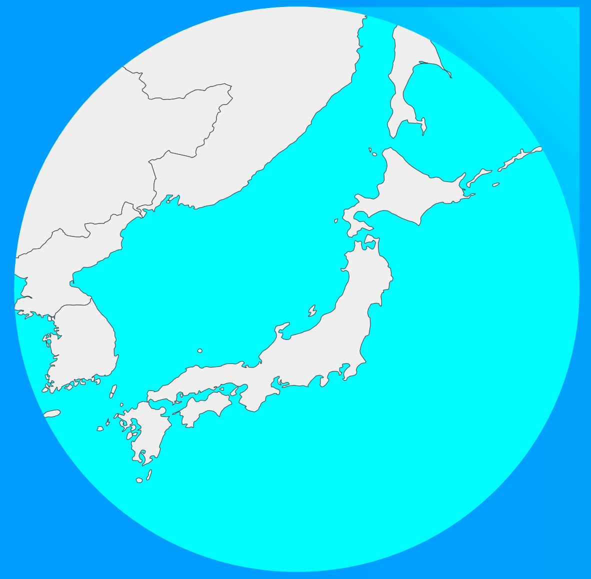
APAC facility count increased by 34 since GSR 2022*

12

facilities currently in operation

8

facilities under construction



240 Mtpa

Japan's CCS Long-Term Roadmap sets target for first commercial CCS projects to commence by 2030 and aims to store up to 240 Mtpa of CO_2 by 2050; JOGMEC selects seven candidate projects for feasibility studies.

17

Facilities in development include 17 in CO_2 transport and storage and 11 in natural gas processing.

4.9%

Australia's reformed Safeguard Mechanism establishes framework for future regulation of emissions reduction, including a decline in baseline emissions of 4.9% per year to 2030.

*This excludes "announced" projects.

4.2 ASIA PACIFIC

Overview

The Asia Pacific region presents a dynamic environment for the deployment of CCS, with significant activity from both government and industry across the region in the past 12 months. Nations that took early actions such as Australia and Japan continue to develop domestic policies and legislation, with both nations introducing new measures targeted at promoting the technology's deployment.

After reducing support for CCS by cancelling its CCUS Hubs and Technologies Program, the current Australian government has taken some positive actions towards supporting CCS. These actions include important steps towards enabling the transboundary transport and geological storage of CO_2, an issue of significant importance for the broader Southeast Asia region. Japan has announced funding for the development of seven CCS projects, two of which will involve transboundary CO_2 transport and storage.

New project-level developments in Southeast Asia also reflect the pace of deployment across the region. Recent project announcements, which are being led by the oil and gas sector, offer significant potential for emissions mitigation in the region's natural gas sector and are positioned as a key aspect of countries' transition pathways towards clean energy. It is clear, however, that further policy and regulatory development will be required to support development at the scale envisaged by industry and governments.

There are currently 54 facilities in development, construction or operation across the Asia Pacific region, with 34 added since the release of the 2022 Global Status of CCS Report. Twelve facilities are in operation (11 in China plus Gorgon in Australia) and eight are in construction (six in China plus Kasawari in Malaysia and Santos' Moomba project in Australia).

Thirty-four facilities are in early or advanced development across the region, of which 11 are in natural gas processing. Natural gas processing involves stripping reservoir CO_2, and other unwanted gases such as H_2S from the methane before it is sold. This produces a near-pure stream of CO_2 that is generally released into the atmosphere.

However, as companies and countries adopt net-zero emission targets, the capture, compression, and re-injection of reservoir CO_2 will become standard operating practice. Gas fields with high CO_2 (>10% and up to 70%) are being developed with CCS, and almost all facilities are vertically integrated with offshore storage. Once infrastructure to re-inject CO_2 is established, the owners of these facilities will have the option to offer CO_2 storage services to third parties for a fee. This development strategy is being considered by almost every vertically integrated natural gas processing CCS project in the Asia Pacific region.

Seventeen facilities in development are CO_2 transport and/or storage projects. These projects do not have a CO_2 capture source within their ownership structures. Each may provide CO_2 transport and storage services potentially to multiple customers that require a CO_2 management solution. These projects, together with the vertically integrated natural gas processing projects mentioned in the previous paragraph, have the potential to create multiple CCS networks serving industry across the Asia Pacific region, with CO_2 transport by pipeline and by ship.

However, where transboundary transport of CO_2 is required, bilateral agreements between exporting and importing countries will be required, following the promulgation of appropriate CO_2 storage regulation and where applicable, the ratification of amendments to the London Protocol. These issues are further described in section 3.2 of this report.

There are currently 54 facilities in development, construction or operation across the Asia Pacific region.

China

Policy

Strong momentum for CCS development continues in China since the successful start of full operations of its first integrated megatonne-scale CCS project in Shandong province in August 2022.

The signals are clear, but concrete policy tools are limited. Since 2020, most of the released policy documents within China's "1+N" climate framework at the national and sectoral level have incorporated CCS. The "1+N" climate framework refers to a series of directives guiding China's efforts to peak emissions before 2030 and achieve carbon neutrality by 2060.

There is also a growing interest from the sub-national authorities – around 10 provincial governments have included CCS development in their decarbonisation efforts. The national consensus is clear that CCS will play an essential role in China's carbon neutrality journey.

Credit: Hainan International CO_2 Capture Test Platform, image courtesy of Huaneng Clean Energy Research Institute.

Projects

In China, there are four CCS facilities in development, six in construction and 11 in operation. Ten of these projects are in the chemical industry, five are in power generation, two are in gas processing, two are CO_2 transport and storage, one is in iron and steel production and one in oil refining.

Some of the more significant developments in China since the 2022 Global Status of CCS report was published are summarised below.

November 2022: SINOPEC, Baowu, Shell and BASF announce they will jointly explore an up to 10 Mtpa large-scale open-source CCUS hub in Yangtze River Delta region.

December 2022: Huaneng, one of China's largest power producers, commences construction of the world's largest, 1.5 Mtpa, coal-fired power integrated CCUS project in Gansu province.

January 2023: CNOOC, Guangdong Provincial Development, Shell, and ExxonMobil advance the 10 Mtpa Daya Bay CCS hub project by reaching a Joint Study Agreement.

May 2023: Construction begins on a 3 Mtpa CCUS project in Ningxia region by China National Energy Investment with the first phase to capture 500 ktpa CO_2 from a coal-to-liquids facility for enhanced oil recovery.

Early June 2023: China Energy Investment's 500 ktpa coal power CCUS project enters full operation in Jiangsu province, becoming Asia's largest CCUS project in the power sector; CNOOC commences operations at China's first offshore CO_2 storage project.

28 June 2023: China United Cement Group begins construction of the world's largest oxyfuel CCUS project in the cement industry in Qingzhou, Shandong. The captured CO_2 will be used for food and chemical production. Whilst this project does not currently involve the storage of CO_2 and so is not included in the Institute's database of CCS projects, it is noted here due to the significance of the application of CO_2 capture technology at a cement plant.

July 2023: China's first commercial-scale CO_2 transport pipeline with a length of 109 km starts full operations, serving SINOPEC's Qilu-Shengli CCUS project; China's first Natural Gas Combined Cycle Carbon Capture Test facility enters operation at a scale of 2,000 tpa at Hainan Island, developed by Huaneng Group.

Credit: Shanghai Shidongkou Coal-Fired Power CO_2 Capture Facility, image courtesy of Huaneng Clean Energy Research Institute.

Japan

Policy

The Ministry of Economy, Trade and Industry (METI) announced its CCS Long-Term Roadmap in January 2023, setting a target for Japan's first commercial CCS projects to commence by 2030 and aiming to store up to 240 Mtpa of CO_2 by 2050. Key items included in the Long-Term Roadmap are:

- Capital support from METI (seven candidate projects have been selected).
- Future CCS cost targets (40% cost reduction).
- Enhancing public acceptance of CCS.
- Promoting overseas CCS Projects, especially in Southeast Asia.
- Establishing a comprehensive regulatory framework for CCS.

In June 2023, METI presented a set of draft rules for the common governance of CCS with Australia and Southeast Asia at an Asia Zero Emission Community (AZEC) meeting in Indonesia. The adoption of shared rules is aimed at lowering the cost of CCS and shortening construction timelines. A detailed proposal on shared rules will be tabled at an AZEC ministerial meeting in early 2024.

Projects

In accordance with the CCS Long-Term Roadmap, the Japan Organisation for Metals and Energy Security (JOGMEC) selected seven candidate projects for feasibility studies. These projects span a wide range of sectors including power generation, oil refining, steel, chemicals, pulp and paper, and cement. In total, the projects aim to store approximately 13 Mtpa of CO_2. Five projects will store CO_2 in Japan and the remaining two in Malaysia and Oceania, respectively.

Based on data and knowledge obtained through the exploration of oil and gas, the CO_2 storage potential of Japan has been broadly characterised by geological surveys that found storage resources in deep saline formations within geological structures to be an estimated total of 16 billion tonnes across 11 structures.

The selected project proponents are:

1 JAPEX, Idemitsu, Hokkaido EPC
2 Itochu, Nippon Steel, Taiheiyo Cement, Mitsubishi Heavy Industries, INPEX, Taisei Corporation (General Constructor)
3 JAPEX, Tohoku EPC, Mitsubishi Gas, Hokuetsu (Paper mill), Nomura Research Institute (Consulting)
4 INPEX, Nippon Steel, Kanto Natural Gas
5 ENEOS (Refinery), JX Oil, J-Power
6 Mitsui & Co.
7 Mitsubishi Corp., Nippon Steel, Exxon Mobil Asia Pacific

In line with the Japanese government's Sixth Strategic Energy Plan (2021) that included CCS as one of the pathways to achieving an emissions reduction of 46% from 2013 levels by 2030, ITOCHU Corporation, Mitsubishi Heavy Industries, INPEX Corporation and Taisei Corporation signed a memorandum of understanding in January 2023 to conduct a feasibility study on a large-scale, wide area CCS value chain project. The study will include separation, capture, transportation and storage of CO_2.

Credit: The Tomakomai Project, image courtesy of JCCS

Japanese companies are active investors in, or technology suppliers to, many CCS projects around the world. These projects are mostly associated with fossil point sources of CO_2. However, interest in direct air capture (DAC) and biomass is now emerging.

Tokyo Gas Co., Ltd. became the first Japanese company to invest in Denver-based Global Thermostat to implement its DAC technology. In April 2023, NextGen, a South Pole/Mitsubishi Corporation joint venture, established the world's largest diversified portfolio of permanent certified carbon dioxide removal certificates (CDRs) through the advance purchase of 193,125 tonnes of CDRs from carbon removal projects.

The advance purchase will include CDRs from Summit Carbon Solutions' $5.1 billion biomass carbon removal and storage (BiCRS) project being implemented in the US Midwest; the world's largest direct air capture and storage (DACS) project being developed by 1PointFive in Texas; and Carbo Culture's inaugural high technology biochar project in Finland.

South Korea

Policy

CCS is featuring as a core emissions reduction component across several of South Korea's national climate change mitigation strategies and action plans, with the designation of CCUS as one of the Ten Major Technologies for Carbon Neutrality Technology Innovation in the country's 2050 Carbon Neutral Promotion Strategy, accompanied by a commitment to commercialise the technology by 2030.

In March 2023, the South Korean government published a draft of its first National Framework Plan for Carbon Neutrality and Green Growth, which sets out the country's plan to achieve its 2030 emissions reduction target. It also commits to developing two national policies to support CCUS and legislation addressing business, safety and certification of CCS projects. These developments underpin the strong interest in and uptake of CCS project partnerships across the country's industrial sectors and will likely enhance the development of further policy and regulatory frameworks to facilitate deployment of the technology.

Projects

Multiple project announcements and cooperation agreements between South Korea's leading energy and industrial companies to assess opportunities for CCS technologies have seen CCS-related development gain momentum over the past 12 months. Notable examples include:

- TCRK Environmental Services' collaboration with Asia Cement, a leading cement production company in South Korea, to develop carbon capture technology for Asia Cement's plants in pursuit of the company's 2025 emissions reduction targets.
- Hyundai Merchant Marine's partnership with PANASIA, and the collaboration between Samsung Heavy Industries (SHI) and BASF, to assess the feasibility of carbon capture systems onboard maritime shipping vessels.

Transboundary CO_2 storage opportunities
Business models involving transboundary CO_2 transport and storage activities are emerging, with multiple consortiums formed in the past year in South Korea's private sector to explore opportunities in the region.

In November 2022, a consortium of eight South Korean energy companies signed a memorandum of understanding with Caltex to cooperate on and promote the development of CCUS in South Korea. The companies will capture CO_2 produced from their plants at the Yeosu National Industrial Complex for use as raw material for chemical and mineral carbonation processes, with the remainder to be transported overseas for geological storage.

Similarly, a consortium of six leading industrial companies in South Korea announced a partnership with Malaysia's Petronas to implement a cross-border CO_2 transport and storage project between South Korea and the proposed CCS hub in Sarawak, Malaysia.

India

Policy

India's central government in June 2023 passed an amendment to the Energy Conservation bill that would set up a domestic carbon credits trading scheme. This came just after India updated its NDCs through the UNFCCC in November 2022 and released a policy framework paper on CCUS through NITI Aayog, an Indian central government think tank, in December 2022.

While CCUS is not yet included in the carbon credits trading scheme, India has included CCUS as a removal activity under the Article 6.2 mechanism. In addition, the Indian government announced the establishment of two National Centres of Excellence in Carbon Capture and Utilization in 2022. These two institutions will focus on research and development, and act as centres for collaboration and other initiatives related to carbon capture and utilisation. In July 2023, India and the US agreed to add carbon capture, utilisation and storage as a work stream under the Emerging Fuels and Technology Pillar of the US-India Strategic Clean Energy Partnership. Further, the US and India welcomed engagement through the Low-Emissions Gas Task Force to reduce emissions through the deployment of emerging technologies including CCUS.

Australia

Policy

In March 2023, Australia's Federal Government announced reforms to its Safeguard Mechanism, to establish a framework for future regulation of emissions reduction by large emitters (emissions >100,000 tonnes per year). Key amendments include baseline setting for covered facilities, an annual rate of decline in baseline emissions of 4.9% year-on-year to 2030, generation and use of Safeguard Mechanism Credits (SMCs), greater transparency requirements, and a "hard cap" on total emissions between 2020 and 2030.

Covered facilities could utilise carbon capture technology on site to meet their baselines, however such abatement projects, which directly reduce emissions from the operations of a covered facility, will not be eligible for Australian Carbon Credit Units (ACCUs) under the new rules. Covered facilities whose emissions are below their baselines will automatically generate tradeable Safeguard Mechanism Credits.

The Western Australian state government introduced the Petroleum Legislation Amendment Bill, integrating transport and storage of greenhouse gases into current state legislation. The amendment legislation aims to provide industry with the opportunity to decarbonise through CCS.

Key provisions include permitting requirements for onshore and offshore storage operations, transfer of liability for stored CO_2 to the state following a 15-year post-closure period, prescriptive site closure requirements and allowance of GHG transport via pipelines to depleted petroleum reservoirs in the state.

The federal government's House of Representatives Standing Committee on Climate Change, Energy, Environment and Water in June 2023 recommended that Australia ratify both the 2009 and 2013 amendments to the London Protocol, which will remove barriers to transboundary transport of CO_2 for offshore storage.

Rest of Asia Pacific

High domestic emissions, limited domestic storage potential and close geographic proximity to suitable storage sites in the territorial waters of neighbouring countries have strengthened the case for export and import of CO_2 and the establishment of storage hubs in the Asia Pacific region.

Several world-class sedimentary basins exist in the region, creating the opportunity for a new regional CO_2 transport and storage industry. Malaysia, Indonesia, Thailand, Brunei and Timor-Leste are all moving forwards to develop opportunities to receive CO_2 from other countries. In every case except Indonesia and the Malaysian state of Sarawak, the absence of comprehensive CCS regulation is a barrier to CCS deployment in these countries. Nonetheless, efforts are underway in the region to develop and promulgate regulation to remove those barriers, and policies that support investment in CCS are now being implemented in some nations.

Table 4.2–1 on the following page summarises the policy and regulatory environments and CCS projects of nine Southeast Asian countries.

SEACA collaboration

There is a great need for CCS in hard-to-abate sectors, particularly those with process emissions and in economies that rely upon fossil fuels to support their rapid economic growth. Consequently, it is imperative that CCS advances rapidly in Southeast Asia, which hosts a significant proportion of the world's emissions-intense industry and has a growing dependence on fossil energy.

Whilst CCS projects are being developed in this region, gaps in policy, regulation and storage resource development present significant headwinds to reaching FID. In response, the Global CCS Institute created the Southeast Asia CCS Accelerator (SEACA) initiative to work with governments, multilateral organisations and the private sector to help accelerate investment in CCS as an essential component of the region's broader efforts to mitigate climate change. The Institute plans to run three SEACA workshops in 2023/2024.

The Institute partnered with the ASEAN Centre for Energy to deliver the first SEACA workshop on 15-16 May 2023 in Bangkok, Thailand. Delegates representing Southeast Asian governments, the governments of Japan and Australia, project developers and other stakeholders met to discuss how to accelerate investment in CCS in the region. Discussion focused on three pillars: CCS regulation, enabling policy, and geological storage resource development.

The SEACA workshop demonstrated the potential for CCS in Southeast Asia and the willingness of governments and project developers to come together to discuss how this essential technology can be deployed in support of achieving net-zero emissions.

A clear conclusion from the discussion is that success can only be achieved through active collaboration between the public and private sectors. Waiting for the market to deliver CCS without a strategy, without cooperation between governments and project developers, or without the necessary interventions will not achieve the scale of deployment required to meet climate goals.

Credit: Photo taken by Alex Zapantis

Table 4.2-1: CCS in other countries in APAC (does not include "announced" projects)

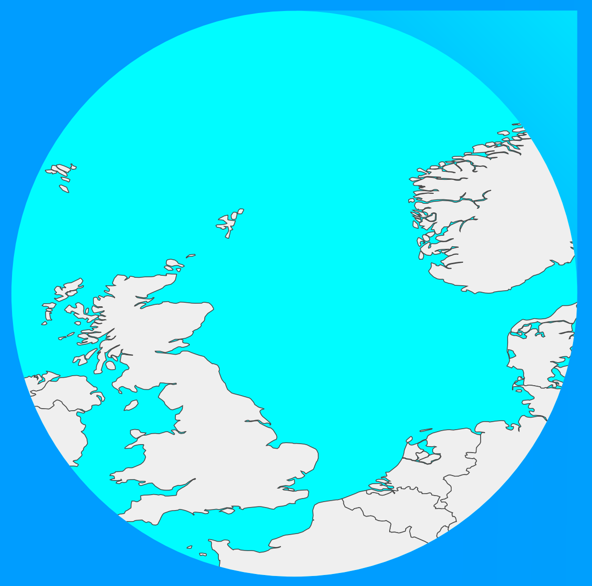
	Malaysia	Indonesia	Vietnam	Thailand	Singapore	Brunei	Philippines	Timor-Leste	Papua New Guinea
International Climate Change Commitment (NDC)	45% reduction in GHG emission intensity against GDP by 2030	32% reduction and conditional reduction target up to 43% of the business-as-usual scenario, by 2030	Unconditional 15.8% reduction of GHG emissions by 2030	30% reduction of GHG emissions by 2030	Reduce GHG emissions to around 60 $MtCO_2e$ in 2030	20% reduction of GHG emissions relative to business as usual by 2030	75% reduction of GHG emissions relative to business as usual by 2030; Conditional 2.7%	No set emissions reduction targets	Reduce emissions from deforestation, forest degradation and agriculture by 10Mt compared to 2015 by 2030^
Net Zero Target	Pledge – 2050	Proposed – 2060	Policy – 2050	Policy – 2050	Policy – 2050	Proposed – 2050	✘	Proposed – 2050	Policy – 2050
Party to the London Protocol	Limited to UNCLOS	Limited to UNCLOS	Limited to UNCLOS	Limited to UNCLOS	Limited to UNCLOS	Limited to UNCLOS	✔	Limited to UNCLOS	Party to the London Convention, not the Protocol
CCS-specific domestic policies or incentives	Tax incentives proposed for CCS in 2023 Budget	National Action Plan recognises role of CCS	Latest NDC includes a reference to CCS within a technology transfer objective	Corporate tax exemptions	Singapore Economic Development Bank commitment to support CCS RD&D efforts through the S$49 million Low Carbon Energy Research Funding Initiative MOU with Australia committing to collaboration around CCUS activities	MOU with Singapore committing to strengthen bilateral collaboration on CCS 50% state-owned Brunei Shell Petroleum's MoU with Shell Eastern Petroleum to explore feasibility of CCS between Brunei and Singapore	✘	✘	✘
CCS projects in development	Petronas Kasawari (in construction) and PTTEP Lang Lebah	PAU Central Sulawesi Clean Ammonia, Repsol Sakakemang, BP Tangguh, Pertamina Sukowati, Carbon Aceh Arun Hub, ExxonMobil Indonesia Regional Storage Hub, Pertamina Jatibarang	✘	Proposed PTTEP project at Arthit offshore gas field	✘	✘	✘	Bayu Undan project	TotalEnergies Papua LNG
CCS-specific legal and regulatory framework	Applicable only in the state of Sarawak	✔	✘	✘	✘	✘	✘	✘	✘
Existing legislation applicable to CCS operations	✔	✔	✔	✔	✔	✔	✔	✔	✔

119

projects across Europe

63%

63% rise in projects in various stages of development and operation since GSR 2022.



North Sea

North Sea sites continue to dominate as preferred locations for CO_2 storage, but other opportunities emerging.

2024

Northern Lights, the world's first open-source CO_2 transport and storage infrastructure, expected to be online in 2024 – and built ready for expansion.

4.3 EUROPE & UK

Overview

Momentum for CCS continues to build in Europe, with the European Commission initiating a number of new legislative proposals in recent months, adopting others that have been in the works since last year and making further progress in funding CCS projects through the Innovation Fund and Connecting Europe Facility.

Many European countries have also made important advancements in CCS deployment, including Germany and France launching consultations on policies that aim to support CCS. Funding support through the Innovation Fund and Connecting Europe Facility as well as individual national subsidy programs (notably in Denmark, the Netherlands, Norway and the UK) continue to support the business case for CCS deployment in Europe. In addition, the ETS price reached a new high of €100 per tonne of CO_2 in February 2023, contributing to an improved business case for CCS projects in some sectors. Germany and France are also looking into carbon-contracts-for-difference.

North Sea sites continue to dominate as preferred locations for CO_2 storage in Europe, but other storage opportunities are emerging. Bulgaria, Croatia and Greece are in the process of developing new on- and offshore CCS projects, while Italy has awarded a pilot storage license to the Ravenna CCS Hub project in the Adriatic.

Denmark, in addition to developing offshore storage in the North Sea, is also considering onshore storage, along with Poland.

Several European countries have committed to capture CO_2 as part of their climate mitigation strategies but not store it domestically due to geological limitations or public opposition. Switzerland, Finland, Sweden, Germany and Belgium are looking to store their CO_2 in other European Economic Area countries. Denmark, Belgium, France, the Netherlands, Norway, Germany, Switzerland and Iceland have engaged in bilateral agreements, declarations and/or collaboration on CCS and CO_2 transport.

Despite overall progress, there have been setbacks and slowdowns in 2023 as well. The Porthos project has not proceeded to FID because of a lawsuit which has now concluded in favour of the project while Celsio Oslo has been halted temporarily due to cost concerns.

European Union

Policy

Certification of carbon removals

As a follow-up to the EU communication on Sustainable Carbon Cycles, the European Commission in November 2022 adopted a legislative proposal for the first EU-wide voluntary framework to reliably certify carbon removals. Removals have been defined under three categories – permanent carbon removals (including CCS), carbon farming practices that store CO_2 in the soil or in forests, and carbon storage in long-lasting products and materials.

The proposal also detailed certification rules for the measurement, monitoring, reporting and verification of carbon removals. Co-legislators are expected to finalise their position before December 2023 in order to reach an inter-institutional agreement by the new legislative mandate (2024-2029).

Green Deal Industrial Plan

In February 2023, the European Commission released its Green Deal Industrial Plan to further support climate neutrality targets and heighten Europe's growing net-zero industrial sector. The plan aims to scale up European manufacturing capacity of green technologies. The plan's focus has four key pillars: a predictable and simplified regulatory environment, faster access to funding, enhancing skills, and open trade for resilient supply chains.

Credit: Öresundskraft demonstration unit in Sweden, image courtesy of CapsolGo.

Net-Zero Industrial Act

As part of the first pillar of the Green Deal Industrial Plan, the European Commission proposed the Net-Zero Industry Act in March 2023, which seeks to scale up technologies that will drive decarbonisation, including CCS. In particular, the Act proposes an injection target of 50 Mt of CO_2 stored per year within the EU by 2030.

The Commission stated that further development of permanent geological CO_2 storage will enable capture projects to be realised and called on member states to enhance transparency and reporting, particularly in relation to geological data, to ensure the injection target is met. The proposal is currently under revision by co-legislators the European Parliament and the Council of the European Union, with an aim to commence inter-institutional negotiations by the end of 2023.

ETS revision and ETS price

A reform of the EU Emissions Trading System (EU ETS) was published in the Official Journal of the EU in May 2023 which, after two years of negotiations, is set to support the target of a 55% reduction of GHG emissions by 2030 while including new sectors (maritime transport). It also extended the scope of covered activities to all means of CO_2 transport. In February 2023, the price of permits in the EU carbon market hit €100 per tonne for the first time, boosting the business case for CCS and other green technologies.

Carbon Border Adjustment Mechanism

The CBAM regulation also entered into force in May 2023 along with the revised EU ETS directive. This tool aims to put a fair price on the carbon emitted during the production of goods entering the EU market, stimulating de facto cleaner production processes in countries outside of the EU. Since launching its transitional phase in October 2023, the CBAM applies to carbon-intensive or carbon leakage risk imports (cement, iron and steel, aluminium, etc). The first reporting period for importers will end on 31 January 2024.

European CCUS Strategy

The European Commission in June 2023 called for evidence and public consultation on industrial carbon management to collect insights by late August to feed into the preparation of a new EU communication on CCUS deployment due by year end. The strategy will cover what role these technologies can play in decarbonising the EU economy by 2030, 2040, and 2050 and what policy and regulatory measures are needed to optimise their potential, including the deployment of EU-wide CO_2 infrastructure.

CCS Directive Guidance Document review

The Directorate-General for Climate Action (DG CLIMA) is working towards revising the CCS Directive Guidance Documents to reflect the global state of play of CCS and remove ambiguities identified during the development of the first projects in the European Economic Area. Capacity-building workshops will be organised for Member States in early 2024.

Funding

Innovation fund – third call for large-scale projects

The European Commission launched its third call for large-scale projects in November 2022 with a budget that was doubled due to higher ETS prices (to around €3 billion), which closed five months later with 239 applications. For the first time, the EU has divided its Innovation Fund budget, with CCUS to be funded under the €1 billion allocated to "General Decarbonisation". Energy-intensive industries accounted for more than two-thirds of all applications, demonstrating clear momentum in this sector and a clear need for CCUS. The Commission selected 41 projects, including 10 on CCS and carbon capture utilisation, in July 2023, with final grant decisions to be announced in Q4.

Connecting Europe Facility

In addition to the Innovation Fund, several CCS projects have been funded as Projects of Common Interest (PCI) that link the energy systems of EU countries and can benefit from accelerated permitting procedures and access to funding through the Connecting Europe Facility, an EU subsidy scheme that co-finances and supports investments in the trans-European Network for Energy (TEN-E network). Six CO_2 transport projects were included in the 5th PCI list published in November 2021, five in the North Sea and one in Poland. Three industrial CO_2 capture and storage proposals have been selected for funding under the Connecting Europe Facility (Antwerp@C CO_2 Export Hub, Ghent Carbon Hub and D'Artagnan hub).

Country policies and projects

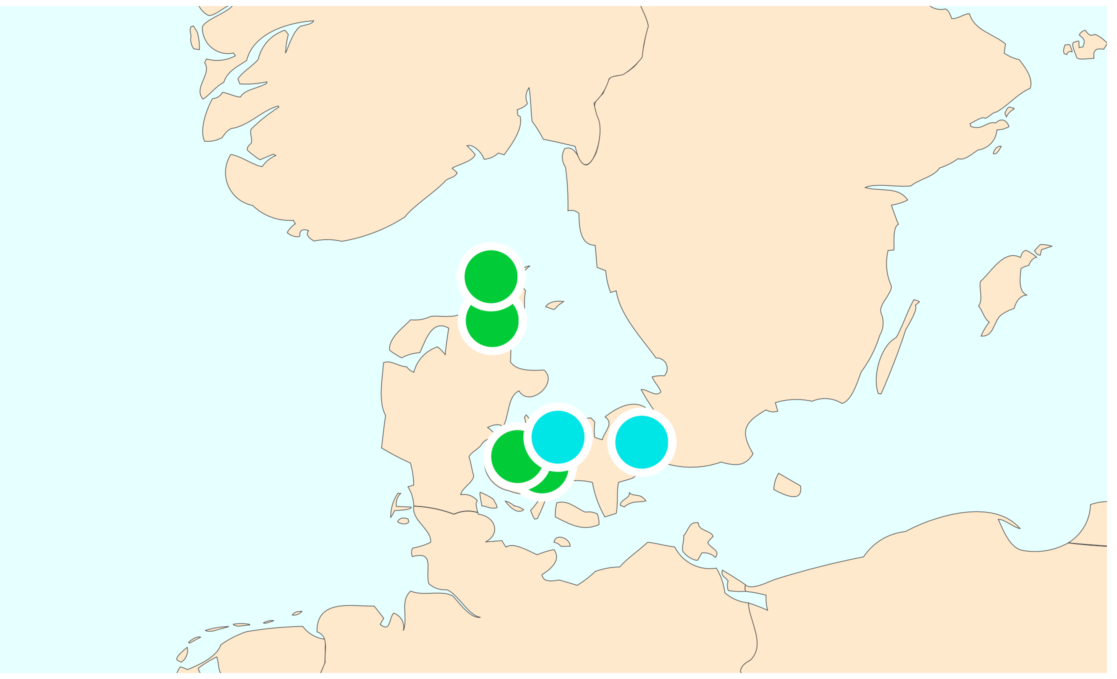
The number of projects in various stages of development, construction or operation has increased by 63% since last year's reporting, with 119 projects across Europe compared to 73 projects in the GSR 2022.

Denmark, Norway, the UK and the Netherlands are leading the way, with Denmark and the UK, recently launching their first tenders for CO_2 storage licenses in the North Sea, including in both saline formations and depleted oil and gas fields. The Norwegian Petroleum Directorate has recently offered Wintershall DEA and CapeOmega an exploration license for CO_2 storage in the North Sea.

The world's first open-source CO_2 transport and storage infrastructure, Northern Lights , is expected to be online by 2025 and is being built ready for expansion to accommodate increasing storage demands. In the Netherlands, the Aramis project will allow several CO_2 storage sites to connect to its offshore transport backbone.

Several European governments offer explicit policy support for CCS through its inclusion in their national decarbonisation strategies and/or through dedicated subsidy. Denmark, Norway and the Netherlands are also leading the way in developing and implementing rules for CO_2 storage and transport licenses.

Denmark



Denmark continues to develop CCS regulations and move towards implementation with speed. It aims to become a European CCS Hub with a total expected capacity of up to 52 Mtpa in 2030-2032. The Danish Ministry of Climate, Energy and Utilities in 2023 has granted the first three exclusive licenses for exploration of full-scale CO_2 storage in the Danish North Sea. The government is supporting CO_2 storage and capture development through subsidies, with €3.6 billion allocated for two tenders to store an estimated 3.2 million tonnes of CO_2 per year from 2029 through CCS projects. The European Commission has approved €1.1 billion for a Danish scheme that will contribute to the roll-out of CCS technologies in the country.

The government had awarded three full-scale exploration permits for offshore storage as of early February 2023. A TotalEnergies-led consortium (with Noreco, Nordsøfonden, Ørsted, DTU etc.) has received two exploration licenses, with expected storage capacities of 2-3 Mtpa in 2029-2030 and of 10-15 Mtpa in 2030-2032. An INEOS-led consortium (Maersk Drilling, GEUS, Wintershall DEA etc) has received both a pilot storage permit and a full scale exploration permit, kicking off the world's first cross-border offshore CCS transport and storage value chain, which will have an expected storage capacity of up to 1.5 Mtpa in 2025 and up to 8 Mtpa by 2030. Onshore storage is also being considered, at least as temporary storage before CO_2 is transported for permanent offshore storage in the Danish North Sea.

On the capture side, the Danish Energy Agency received final offers in the first round of its CCUS subsidy scheme and awarded approximately half of its DKK 216 billion fund to Ørsted Bioenergy & Thermal Power in support of their capture and storage of at least 400,000 tonnes of CO_2 per year starting from 2026 for 20 years.

52 Mtpa

Denmark's total expected storage capacity in 2030-2032 under its plans to become a European CCS hub.

Norway

Credit: Brevik Heidelberg Capture Plant, image courtesy of Aker Carbon Capture

Progress on Norway's full-scale CCS project Longship continues, which is owned by Equinor, Shell and TotalEnergies. Longship includes two capture plants and aims to capture and store 5 million tonnes of CO_2 per year. The government is providing support of US$2.3 billion support to the project.

Northern Lights has completed well drilling and started production of its ships. The Heidelberg Materials Brevik cement plant, which reports being on schedule and on budget, is expected to launch operations in 2024 and is thus on track to become the world's first commercial cement factory equipped with CCS. The Celsio Oslo waste to energy facility, which will also receive CO_2 transport and storage services from Northern Lights, has paused the installation of the capture plant following receipt of higher than expected cost estimates.

After developing the commercial crossborder CO_2 T&S agreement last year with Yara, Northern Lights has signed another international agreement. It will be partnering with Orsted for the commercial transport and storage of 430,000 tonnes of biogenic CO_2 per year for 10 years. According to verbal reports from Equinor and Gassnova, the Northern Lights capacity is now fully booked. Equinor is leading the planning behind a larger project covering the whole CCS value chain known as the EU2NSEA project, which is an applicant of the European Commission's PCI list and 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 30-40 Mtpa of CO_2.

Norway has also started awarding other exploration and storage licenses to expand its CO_2 storage capacity to meet growing demand in Europe. Other storage projects underway are Poseidon (exploration license) as well as Luna, Smeaheia and Havstjerne (storage licenses). The floating injection unit being proposed by Altera Infrastructure and Wintershall DEA for the Havstjerne license is an exciting development.

30-40 Mtpa

Expected capacity of EU2NSEA project to transport via pipeline and store CO_2 in the North Sea.

The Netherlands

Credit: Twence Capture Plant,
image courtesy of Aker Carbon Capture

The Dutch government has continued to reward early deployment of CCS in 2023, along with other green technologies, through its SDE++ subsidy. A new round was opened in June 2023 with a budget of €8 billion that will, if the whole budget is fully allocated, realise up to 4 Mtpa of CO_2 stored by 2030. The new envelope for this scheme was approved by the European Commission under EU state aid rules in July.

In August the highest administrative court in the Netherlands, the Council of State, gave its final decision on the Porthos Project. It concluded that the nitrogen oxide emissions during construction would not have a significant impact on nearby natural areas. The Porthos Project is now set to proceed to FID after this positive ecological assessment.

The Aramis project, a joint initiative between TotalEnergies, Shell, Energie Beheer Nederland (EBN) and Nederlandse Gasunie that will offer CO_2 transport infrastructure from Rotterdam to multiple storage fields in the high North Sea, appears to be fully subscribed for the first 5 Mtpa of CO_2 of capacity. Nine Heads of Terms have been signed. While non-binding, they contain an exclusivity clause in return for a provisional capacity reservation. The full-scale project will provide 22 Mtpa capacity for CO_2 transport and offshore storage.

Neptune Energy is pushing ahead with the L10 storage project that is expected to be able to take CO_2 supplied through the Aramis pipeline as well as by ships. L10 has the potential to safely store 120-150 million tonnes of CO_2. Currently in FEED, FID is expected by the end of 2023 with first CO_2 injection in 2026.

4 Mtpa

Volume of CO_2 stored by 2030 if the Dutch government's latest round of subsidies is fully allocated.

Belgium

Belgium is emerging as an active player in the CCS market. The Flemish government in April 2023 approved the first version of its regulatory framework for CO_2 transport, laying down rules on the management of the future CO_2 networks, after deeming CCS one of the most promising instruments to reduce emissions in Flanders in its long-term strategy for the region. At the national level, given the lack of available local storage sites, the government has intensified international cooperation.

The Antwerp@C CO_2 Export Hub project aims to develop an open-access modular infrastructure for the transport, liquefaction, and export of CO_2 captured by industries in the Antwerp port area and it has secured €145 million in funding from the Connecting Europe Fund.

The hub will have an initial export capacity of 2.5 Mtpa, with the ambition to reach up to 10 Mtpa by 2030. The BASF/Air Liquide plant is the biggest local emitter.

ArcelorMittal in Ghent has inaugurated its Steelanol CCU project which recycles carbon-rich industrial waste gases into advanced bioethanol by way of a novel microbe induced gas-fermentation technology. Holcim has started the first phase of its Go4Zero project, an innovative, pollutant-free carbon negative clinker plant coupled with a CCS solution. Carmeuse has received EU funding for its Columbus CCU project which targets the avoidance of direct CO_2 emissions from lime production by transforming CO_2 into e-methane. Both projects have been awarded support from the 2023 EU Innovation Fund.

2.5 Mtpa

Initial capacity of Antwerp@C CO_2 Export Hub.

United Kingdom

The UK government in March 2023 made a new CCUS funding commitment in its Spring Budget. It aims 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 target is to capture 20 - 30 million tonnes of CO_2 per year. This builds on the government's cluster sequencing process, to build first-of-a-kind capture networks in the UK. The Hynet Cluster (North-West England and Wales) and the East Coast Cluster (Humber and Teesside) were selected as part of Track-1 of that process. Recently, the government announced that the Transport and Storage systems Acorn CCS (North-East Scotland) and Viking CCS (Humber) will form the next two clusters as part of Track-2.

The government through a Dispatchable Power Agreement (DPA) to support power generation with CCS aims to:

- Incentivise power CCUS to operate flexibly, dispatching after renewables and nuclear, but ahead of other unabated power plants as part of a flexible electricity system;
- Have the capacity to be competitively allocated;
- Provide fair return on investment with appropriate risk allocation and without overcompensation;
- Ensure costs are affordable for electricity consumers.

The Department for Energy Security and Net Zero has selected the final eight projects to proceed to negotiations for support through the relevant Business Models:

- The East Coast cluster projects are Net Zero Teesside Power (gas fired power), H2Teesside (low carbon hydrogen) and Teesside Hydrogen CO_2 Capture.
- The HyNet Cluster projects are Hanson Padeswood (cement), Viridor Runcorn (waste-to-energy), Protos Energy (waste-to-energy), Buxton Net Zero (lime) and HPP1 HyNet (hydrogen).

In 2022, the North Sea Transition Authority (NSTA) launched the UK's first ever carbon storage licensing round – likely to be the first of many – and received 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, alongside the six licences which have been issued previously by the NSTA, could have the ability to make a significant contribution towards the aim of storing 20-30 million tonnes of CO_2 per year by 2030.

France

France released its CCUS Strategy in summer 2023 as part of government efforts to reach carbon neutrality by 2050, which notes that CCUS could have the potential to capture and store 4-8.5 Mt of CO_2 emissions per year by 2030. CCUS deployment in the country will be conducted in three stages and focused on industrial zones such as Dunkerque, Le Havre, Fos-sur-Mer, Lacq/Sud-Ouest, Loire-Estuaire and Grand Est. To support project developers and scale up CCS deployment, the government will launch a call for tenders through a Contracts for Difference scheme. Under the strategy, a framework for CO_2 transport will be developed, and geological storage sites will undergo pilot testing from 2024-2025 onwards.

Sweden

Sweden promotes negative carbon dioxide emissions/BECCS through its Industrial Leap program that supports the transition to net-zero emissions of greenhouse gases by 2045 and negative emissions thereafter.

The country's Cementa plant from HeidelbergMaterials in Slite, Gotland aims to develop the world's first carbon-neutral cement plant by capturing and storing the Slite plant's total emissions of 1.8 Mt of CO_2, equating to around 3% of Sweden's total emissions.

Germany

The German government is developing a Carbon Management Strategy for CCS, which it considers essential to achieve its carbon neutrality objective by 2045. The strategy is due for publication by year end. The country's Ministry of Economics and Climate Protection in December 2022 released an evaluation of the Carbon Dioxide Storage Act, 10 years after the law was passed to frame the first demonstration CCS projects in Germany.

Germany has launched a €50 billion bid to decarbonise its heavy industry. Following a preparatory phase starting in June 2023, it plans to introduce Carbon Contracts for Difference (CCfDs) that compensate energy-intensive companies for emission reductions.

The 2023 Innovation Fund call has awarded funding to a full-value chain, full-scale carbon project from HeidelbergMaterials in Geseke (North Rhine-Westphalia). The CO_2 will be transported by rail to a geologic storage site under the North Sea. The Fund also awarded funding to nearby lime plant Rheinkalk for its decarbonisation project.

Eastern and Southern Europe

The first phase of the Eni/Snam Ravenna CCS Hub in northern Italy is taking shape, with the phase 1 storage license granted and operations expected to start in Q1 2024 for injection into a depleted offshore gas field. The project is expected to start with capturing emissions from Eni's natural gas treatment plant.

HeidelbergMaterials has secured €190 million from the EU Innovation Fund for its ANRAV project in Varna, Bulgaria, which intends to store CO_2 under the Black Sea. Other companies to have secured funding from the 2023 Innovation Fund include Holcim's KOdeCO project in Croatia and Motor Oil Hellas' IRIS project and Titan Cement's IFESTOS project in Greece for likely storage in the Prinos basin from Energean.

In Katowice, Poland, a new cluster is emerging around local emitters in the cement, lime, fertiliser, zinc and power sectors.

Transport infrastructure

Pipelines

Pipelines continue to dominate as the preferred way to transport CO_2 from capture facilities to storage facilities. Pipeline infrastructure projects currently in development in Europe include:

- Aramis (Netherlands), for which the preparation phase is almost complete. Once the preferred options for the pipeline route and landing location have been determined, the project can enter the FEED phase, after which the FID will be made.
- Belgian gas operator Fluxys is planning a CO_2 network inside and out of Belgium to international storage locations.
- The Netherlands' Gasunie, Shell, BASF and OGE are in the feasibility stage of a similar network between Rotterdam and the Ruhr area in Germany.
- Equinor and Fluxys have unveiled plans for a CO_2 pipeline from Belgium to Norwegian offshore storage sites.
- Equinor and Wintershall Dea are collaborating on infrastructure for the transportation, injection and storage of CO_2 from Germany to Norway.
- A new 1,000 km onshore pipeline project by OGE in Germany will connect industries to the port of Wilhelmshaven.

Shipping

Transporting CO_2 by ship is crucial for large-scale CCS deployment in Europe, enabling flexibility for connecting emitters in Europe with permanent storage offshore and encompassing both cross-border CO_2 shipment and domestic projects. Transport of CO_2 by ship has been recognised as essential both at the EU level – in the European Taxonomy for Sustainable Activities and the EU ETS Directive – and at a national level, including the Dutch SDE++ subsidy scheme and UK CCUS programme.

The Northern Lights CO_2 storage project in Norway, Aramis CO_2 infrastructure project in the Netherlands and D'Artagnan and Grand Ouest CO_2 projects in France include ships for CO_2 transportation. Shipping CO_2 has also emerged as a popular project proposal under the EU PCI program, with about 15 import or export terminals referenced in PCI descriptions.

Bilateral agreements

A list of agreements, declarations and memoranda are being developed across Europe to facilitate cross-border collaboration and transportation of CO_2. Specifically, Denmark and Norway are looking to position themselves as CO_2 storage hubs for Europe and neighbouring countries are turning to them for CO_2 storage opportunities. Table 4.3–1 shows the current list of bilateral agreements in Europe.

Table 4.3–1: Current list of bilateral agreements in Europe

	Belgium	Denmark	France	Germany	Iceland	Netherlands	Norway	Sweden	Switzerland	UK
Belgium		MoU		Agreement		MoU	Negotiations for bilateral agreement			
Denmark	MoU			Declaration of Intent		MoU	MoU			MoU
France						Pact	Letter of Intent			
Germany	Agreement	Declaration of Intent					Declaration to cooperate			
Iceland									Declaration of Intent	
Netherlands	MoU	MoU	Pact				Mou		MoU	
Norway	Negotiations for bilateral agreement	MoU	Letter of Intent	Declaration to cooperate		Mou		MoU	Exploring collaboration	MoU
Sweden							MoU			
Switzerland					Declaration of Intent	MoU	Exploring collaboration			
UK		MoU					MoU			

8%

Regional operating capture capacity ~8% of global total

COP28

Hosting COP28 turns spotlight on region's commitment to sustainability – making adoption of CCS even more pressing and attractive.

19.5 Mtpa

19.5 Mtpa – Combined capture capacity of CCS projects in development, construction and operation in Qatar, Saudi Arabia, the UAE and Oman.

11 Mtpa

Saudi Aramco targets storing 11 Mtpa by 2035.

4.4 MIDDLE EAST & AFRICA

Overview

Carbon capture and storage has already established a significant presence in the Middle East and Africa region, accounting for approximately 8% of operating global capture capacity, but is now on the cusp of a remarkable uptrend, driven by several factors.

The first factor is the increasing recognition of the urgent need to address climate change and reduce greenhouse gas emissions. The United Arab Emirates (UAE) and Saudi Arabia have made strong commitments by announcing net-zero targets for 2050 and 2060, respectively. These ambitious goals serve as catalysts for the accelerated adoption of CCS technologies by providing a roadmap for transitioning towards a low-carbon future.

The second factor is the emergence of low-carbon hydrogen as an export market. With abundant natural gas, geological storage resources, renewable energy, and existing expertise in the energy sector, the Middle East and Africa region is well positioned to capitalise on the growing global demand for clean hydrogen. By leveraging CCS to capture and store carbon emissions from hydrogen production, the region can rapidly offer commercial quantities of low carbon hydrogen, facilitating economic growth and sustainability simultaneously.

There is also a strong emphasis on industrial diversification in the region, aiming to foster clean and competitive growth. This diversification strategy involves reducing the carbon footprint of existing industries and developing new sectors aligned with sustainability goals. Regional initiatives have been launched, such as the Middle East Green Initiative led by Saudi Arabia, which seeks to enhance environmental preservation and promote sustainable development.

Entities like Saudi Aramco have emphasised sustainability in their operations and published comprehensive sustainability reports outlining their commitment to CCS, with a stated target of 11 million tonnes CO_2 per year by 2035. Collaborative efforts are also underway including the Alliance for Industry Decarbonization (AFID), which brings together public and private stakeholders to accelerate the deployment of Bioenergy with CCS (BECCS) and other decarbonisation solutions across multiple industries.

With favourable conditions, strong commitments and a comprehensive range of initiatives, the Middle East and North Africa region is well positioned to significantly increase CCS deployment and play a central role in global decarbonisation efforts, contributing to a sustainable and low-carbon future.

Policy

The deployment of CCS in the power sector is gaining increasing interest in the region as numerous countries actively seek to integrate CCS technologies into their power generation infrastructure with the aim of reducing emissions arising from fossil fuel-based electricity production.

Moreover, CCS aligns with the region's focus on sustainable development and diversification of economies. By investing in CCS infrastructure, the Middle East and Africa can position themselves as leaders in the global efforts to mitigate climate change. These actions demonstrate their commitment to addressing climate challenges while ensuring the sustainability and competitiveness of their industries.

In parallel, regional voluntary carbon market initiatives that promote CCS projects and carbon offset mechanisms can further enhance the region's commitment to addressing climate challenges. These initiatives provide opportunities for companies and organisations to voluntarily go beyond regulatory requirements and actively participate in mitigating climate change.

Projects

CCS projects (in development, construction and operating) in the Middle East and Africa are located in Qatar, Saudi Arabia, the UAE and Oman, with a combined annual capture capacity of 19.5 million tonnes per annum (Mtpa) of CO_2.

In Qatar, Qatar Gas captures 2.1 Mtpa of CO_2 from the Ras Laffan gas liquefaction plant and plans to increase the capture rate to 5 Mtpa by 2025, driven by the announcement of the North Field expansion, the world's largest liquefied natural gas (LNG) project. In Saudi Arabia, Saudi Aramco captures 0.8 Mtpa of CO_2 at its Hawiyah Naturals Gas Liquids plant, utilising the captured CO_2 to demonstrate the viability of enhanced oil recovery (EOR) at the Uthmaniyah oil field.

The Al Jubail CCUS industrial hub in Saudi Arabia, a collaboration between Saudi Aramco, SLB, and Linde that aims to capture and store CO_2 emissions from industrial facilities, targets capturing 9 Mtpa by 2027 and 44 Mtpa by 2035. The first of its kind in the region, the hub highlights the kingdom's commitment to CCS, fostering sustainable development and demonstrating a commitment to climate change mitigation.

In the UAE, ADNOC's CCS projects are being implemented in multiple phases, with 0.8 Mtpa of CO_2 captured at Al Reyadah the Emirates Steel plant in Abu Dhabi as Phase 1. ADNOC estimates that Phase II and Phase III will capture approximately 5 Mtpa of CO_2 before 2030, with sources including the Shah sour gas plant (2.3 Mtpa) and the Habshan-Bab gas processing facility (1.9 Mtpa).

There are also two CO_2 utilisation facilities in the region; Saudi Basic Industries Corporation captures 0.5 Mtpa of CO_2 at its Jubail ethylene facility for use in methanol and urea production and Qatar Fuel Additive Company captures 0.2 Mtpa of CO_2 at its methanol refinery.

It is worth noting that there are additional smaller-scale CCS initiatives and projects. ADNOC announced its first CO_2 sequestered injection project and partners with 44.01 to turn CO_2 into rock via mineralisation technology. The King Abdullah University of Science and Technology, ENOWA, NEOM's Energy & Water company and the Saudi Electricity Company are collaborating on a cryogenic carbon capture technology pilot project to capture 30 tonnes of CO_2 per day.

Moreover, Saudi Arabian Mining Co. (Maaden) has signed an agreement with Gulf Cryo to build and operate a new CO_2 plant in its phosphate comple in Ras Al Khair that will capture 300,000 tonnes of CO_2 emissions per year from Maaden's three ammonia plants.

> Qatar Gas captures 2.1 Mtpa of CO_2 from the Ras Laffan gas liquefaction plant and plans to increase the capture rate to 5 Mtpa by 2025.

Egypt possesses significant onshore storage capacity in saline aquifers, allowing for CO_2 storage without costly offshore infrastructure.

Moreover, Saudi Arabian Mining Co. (Maaden) has signed an agreement with Gulf Cryo to build and operate a new CO_2 plant in its phosphate complex in Ras Al Khair that will capture 300,000 tonnes of CO_2 emissions per year from Maaden's three ammonia plants.

The interest in the deployment of CCUS hubs is gaining major interest. The Global CCS institute with support from the Oil and Gas Climate Initiative (OGCI) has conducted a study to examine Egypt's potential for developing CCS hubs to reduce industrial CO_2 emissions, which covered all elements related to policies, regulations, storage capacity, economics and hubs potential. The study concluded that Egypt has potential for large-scale CCS projects, enabling the reduction of CO_2 emissions and supporting the development of low-emission industries, including clean hydrogen production.

Egypt possesses significant onshore storage capacity in saline aquifers, allowing for CO_2 storage without costly offshore infrastructure.

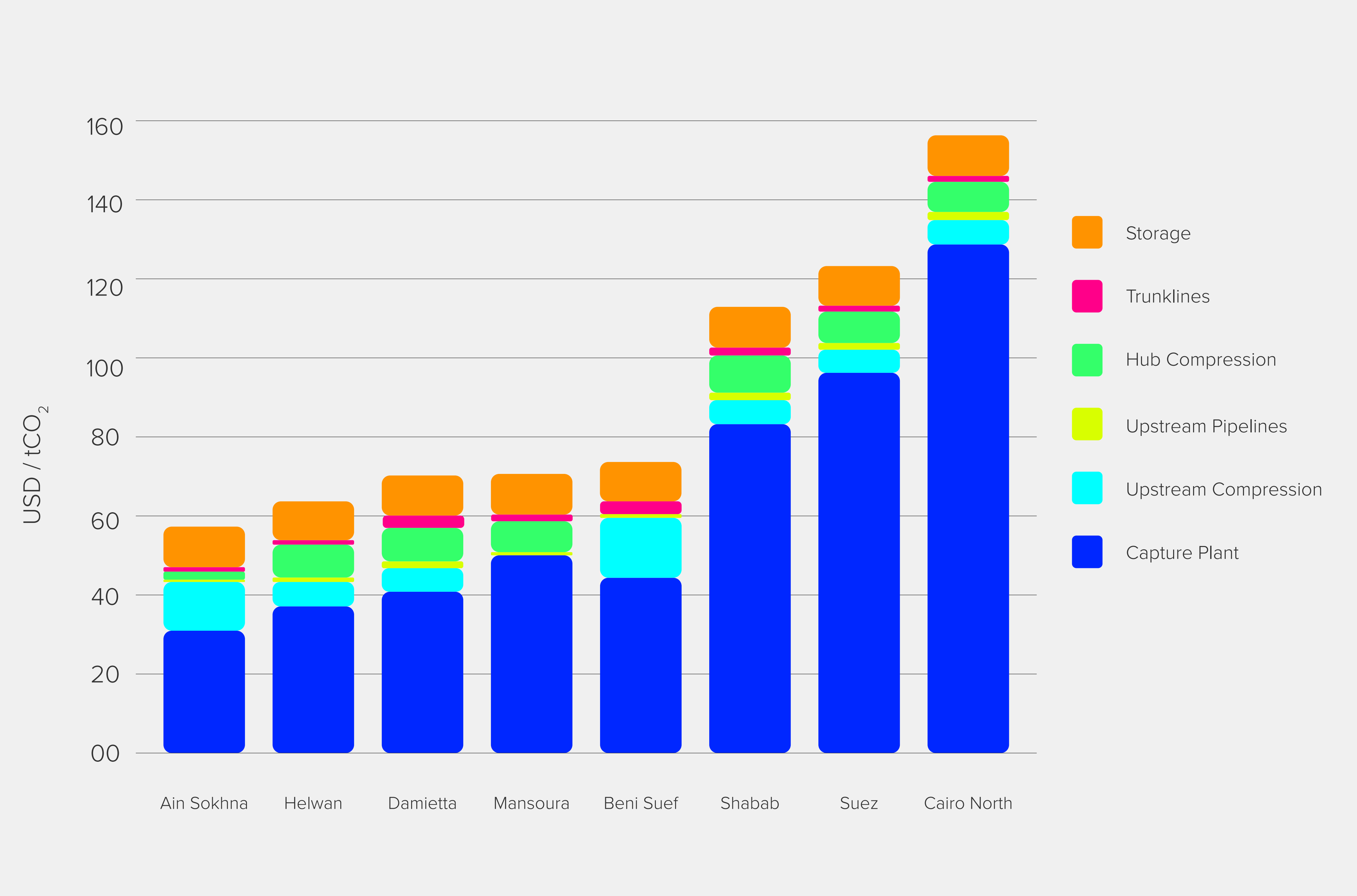
The CCS hubs would significantly bolster Egypt's climate change commitments – ultimately contributing 100 Mtpa of reductions – reducing Egypt's emissions an additional 25% from its stated goals in its NDC and climate strategy and putting the country much closer to a CO_2 pathway fully compatible with the long-term Paris Agreement goals.

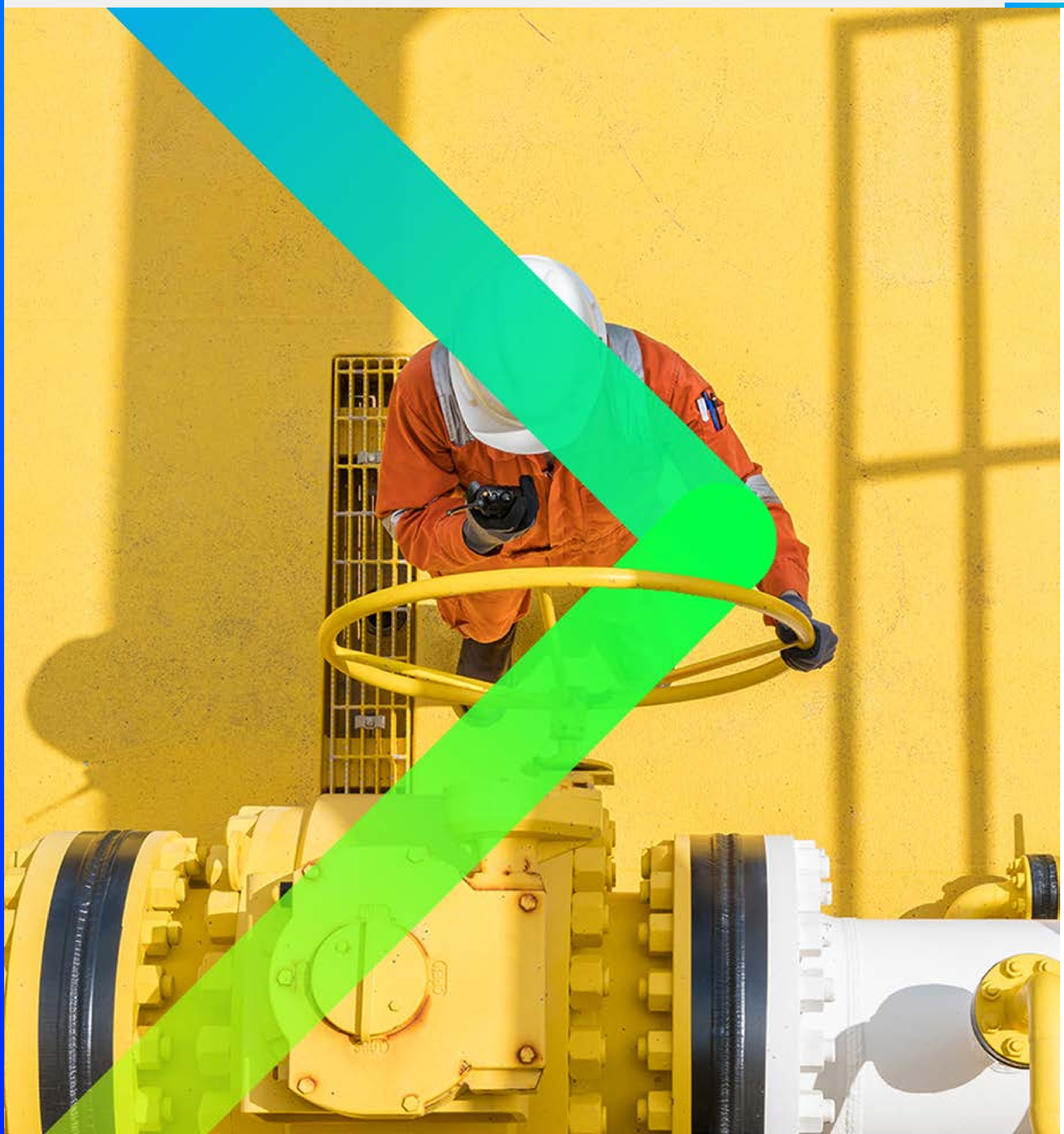
The CCS hub infrastructure can also help develop clean hydrogen in addition to Egypt's ambitious plans for renewable hydrogen, set to begin coming online around 2030. For example, low-carbon cement exports to the EU and elsewhere may be an opportunity for Egypt by capturing and storing CO_2 in cement production.

Two CCS hub models were considered: a pipeline transport model utilising existing infrastructure and a local hub model with storage near compression sites. The pipeline CCS hub cost was estimated at US$85 per tonne of CO_2, while the costs of local CCS hubs ranged from US$53-150 per tonne of CO_2, offering potential benefits with fewer pipelines and lower compression costs (Figure 4.4–1). These costs are for the full CCS value chain; CO_2 capture, compression transport and geological storage.

The cost of clean hydrogen production at Damietta, part of a CCS hub, was estimated to be slightly over US$2.25 per kg. Lower costs of capital, electricity and CO_2 injection can further reduce hydrogen production costs. In addition, the analysis emphasises the importance of early development and supportive policies for CCS projects in Egypt to effectively manage CO_2 emissions and support the country's net-zero strategies.

Figure 4.4–1: Levelised costs per tonne of CO_2 for each component in the CCS value chain for the Egypt local CCS hubs





Outlook

The positive outlook for CCS in the Middle East and Africa is maintained by several factors, including the region's positioning and the wealth of opportunities it presents. As the host of COP28 in 2023, the region has an opportunity to showcase its commitment to addressing climate change and the significant role CCS can play in achieving global emission reduction goals.

The engagement of the Global CCS Institute in the region further emphasises the growing momentum for CCS. With the establishment of a new office, attracting new members and the successful inaugural MENA region CCS forum and member meeting held in the UAE, early signs of collaboration and progress are emerging. The involvement of key stakeholders and industry players underscores the region's readiness to embrace CCS as a crucial solution.

There is a shared expectation that CCS project activities will become more prevalent in the short term. The urgency to mitigate climate change, combined with the region's abundant resources and carbon-intensive industries, provide incentive to invest in CCS technologies and infrastructure.

Additionally, the technical scope for CCS implementation in the Middle East and Africa is substantial. Leveraging existing infrastructure, such as natural gas fields and industrial clusters, provides a foundation for integrated CCS projects capable of capturing and storing significant amounts of CO_2 emissions.

As the region prepares to host COP28, the spotlight will be on the Middle East and Africa's commitment to sustainability, making the adoption of CCS a pressing and attractive proposition.

5.0 ANALYSIS

5.1 THE VALUE OF CCS IN A NET-ZERO WORLD

CCS is critical in reaching net zero climate targets. The International Energy Agency says that "achieving net-zero goals will be virtually impossible without CCUS". However, while much has been written on the cost of CCS, the literature on quantifying the value of CCS in reaching those targets is limited.

A few recent papers explore the value of CCS. Ganzer & Dowell found CCS in industry and the power sector can significantly increase Gross Value Added (GVA) economic productivity in the UK compared against moving production offshore and not deploying CCS. Another paper by Sabraveti et al. considered how CCS can be used through the value chain for materials needed to construct a bridge and found that CCS can reduce the value chain emissions by 51% while increasing the cost of the bridge by only 1%.

However, few studies attempt to evaluate the value of CCS for the whole energy system.

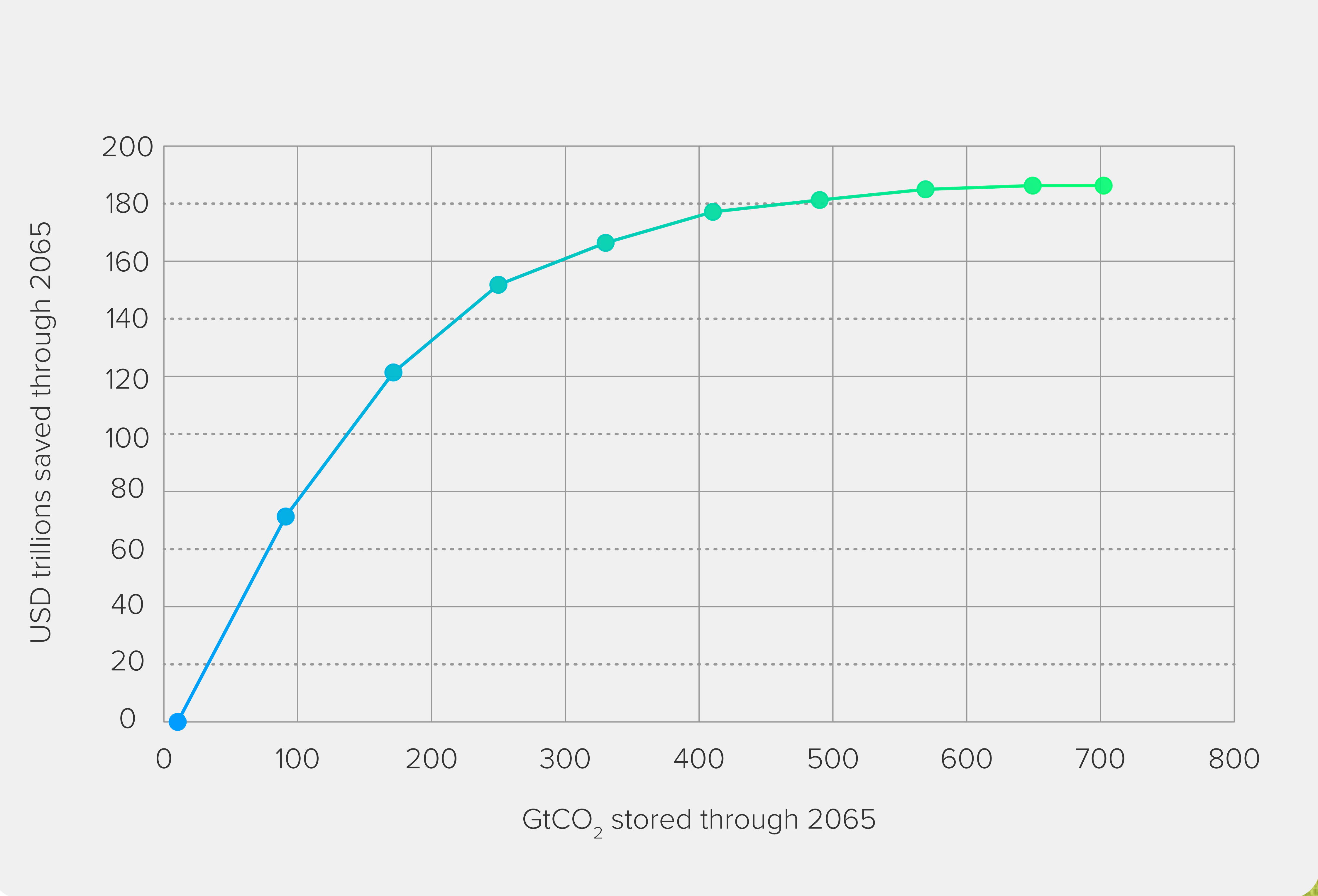
In 2014, the Energy Modelling Forum 27 (EMF27) conducted a series of modelling scenarios for reaching 450 ppm, including scenarios with and without CCS; results were published in a special issue of Climatic Change, Volume 123, issue 3-4, April 2014.

IPCC AR5 included analysis of these scenarios, concluding that without CCS, the cost of reaching 450 ppm is expected to be 138% more expensive (in the range of 29%-297%) than achieving 450 ppm with CCS.

The Global CCS Institute has developed the Global Economic Net Zero Optimisation (GENZO) model. GENZO has 23 regions and a detailed representation of the global energy system with a full suite of zero and low-carbon technology options. A description of the GENZO model can be found here.

We present results from GENZO that provide insight into the global value of CCS. Given the default assumptions in the model, including pledged net-zero targets, we find that the optimum storage of CO_2 through 2065 is a cumulative 703 $GtCO_2$, which includes a mix of fossil CCS, BECCS and DACCS. Fossil CCS includes combustion and process CO_2 emissions for processes that utilise fossil fuels as opposed to biomass. We also find that the absolute minimum cumulative CO_2 stored for the model to meet those net zero targets is 10 $GtCO_2$.

Figure 5.1–1: Total undiscounted energy system cost savings with cumulative $GtCO_2$ stored through 2065



Interestingly, to achieve the climate targets at only 10 $GtCO_2$ stored, an additional 28 $GtCO_2$ is captured using BECCS and DACCS to create net zero-carbon synthetic fuels. We then limit the cumulative CO_2 stored in increments between the optimum and the minimum to understand how the total cost of the energy system changes. In these scenarios, we assume that regions can trade emission reduction credits.

The model also allows for CO_2 to be shipped and stored in other regions if cost-effective to do so. For the scenarios with CO_2 storage limits, GENZO finds the best time and region to store the allowed quantity of CO_2. We find that CCS offers significant cost savings (Figure 5.1–2).

As we increase CO_2 storage from the minimum 10 $GtCO_2$, the cost savings are exceptional. From 10 $GtCO_2$ to 90 $GtCO_2$, we see US$886 billion in savings per additional 1 $GtCO_2$ stored (US$886 for each tonne of CO_2 stored), after accounting for all CCS-related costs. From 330 $GtCO_2$ to 410 $GtCO_2$ stored, our constrained CCS deployment scenario, we see diminishing savings of US$135 billion per additional $GtCO_2$ stored (US$135 per tonne CO_2 stored), while the constrained CCS deployment scenario (410 $GtCO_2$ stored) offers 95% of the savings potential of the optimal CCS scenario (703 $GtCO_2$ stored). By the time that we move from 650 $GtCO_2$ to 703 $GtCO_2$ stored, the marginal savings benefits are at less than US$10 billion per additional $GtCO_2$ stored (US$10 per tonne CO_2 stored).

For perspective, the annual mass of CO_2 captured in 2030 for the minimum scenario, constrained deployment scenario, and optimum CCS scenario is 40Mt, 1.07Gt, and 2.5 Gt respectively. In 2050, the annual mass of CO_2 captured is 80Mt, 12.8Gt, and 24.5 Gt respectively. In 2065 the annual mass of CO_2 captured is 1.5Gt, 22.3Gt and 35 Gt respectively.

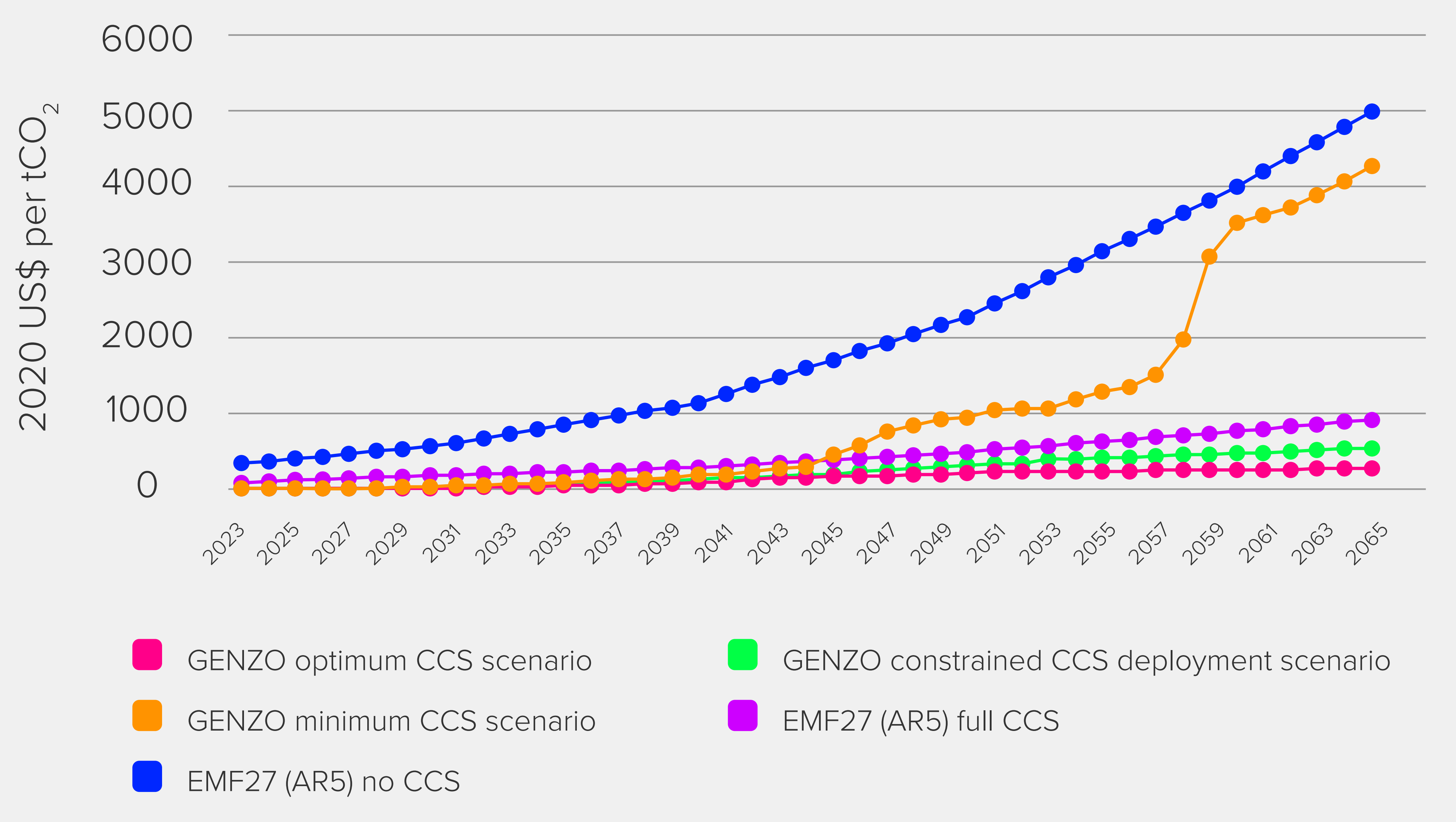
We present the CO_2 prices for the minimum, constrained deployment, and optimum CCS scenarios in Figure 2. These are the prices that would be required to deliver net-zero commitments given the mix of technologies available in each scenario. We also plot for reference the inflation-adjusted CO_2 prices from the average of the EMF27 scenarios with and without CCS, as analyzed in Budinis et al., 2018. We estimate that the CO_2 stored through 2065 in the EMF27 scenario with full CCS is 465 $GtCO_2$.

The EMF27 scenarios are almost 10 years old, and there have been significant developments in many low-carbon technologies and CCS technologies, such as direct air capture, which in the GENZO optimum CCS scenario plays a significant role in effectively capping the CO_2 price. The EMF27 scenarios also use a 450 ppm climate target, whereas GENZO is based on pledged net-zero targets. Nevertheless, the resulting CO_2 prices are well-aligned. CCS clearly works to reduce CO_2 prices even as we meet stringent net-zero targets.

From our analysis, we can conclude that at least 10 $GtCO_2$ must be captured and stored (plus an addition 28 $GtCO_2$ captured via DACCS and BECCS to create synthetic fuels) in order to reach climate targets at all. The more CO_2 that can be captured and stored, the lower the overall cost will be in reaching climate targets up to the optimum level of storage. While 703 $GtCO_2$ is the optimum level of CO_2 to store based on the assumptions in the GENZO model, even if we fall short at a little over half (410 $GtCO_2$) of the optimum level, we can still achieve 95% of the potential cost savings worth approximately USD180 trillion between now and 2065.

While government support of CCS in various jurisdictions, such as the United States, Canada, Norway, the UK and the Netherlands, is substantial – on a per tonne basis generally in the US$70-90 range – the value created by these policies in fostering the first tonnes of CO_2 storage at scale is many times more than their cost, making CCS policy support not only critical to achieve climate goals, but enormously cost-effective.

Figure 5.1–2: Global CO_2 prices at different levels of CO_2 storage in GENZO and other modelling



5.2 DRIVERS OF CCS INVESTMENT

Investment in CCS and most other climate mitigation technologies is driven predominantly by government policy and regulation. The policy tools available are well established and in force to varying degrees in different jurisdictions. They all work to create economic value from climate mitigation investment and fall into the following broad categories:

- Emission trading systems (cap and trade, carbon offsets, baseline carbon credits).
- Carbon taxes.
- Direct or indirect subsidies such as tax credits, provision of loans, grants or loan guarantees.
- Command and control mechanisms that mandate the phased elimination of emissions.

All these mechanisms have the potential to drive demand for CCS if designed appropriately.

There have been several recent policy developments that have materially improved the invest-ability of CCS projects around the world, including the promulgation of the Inflation Reduction Act (IRA) in 2022 and the Bipartisan Infrastructure Law in 2021 in the United States and changes to the EU Emissions Trading Scheme with the Fit for 55 package in Europe.

To illustrate how targeted policy can support investment in CCS, this section presents a brief case study of clean ammonia/hydrogen production in the US.

Figure 5.2–1: Polices that drive demand for CCS

	Mechanism	Potential to drive demand for CCS	Incentive to abate
Carbon markets (Cap and trade or baseline)	Increases the cost of emissions	Demand **Up**	Incentive **Up**
Carbon tax	Increases the cost of emissions	Demand **Up**	Incentive **Up**
Subsidies/grants for abatement	Decreases the cost of abatement	Demand **Up**	Incentive **Up**
Command and control	Mandates abatement	Demand **Up**	Incentive **Up**

US Gulf Coast clean ammonia/hydrogen production

The expected future growth in global demand for low-carbon energy carriers like hydrogen, ammonia and methanol as alternatives to coal and LNG for power plants and for bunkering fuel in maritime shipping has the potential to create a substantial market for these products.

In 2022, global trade of LNG was 409 million tonnes and global bunker fuel demand was 135.6 million tonnes. Replacing only 10% of the current demand for these fuels and not even including conventional natural gas and coal would require the production of more than 130 Mtpa of low-carbon ammonia. Replacing current ammonia production (195 million tonnes in 2022; 80% used for fertiliser) with clean ammonia would add even more demand.

Japan and South Korea are already actively investigating creating supply chains for clean ammonia or hydrogen and demand in Europe is likely to be driven by a rising carbon price. Based on this simple analysis, demand for clean ammonia could easily be tens of millions of tonnes per year within a decade.

The US has both the factors of production and the policy and regulatory environment necessary to support rapid growth in clean ammonia/hydrogen production. The US Gulf Coast in particular has abundant natural gas resources proximate to high-quality geological storage resources for CO_2. It also has ports and other essential infrastructure, a large existing petrochemical industry and a skilled workforce.

Following the promulgation of the IRA in 2022, the tax credit for the geological storage of CO_2 was increased to US$85 per tonne over a 12-year period and a new tax credit for low-carbon hydrogen production was introduced. The value of the hydrogen tax credit depends on its production emissions intensity, with the highest value being US$3 per kg of hydrogen for emissions intensities of less than 0.45kg CO_2/kg H_2 over a 10-year period. A project can claim one credit or the other, but not both. There are also other significant financial support mechanisms for research and development and capital expenditure in the IRA, including a loan or loan guarantee program of more than US$300 billion.

The result of this confluence of factors of production, targeted effective policy and expected robust future demand is the announcement of clean ammonia/hydrogen projects with a total capacity of over 30 Mtpa of ammonia in the US Gulf Coast (Table 5.2–2).

Table 5.2–2: Planned clean hydrogen/ammonia projects in the Gulf Coast

Facility	Product	Capacity (NH_3) Mt/yr	Target operational commencement
CF Industries Blue Point*	Clean ammonia	1.2	2030
CF Industries Donaldsonville	Clean ammonia	1.2	2025
Linde Beaumont hydrogen plant	Clean ammonia	1.1	2025
Yara Hydrogen Texas	Clean ammonia	1.4	2027
Clean Hydrogen Works Ascension Clean Energy	Clean ammonia	7.2	2027
RWE Lotte Blue Ammonia Corpus Christi*	Clean ammonia	10	2030
Grannus Blue	Clean ammonia	0.15	2027
Air Products and Chemical Louisiana Clean Energy Complex	Clean hydrogen/ammonia	1.4	2026
ExxonMobil Baytown Low Carbon Hydrogen	Clean hydrogen/ammonia	6	2027
St. Charles Clean Fuels Hydrogen Louisiana	Clean ammonia	5	2027
Total		34.65	

Source: GCCSI analysis

*These facilities are at the "announced" stage and do not contribute to facility statistics reported elsewhere in this report or appear in the facility list.

Financial analysis

The following analysis calculates the annual rate of return on investment for a hypothetical clean ammonia production facility exporting to Europe. This analysis requires many simplifying assumptions, is indicative, not definitive, and must not be considered as investment advice.

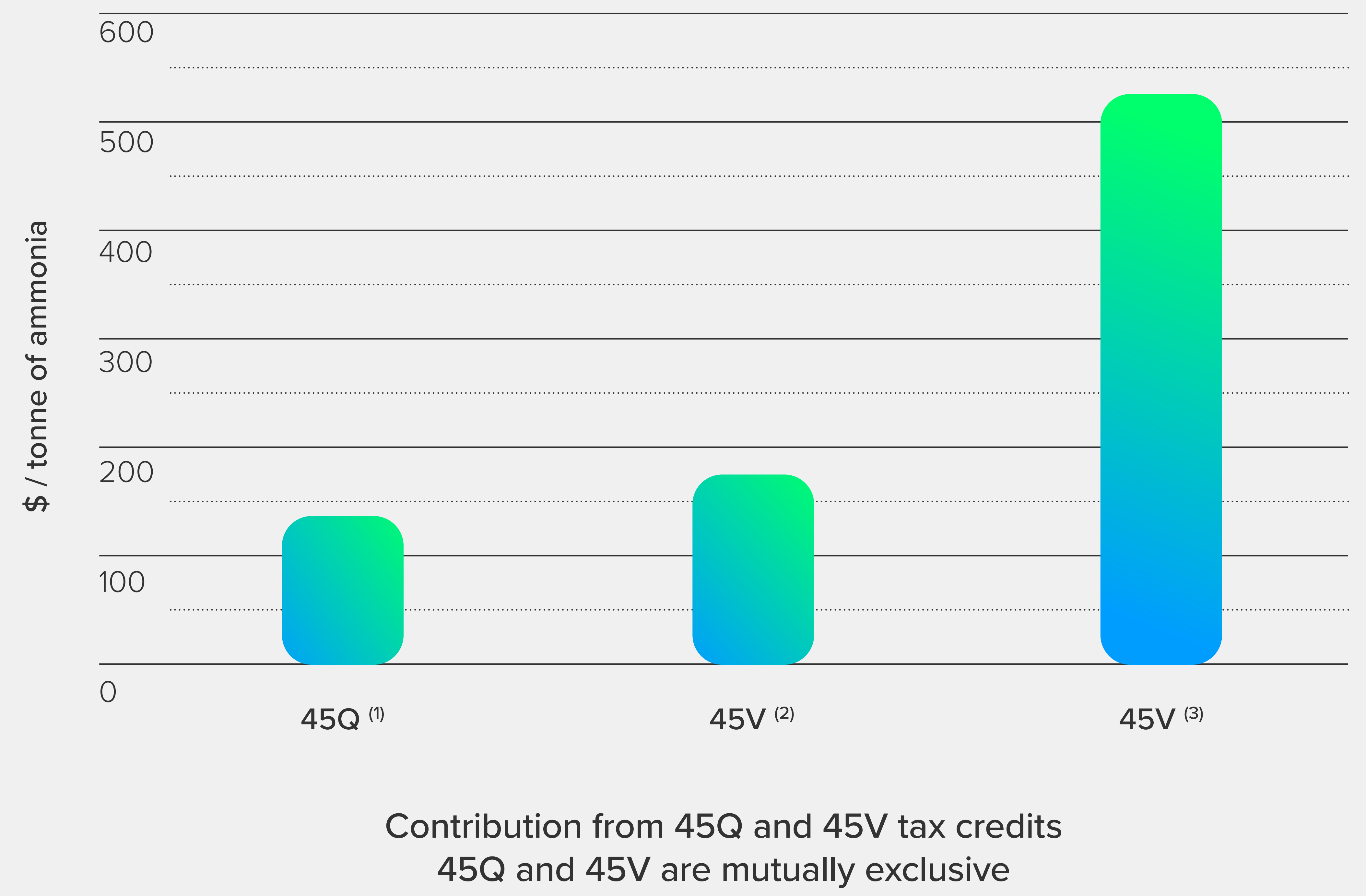
The 45Q tax credit is effectively a US$85 subsidy for each tonne of CO_2 captured and geologically stored for 12 years, the first five years of which are direct pay. The 45V tax credit is provided for producing clean hydrogen at varying rates depending on the life cycle CO_2 emissions during the production process. It is US$1 per kg of hydrogen if the carbon content is between 0.45 kg and 1.5 kg of CO_2 per kg of hydrogen, which is assumed for this analysis. However, for hydrogen produced with a life cycle emissions intensity of less than 0.45 kg of CO_2 per kg of hydrogen, the subsidy triples to $3 per kg of hydrogen.

A producer of clean hydrogen/ammonia can claim either the 45Q tax credit for the CO_2 captured and stored, or the 45V tax credit per kilogram of hydrogen produced, but not both.

The value of these subsidies, per tonne of ammonia produced is shown in Figure 5.2–3.

The sale price of clean ammonia will depend on a number of factors. For the purposes of this analysis, we have assumed an equivalent price to LNG or bunker on an energy basis, and then corrected for CO_2 emissions during utilisation assuming an EU ETS price of Eur91 per tonne of CO_2. As ammonia combustion produces zero CO_2 emissions, this increases the potential price of clean ammonia. The Platts US Gulf Coast CFR Blue Ammonia spot price average for June 2023 is also shown for comparison in Figure 5.2-4 on the following page.

Figure 5.2–3: Monetary value of 45Q, 45V tax credits per tonne of ammonia



1 Based on 45Q Federal tax credit of US$85 per tonne of CO_2 captured and stored. The conversion to ammonia is based on an ammonia-to-captured CO_2 ratio of 1:1.6

2 Based on 45V Federal tax credit of US$1 per kg of hydrogen if CO_2 content per kg of hydrogen is between 0.45 and 1.5 kg

3 Based on 45V Federal tax credit of US$3 per kg of hydrogen if CO_2 content per kg of hydrogen is less than 0.45 kg

Assuming a clean hydrogen emissions intensity of between 0.45 kg and 1.5 kg of CO_2/kg of hydrogen providing a subsidy of US$1 per kg of hydrogen, and the potential prices calculated above, sales of clean ammonia into Europe could generate total revenue of US$530-550 per tonne.

These revenues appear attractive compared to an estimated operational cost of production and freight of around US$240 per tonne (Figure 5.2–4).

Based on announcements by companies developing clean ammonia projects, the capital expenditure per tonne of ammonia production capacity is between US$1,400 and US$2,100. With these assumptions, the unlevered pre-tax internal rate of return is estimated to be between 10.2% and 17.4% with a 25-year economic life and 10-year tax credit.

This simple analysis illustrates how policy can incentivise investment in CCS. In this case, a production subsidy in the US combined with a carbon price in Europe and demand support in Asia contribute to sound returns on investment. Of course, this is a hypothetical case study based on many simplifying assumptions, however, the capital inflows into clean hydrogen/ammonia production on the US Gulf Coast support a conclusion that sound returns are available to investors in these projects, of which CCS is an essential component.

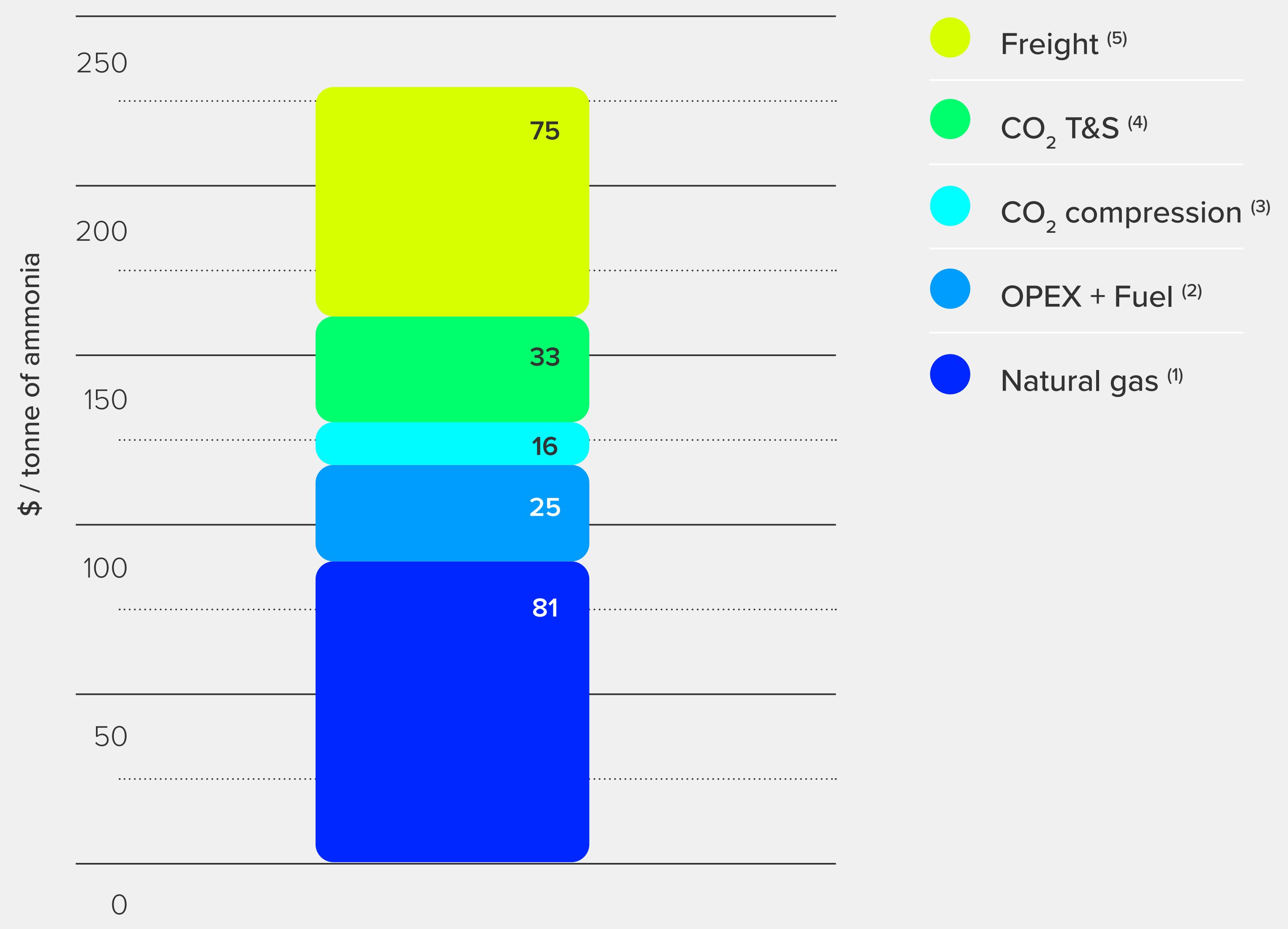
Figure 5.2–4: Hypothetical LNG and bunker fuel equivalent price of ammonia

1 Based on ammonia energy content of 18.8 MJ/kg, vs. LNG 50.0 MJ/kg, CO_2 emissions of 2.57 kg per tonne of LNG, LNG price of Eur45/MWh (TTF) and, ETS price of Eur91 per tonne of CO_2

2 Based on ammonia energy content of 18.8 MJ/kg vs. bunker 40.0 MJ/kg, CO_2 emissions of 2.94 kg per tonne of bunker, bunker price of US$520 per tonne (Houston) and ETS price of Eur91 per tonne of CO_2

3 Spot blue ammonia price (Platts – June 2023)

Figure 5.2–5: Operating cost estimates of ammonia production*



*Based on auto-thermal reforming (ATR) technology

1 Assuming a natural gas price of $2.70/MMBtu (Henry Hub)

2 Includes maintenance, insurance, general and administrative and other expenses

3 CO_2 compression cost of $9.80 per tonne CO_2 (opex only)

4 CO_2 transport and storage fee of $20 per tonne CO_2

5 Based on LNG shipping rate of $150,000 per day and 12-day trip as a proxy

5.3 CCS BUSINESS MODELS AND TRENDS

Business models for CCS projects vary depending on industry specifics, local policies and prevailing market conditions.

Full value chain model

The traditional 'full value chain' model includes capture, transport and storage, typically developed by a consortium of industry players specialising in the various elements of the value chain. This model comes with cross-chain risks that could be a challenge for financiers of large-scale projects, for example if one component of the value chain fails or is unavailable then the whole value chain ceases operation.

This model also presents unique regulatory issues that could prolong project approval timelines such as environmental assessments that cover the full value chain as opposed to a single component, or where the whole project may not be able to proceed due to an environmental or social challenge applicable to only one component of the value chain.

Networks and hubs model

As demand for CCS increases, alternative business models are emerging that have the potential to accelerate deployment, reduce costs and remove supply chain risks. In recent years, CCS network and hub models have emerged in various global jurisdictions.

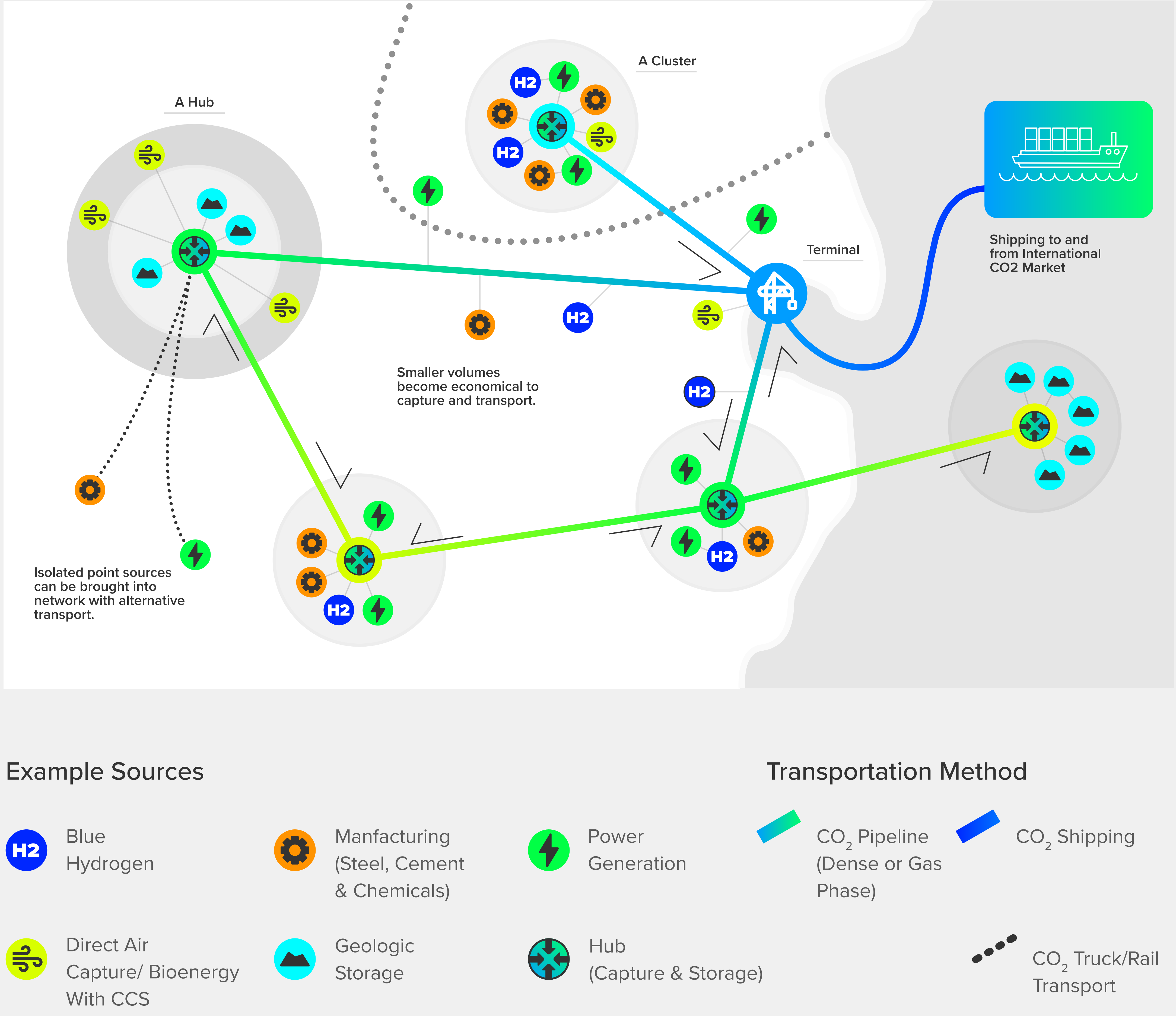
A typical network/hub model involves the establishment of an industrial 'cluster' where one company (or multiple companies in joint venture) invest in the development of CO_2 transport and/or storage infrastructure. This may include pipelines, compressors, port facilities, ships, injection wells or any combination of these facilities. This infrastructure is then available to local businesses that require a CO_2 management solution for a fee.

Networks, where each entity typically operates only part of the full CCS value chain, provide several benefits. They reduce cost and commercial risk by allowing each company to remain focused on their core business and not extend into areas of operations in which they have no competency. They create multiple service providers or customers, greatly reducing counterparty risk. They create economies of scale that would not be available to any individual CCS project, reducing cost.

CCS networks generally consist of pipelines between capture facilities and hubs with shared compression facilities that feed dense phase (high pressure; typically, 100-150 bar) pipelines to the injection wells. Suppliers must ensure CO_2 meets certain specifications before entering the network. As more projects come online, establishing CCS networks and hubs is becoming a default business model in linking captured CO_2 with storage sites.

CCS hubs are typically established in industrial areas where a number of large emitters are located and, as such, will not only serve to accelerate emissions reduction in hard-to-abate industries, but also contribute significantly to domestic regional economies. CCS hubs will likely attract additional carbon emissions-intense industries seeking a CO_2 management solution.

Figure 5.3–1: A CCS Network across various capture and storage hubs ammonia

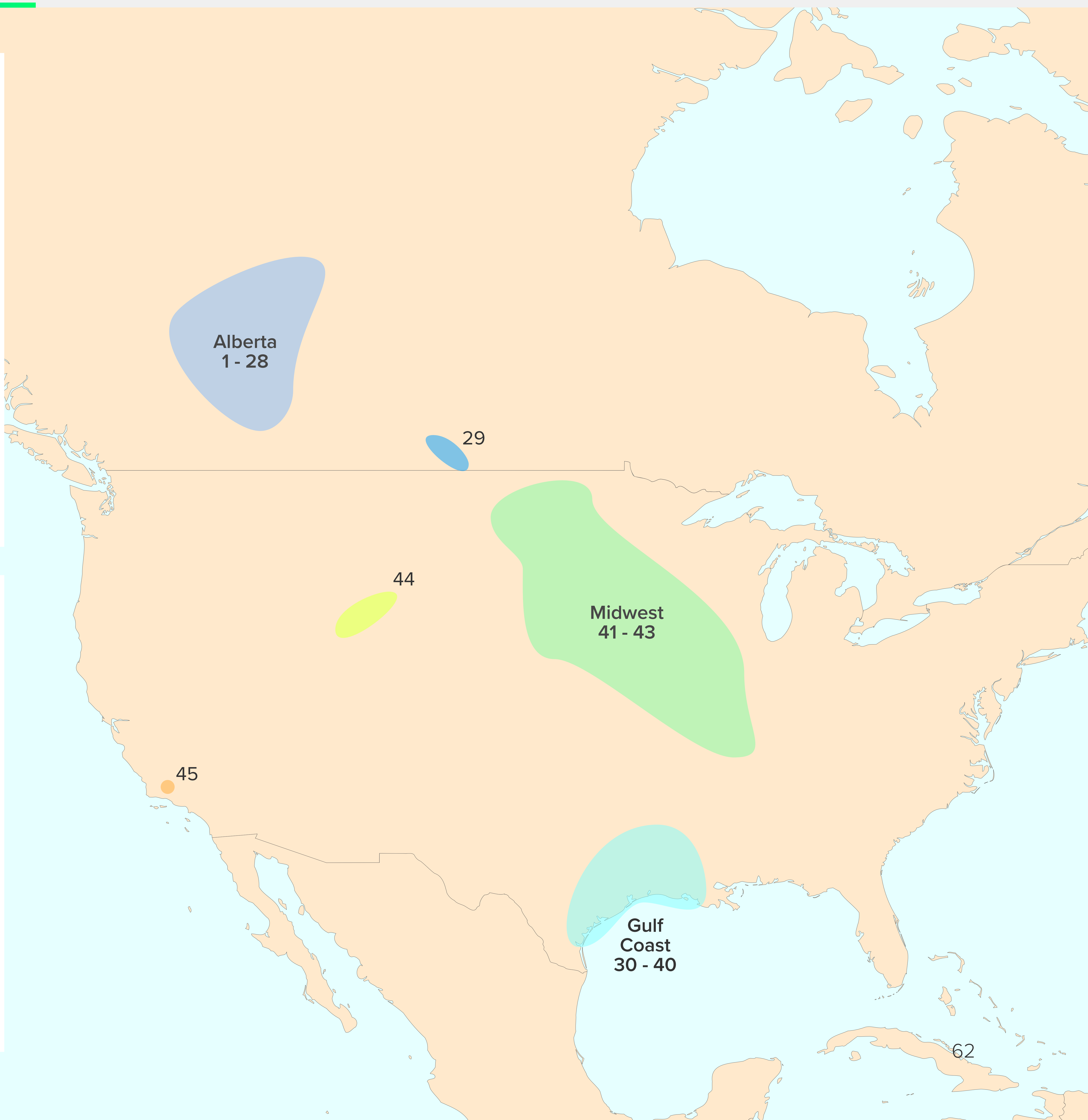


CCS networks have operated in the United States for decades, where most CO_2 has been geologically stored in the process of enhanced oil recovery. Investment in these early CCS networks, involving several thousand kilometers of CO_2 pipelines, was enabled by the revenues generated by additional oil production. Now, climate mitigation is the primary driver of CCS network development. Currently 25% of captured CO_2 is injected for dedicated storage. However going forward, 78% of the total capacity of CCS facilities in development or in construction will use dedicated geological storage (15% of facilities by capacity have not yet announced if they will use dedicated geological storage or enhanced oil recovery). At present, there are more than 100 CCS networks in development. A few examples are described below.

In the US, Summit Carbon Solutions is continuing to progress the development of the Mid West Carbon Express. The network will receive CO_2 from more than 30 ethanol refineries spanning the five states of Iowa, Nebraska, South Dakota, Minnesota and North Dakota for permanent geologic storage in North Dakota. The shared infrastructure, including pipelines and storage wells, demonstrates the breadth that networks can extend to in order to economically service many small CO_2 sources. In the Gulf Coast, ExxonMobil continues to develop its transport and storage business with ongoing development of the 100 Mtpa Houston CCS hub and the acquisition of Denbury and its extensive transport and storage infrastructure.

Figure 5.3–1: Projects in each network

Alberta Carbon Trunk Line (ACTL)	1
Pathways Alliance Oil Sands Pathways CCS Network	2
ARC Resources Greenview Region	3
Bison Meadowbrook Storage Hub	4
Bison North Drumheller Hub	5
City of Medicine Hat Project Clear Horizon	6
Enhance Grand Prairie Hub	7
Entropy Bow River Hub	8
Grand Prairie Net Zero Gateway Storage Hub	9
Heartland Generation Battle River Carbon Hub	10
IPL Alberta Hub	11
Kiwetinohk Maskwa Swan Hills Hub	12
Kiwetinohk Opal Carbon Hub	13
Oil Sands Pathway to Net Zero Alliance	14
Open Access Wabamun Carbon Hub	15
Origins Project Carbon Storage Hub	16
Pembina Alberta Carbon Grid	17
RETI East Calgary Region Carbon Sequestration Hub	18
Shell Atlas Carbon Storage Hub	19
Tidewater Brazeau Carbon Sequestration Hub	20
Tidewater Ram River Carbon Sequestration Hub	21
Tourmaline Clearwater	22
Vault 44.01 Rocky Mountain Carbon Vault	23
Vault 44.01 Athabasca Banks Carbon Hub	24
West Lake Pincher Creek Carbon Sequestration Hub	25
Whitecap Resources Rolling Hills Hub	26
Wolf Central Alberta Hub	27
Wolf Fort Saskatchewan Carbon Hub	28
Southeast Saskatchewan CCUS Hub	29
Talos Coastal Bend	30
Bluebonnet	31
Denbury Gulf Coast	32
Houston Ship Channel	33
Chevron Bayou Bend	34
Central Louisiana Regional Carbon Storage Hub (CENLA)	35
Talos Harvest Bend Louisiana Transport and Storage	36
Gulf Coast Sequestration Storage Hub	37
Crescent Midstream Louisiana Offshore Hub	38
Liberty CCUS hub	39
1PointFive Bluebonnet Hub	40
Mid West Express	41
Mt. Simon CCS Hub	42
Navigator Heartland Greenway	43
Denbury Rocky Mountains	44
Carbon Terravault 1	45



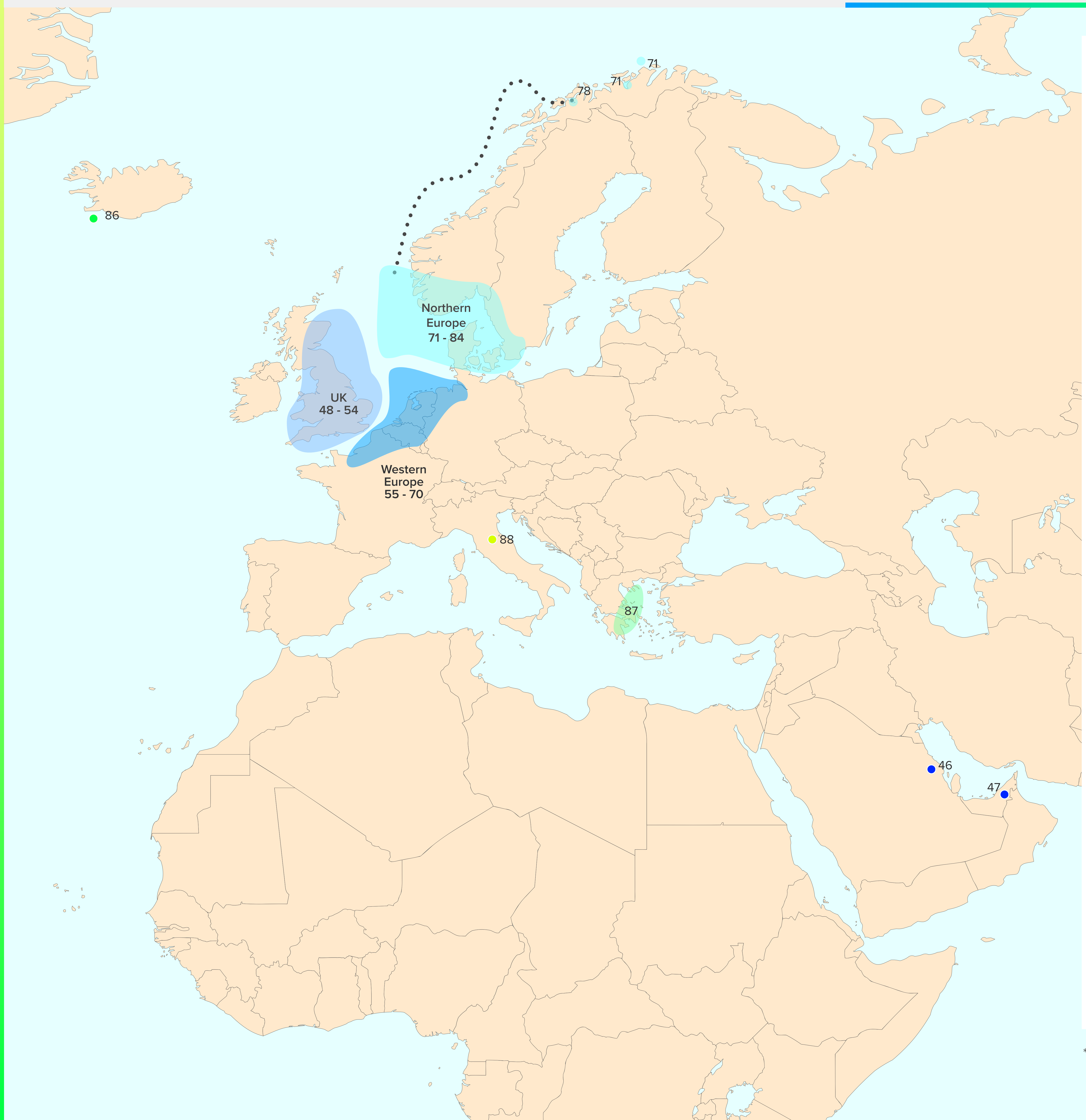


Figure 5.3–2: Projects in each network

●	Saudi Aramco Jubail Hub	46
●	SNOC Sharjah Hub	47
	Bumi Armada Bluestreak CO_2	48
	East Coast Cluster	49
	HyNet	50
	Medway Hub	51
	Scottish Cluster	52
	South Wales Industrial Cluster	53
	Viking CCS	54
	Antwerp@C	55
	Aramis Hub	56
	Axe Seine/Normandy CCS Cluster	57
	Bremen Carbon Dioxide Transshipment Hub	58
	CapeOmega NoordKaap	59
	Carbon Connect Delta	60
	CO_2nnectNow Hub	61
	Dartagnan	62
	Delta Corridor Pipeline Network	63
	Equinor North Sea Pipeline Zeebrugge	64
	EU2NSEA	65
	Fluxys Ghent Carbon Hub	66
	Neptune Energy L10	67
	Porthos	68
	PYCASSO Storage Hub	69
	Smart Delta Resources CarbonConnectDelta	70
	Barents Blue	71
	Aker BP Poseidon	72
	Equinor Smeaheia	73
	Horisont Energi Errai	74
	Wintershall Dea Havstjerne	75
	Wintershall Dea Luna	76
	Neptune Trudvang Storage Project	77
	Langskip	78
	C4 Copenhagen	79
	DUC Bifrost	80
	Fidelis Norne Carbon Storage Hub	81
	Greenport Scandinavia	82
	Project Greensand	83
	Carbon Network South Sweden	84
	Cinfracap	85
●	CODA	86
	Energean Prinos	87
●	ENI Ravenna CCS Hub	88
	Höegh LNG Stella Maris	89*

* Offshore floating injection platform; location not yet defined

In Europe, there is increased growth in cross-border CO_2 networks involving transport by ship as well as pipelines. The flagship Northern Lights project in Norway signed the first cross-border commercial agreement to store 0.8 Mtpa from the Yara Sluiskil ammonia and fertiliser plant in the Netherlands in August 2022. In May 2023 the Northern Lights project expanded its cross-border transport signing an agreement with Ørsted to store 0.4 Mtpa of biogenic CO_2 from two biomass power plants in Denmark. Project Greensand in Denmark successfully commenced the pilot stage of the transport and storage project with the world's first cross-border offshore injection of CO_2.

While historically the North Sea has received attention in Europe, projects are now appearing in the Baltic and Mediterranean seas. The EU CCS Interconnector Project in northern Poland aims to take CO_2 from sources in northern Poland for ship-based transport in the North Sea. Starting at an initial capacity of 2.7 Mtpa before 2030, this network has plans to expand to 8.7 Mtpa beyond 2030.

The CCS Baltic Consortium is considering a similar approach, exporting CO_2 by ship from the port of Klaipeda, Lithuania. Similar transport-based projects are being developed in the Mediterranean Sea, with examples like the Ravenna Project by ENI that intends to bring CO_2 from sources across Europe for storage off the coast of Ravenna, Italy with a target of 4 Mtpa by 2027 through phased infrastructure development. These developments in Europe are providing the framework for what could be a truly cross-regional network.

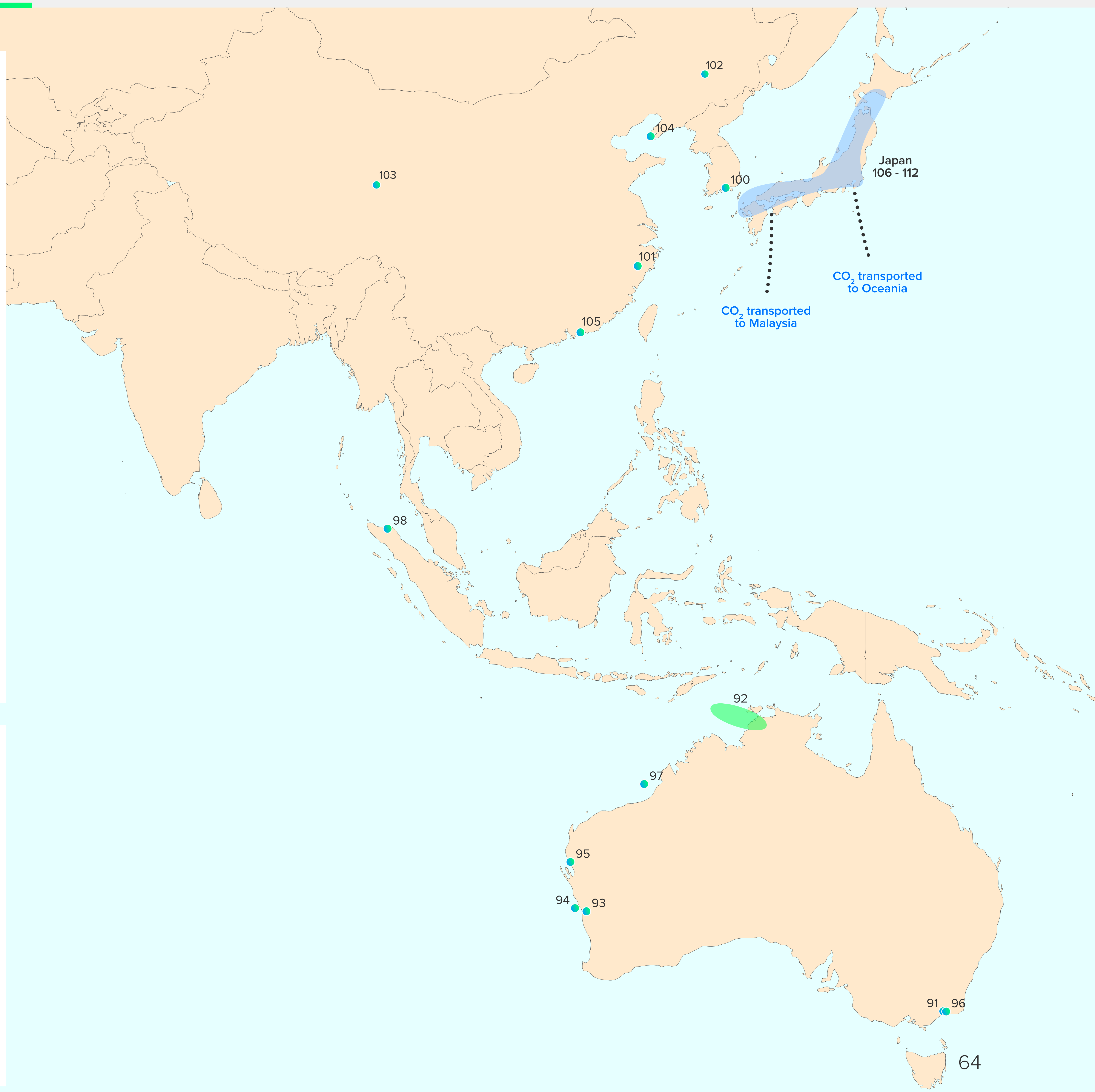
In the UK, several new networks have been announced and development of existing networks continues. The Medway CCS Project being developed focuses on ship-based transport of CO_2 from multiple power stations east of London to offshore storage in the Camelot depleted gas fields in the North Sea. In the northwest, Peel has commenced planning and design of the Protos network, focused on creating a carbon capture-ready industrial destination for existing and new businesses wanting to achieve net zero. The first phase will focus on aggregating emissions from power generation at 0.8 Mtpa CO_2 for transport to the regional Hynet infrastructure with future phases expanding to other industries, both existing and new, increasing capacity to over 1.2 Mtpa. The Protos network will also explore the future potential of bringing liquified CO_2, including by shipping canal and rail, from other operations in the northwest and neighbouring regions not able to connect to the planned regional networks.

The Asia Pacific region is seeing the first elements of CCS networks being developed. The largest of these is the new Arun project looking to develop the depleted Arun gas field in the Indonesian province of Aceh, which will offer open access storage of CO_2 from sources in Indonesia and the Asia-Pacific region. The depleted Arun gas field has the potential to sequester in excess of 1,000 Mt of CO_2, which could make it one of the largest projects globally.

In Australia, there are several CCS networks in development ranging from CO_2 pipeline and storage projects in the state of Victoria by CarbonNet and ExxonMobil to a major low-emissions industrial CCS hub in Darwin with storage in the deep saline formations off Australia and depleted fields in Timor-Leste.

Figure 5.3–3: Projects in each network

deepC Store CStov re1	90	Yangtze River Delta Hub	101
ExxonMobil South East Australia Carbon Capture Hub	91	Songliao Basin	102
Middle Arm Sustainable Development Precinct	92	Junggar Basin Hub	103
Mitsui Mid West Modern Energy Hub	93	Hengli Dalian Changxing Island CCUS	104
Pilot Mid West Clean Energy	94	Daya Bay CCS Hub	105
Santos Reindeer Hub	95	East Niigata Area	106
Victorian Government CarbonNet	96	Kyushu	107
Woodside Burrup Hub	97	Metropolitan Area	108
Carbone Aceh Arun Hub	98	Oceania	109
ExxonMobil Indonesia Regional Storage Hub	99	Offshore Malay	110
Shepherd CCS	100	Tohoku Region West Coast	111
		Tomakomai Area	112



Capture-as-a-service model

Another emerging business model is the deployment of capture technology as a service. Capture as a service can consist of a technology provider designing, building and operating a carbon capture plant on behalf of an emitter all the way up to the full CCS value chain. Aker Carbon Capture is one technology provider actively offering this service and it is likely that other technology providers will adopt this business model in the future.

Transport and storage-as-a-service model

Transport and storage projects are taking several different approaches to scaling up and development.

Projects such as the Midwest Carbon Express are actively working with emitters during the development of the CCS value chain and sizing all infrastructure accordingly.

The acquisition of Denbury by ExxonMobil is a significant indicator of maturation of the CO_2 transport and storage business model. The acquisition of Denbury and its assets delivers ExxonMobil an opportunity to build a CO_2 transport and storage business with the potential to store 100Mtpa from emission sources in the US Gulf coast. This infrastructure includes approximately 2000km of CO_2 pipelines and 10 onshore CO_2 geological storage sites.

> The acquisition of Denbury by ExxonMobil is a significant indicator of maturation of the CO_2 transport and storage business model.

Other networks, such as the Northern Lights, EU CCS Interconnector, Ravenna projects and Project Greensand, focus on staged development. Typically, one or more anchor emitters, typically with low capture costs, enable the development of the infrastructure (transport and storage) in early phases followed by subsequent phases scaling up to accommodate new, and often higher capture cost, emitters. As an example Project Greensand, aims to establish a value chain to transport and store CO_2 (ultimately from various European countries) offshore in Denmark in a staged manner from 2025 to 2030 increasing from 1.5 Mtpa to potentially 8 Mtpa following the successful pilot stage of the project.

Other projects, such as the Arun project, adopt a "build and they will come" approach, where infrastructure for transport and storage is designed and built irrespective of the CO_2 source.

While there are several different transport and storage approaches being taken, they all offer the opportunity to scale up to meet the growing demand for permanent storage of CO_2.

5.4 GLOBAL TRANSPORT METHODS

Carbon dioxide can be transported by pipeline, rail, truck or ship. Each mode of transportation has different operational requirements and capacities that impact suitability for a given project (Figure 5.4–1).

Transportation of CO_2 by pipeline is mature and the preferred method with 41 projects in construction or operation using this method of transportation; 195 of the 325 CCS projects in development also plan to transport CO_2 by pipeline. However, transportation of CO_2 by ship or a combination of transport methods (for example pipeline and shipping) is seeing increased interest, with 11 shipping projects in development and 28 projects with a combination of transport modes in development and a further 3 in construction.

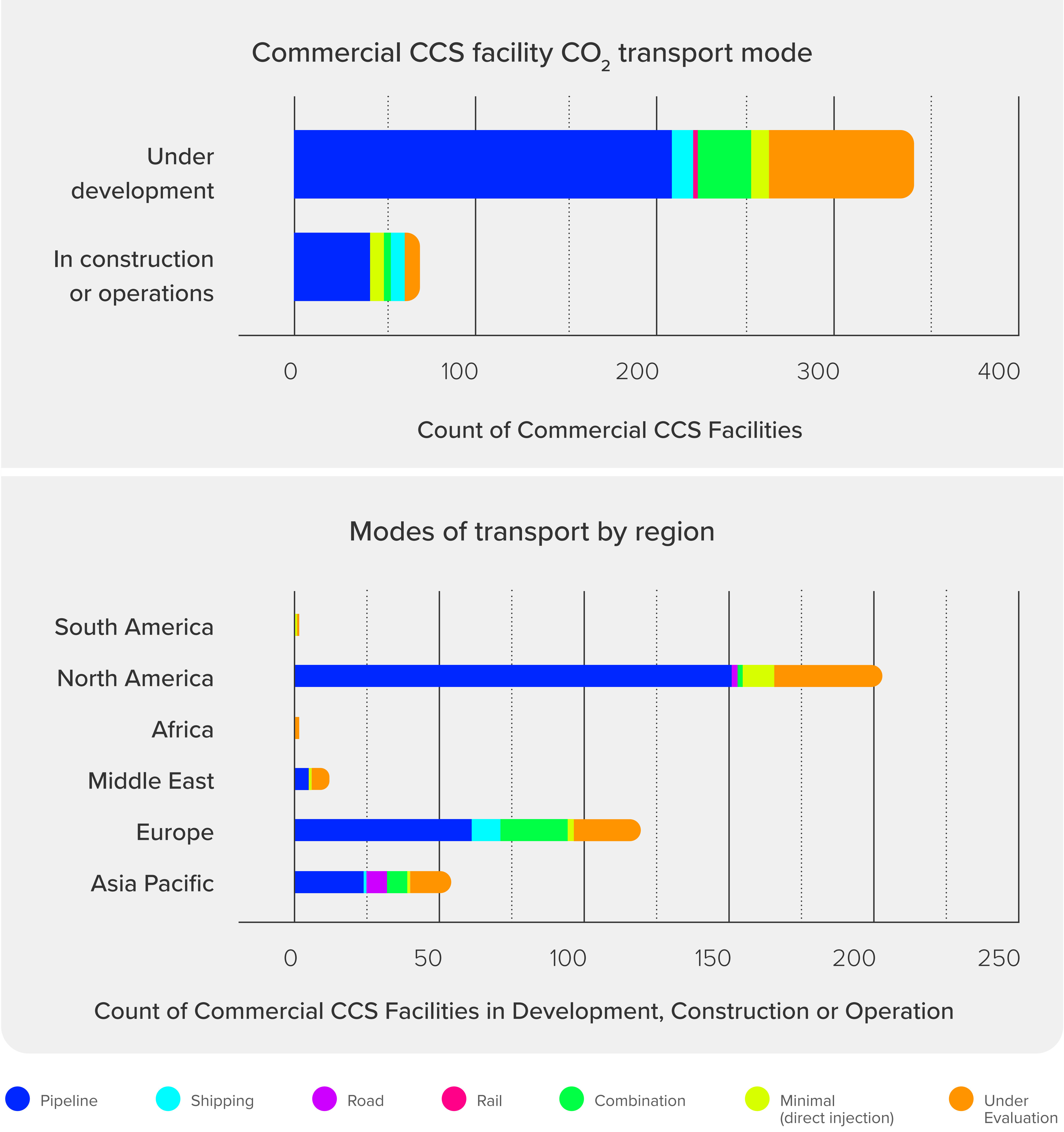
Shipping has seen an increase in uptake as a transport method as it offers a more flexible alternative to pipelines for offshore storage and during the overseas movement of CO_2, especially where there is variability in sources, demand and storage sites.

Figure 5.4–1: Comparison of CO_2 transportation methods.

Transport method	Conditions	CO_2 phase	Current capacity[1]	Remarks
Pipeline	48-200 barg[2], 10 to 34°C	Vapour or dense phase	~110 $MtCO_2$/yr; ~ 9500km of pipeline transport in operation	• Higher capital costs, lower operating costs compared to the other methods. • Low-pressure pipeline transport is generally more expensive than dense phase transport per tonne of CO_2. • Over 50 years of commercial experience.
Ship	7-45 barg, -52 to 10°C.	Liquid	>3 $MtCO_2$/yr	• Higher operating costs, lower capital costs compared to pipeline transport. • Currently applied in food and brewery industry for smaller quantities. • Offers volume and route flexibility.
Truck	17-20 barg, -30 to -20°C	Liquid	>1 $MtCO_2$/yr	• 2-30 tonnes per batch. • Not economical for large-scale CCS projects. • Boil-off gas emits 10% of the load.
Rail	7-26 barg, -50 to -20°C	Liquid	>1 $MtCO_2$/yr	• No large-scale systems in place. • Loading/unloading and storage infrastructure required. • Only feasible with existing rail line. • More advantageous over medium and long distances.

1 Incudes CO_2 that is permanently stored and for further use in fertiliser production, food and beverage, enhanced oil recovery and other uses.
2 barg is gauge pressure, in bar, relative to atmospheric pressure. 1 bar is approximately equal to atmospheric pressure at sea level.

Figure 5.4–2: Transport modes



Shipping offers some significant advantages over pipeline transport of CO_2 in certain circumstances.

- Shipping enables the scale of a project to be rapidly increased if the market demands. Whilst additional or larger ships can be added to increasing CO_2 supply, the capacity of a pipeline needs to be defined from the initiation of the project. This presents an issue of over-engineering a pipeline anticipating greater demand or limiting the demand to pipeline design.
- Shipping enables a single ship, or shuttle shipping, to load from multiple CO_2 sources and offload to a single storage site. From a storage perspective, this increases the economics of multi-user offtake agreements. From a capture perspective, this enables various sized capture facilities, most likely industrial sources clustered in the same region, to access transport and storage at a lower cost.
- Shipping routes can be changed and new storage sites utilised if the original storage site becomes unusable. For example, if a storage site is unavailable due to planned or unplanned maintenance or operational difficulties, the ship can transport the CO_2 to an alternate storage site.
- On the closure of a CCS facility, a ship can be re-routed, sold or reused, whereas a pipeline needs to be decommissioned at a cost.

Regionally the optimum mode of transport is heavily dependent on the relative location of suitable storage resources and emission sources. In the United States, pipeline transport remains the most common mode of transport with over 50 years of commercial experience and well over 8000 km of CO_2 pipelines.

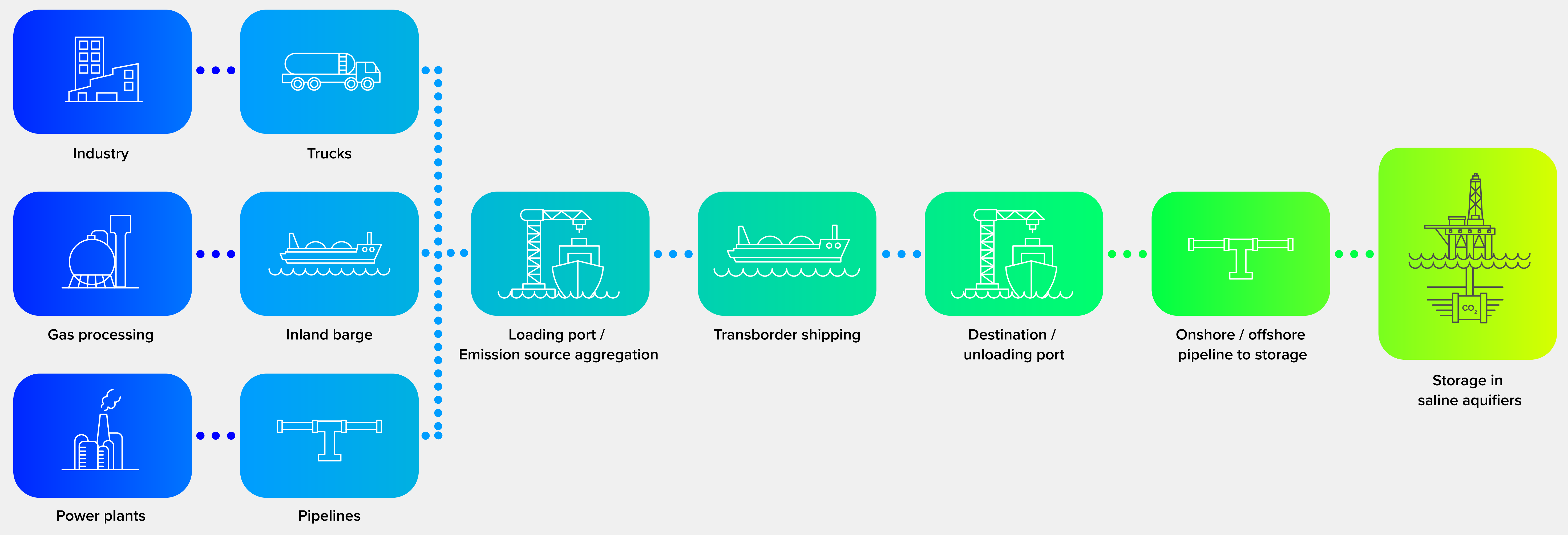
In Europe, projects considering pipeline, shipping or a combination of the two are increasing in number linking regional emissions sources to suitable storage. Several new networks such as the EU CCS Interconnector Project in northern Poland and the CCS Baltic Consortium in Lithuania are considering all modes of transport to bring CO_2 from emissions sources in each country to a suitable location.

Emission sources are expected to use all modes of transport spanning pipeline, truck, rail and inland barges to transport CO_2 to export terminals where it will be loaded onto ships. Ships will then transport the CO_2 either to the storage location or to other ports from which the final transport stage will be by pipeline (Figure 5.4–3 on the next page).

In China, transport by truck has been proven at the 1 Mtpa scale. As an example, the Sinopec Qilu Petrochemical CCS Project in the eastern Shandong province commenced capturing and storing 1 Mtpa is using trucking as the transport method in August 2022 prior to a pipeline being built. The pipeline has now been built and is operational as of July 2023. Whilst a more costly approach for a CCS project overall, it has enabled the project to quickly bring online capture and storage technology for evaluation before moving to pipeline transport for ongoing permanent operation.

As projects grow it is likely that all transport methods will be required to bring together CO_2 from emissions sources of all scales to suitable storage, be it through traditional vertical projects or large-scale regional networks.

Figure 5.4–3: Complex CO_2 transport system considering all transport modes



Transport safety

Recently, new CO_2 pipeline developments have been challenged due to concerns for public safety. Carbon dioxide is much safer to transport than many other substances because it does not form flammable or explosive mixtures with air. Further, CO_2 is not directly toxic to humans or wildlife when released to the atmosphere, except in the highly unlikely event that the release is catastrophic (very rapid and in extremely high quantities).

The safety record of CO_2 pipelines demonstrates that they can be operated with high standards of safety. Over the years, there have been only a few incidents, with the majority being minor releases of CO_2. As an example for the United State, the total amount of CO_2 released from these incidents averages less than 0.01% of the overall amount transported annually. However, a significant incident occurred at the Delhi Pipeline near Satartia, Mississippi in February 2020 due to a rupture caused by a landslide. While no fatalities occurred, residents were evacuated and some required medical attention.

In response to this incident, the Pipeline and Hazardous Materials Safety Administration (PHMSA) issued penalties and proposed updates to CO_2 pipeline standards. These steps are supported by industry groups and aim to strengthen safety measures. Despite occasional incidents, PHMSA's safety data show that CO_2 pipelines in the US can be operated safely using best practices.

Technology advancements

Technology developments in CO_2 transport have been predominantly in shipping with technology advancing rapidly. Mitsubishi Shipbuilding Company launched a 1,450 m^3 liquid CO_2 ship demonstrator in March 2023 to take part in demonstration trials shipping CO_2 to the Tomakomai CCS project in Japan. Other projects in development, such as Northern Lights in Norway, are scaling up with Dalian Shipbuilding Industry Co. Ltd contracted to build two medium pressure 7,500 m^3 vessels.

Other ship designs with capacities of up to 22,000 m^3 have been approved in principle such as for Dan-Unity CO_2 and TGE Marine. Larger designs have been conceived and designed by several ship manufacturers with details given in Table 2. Northern Lights expects delivery of their two medium pressure vessels in 2024, with other manufacturers indicating expected delivery of First in Class ships from 2025.

Figure 5.4–4: Announced liquid CO_2 ship designs and key characteristics

LCO_2 ship manufacturer (M) or CCS project (P)	Volume	Dimensions	Transportation conditions	Ship fuel
Daewoo Shipbuilding & Marine Engineering (M)	70,000 m^3	260 m x 44 m	Not reported	LNG
	40,000 m^3	Not reported	Not reported	Not reported
Dalian Shipbuilding Industry Co. Ltd (M) Northern Lights (P)	7,500 m^3	130 m length	14 barg, -28°C Medium P	LNG
Ecolog (M)	20,000 m^3	167 m x 28 m	8 barg, -55°C Low P	Not reported
	84,000 m^3	275 m x 48 m	8 barg, -55°C Low P	Not reported
Frisian Shipyard (M)	1,670 m^3 (1382 t)	79 m x 14 m	18 barg, between -22.5 and -40°C Medium P	Not reported
Hyundai Heavy Industries and Hyundai Glovis Co. (M)	74,000 m^3	284 m x 42 m	High pressure, low temperature High P	LNG
Hyundai Heavy Industries (M)	40,000 m^3	239 m x 30 m	Not reported (IMO Type C cargo tanks)	LNG
Larvik Shipping AS (M)	1,500 m^3 (1240 t)	80 m x 14 m	14 - 19 barg, -30°C Medium P	Not reported
	2,100 m^3 (1770 t)	83 m x 13 m	14 - 19 barg, -30°C Medium P	Not reported
Mitsubishi Shipbuilding (M) Tomakomai Demonstration Project on CO_2 Transportation (P)	1,450 m^3	72 m x 13 m	Not reported	Not reported
Mitsui O.S.K. Lines and Mitsubishi Heavy Industries (M)	50,000 m^3	Not reported	Not reported	Not reported
Stella Maris CCS (P)	50,000 m^3	238 m x 38 m	6.5 barg, -47°C Low P	LNG / Bio gas / NH_3
Stena Bulk (M)	8,000 m^3	130 m x 21 m	14 barg, -25°C Medium P	Methanol dual fuel
	10,940 m^3	162 m x 21 m	14 barg, -25°C Medium P	Methanol dual fuel
TGE Marine (M)	12,500 m^3	Not reported	Not reported	Not reported
	22,000 m^3	Not reported	Not reported	Not reported

5.5 MANAGING LONG-TERM LIABILITY

Liability for CCS operations continues to be raised by many parties as a critical issue for the deployment of CCS projects globally. While regulators and policymakers in several jurisdictions around the world have enacted regulatory frameworks that explicitly address the topic – in some instances over 15 years ago – the rapid pace of project deployment and absence of legislation in others has led to renewed focus and further intervention.

For some proponents the issue remains a critical consideration for investment in nascent projects, and several have cited the need for clarity as to the parameters for the long-term management of potential liabilities. Policymakers and regulators have been similarly challenged by the need to manage risks throughout the CCS project lifecycle. In addition to ensuring there is a practical model for addressing or remediating any harm caused by CCS activities, liability regimes may also ultimately play a significant role in reinforcing public confidence in the technology.

Defining what is meant by liability

Notwithstanding the strong interest in the topic, it is essential to ensure there is clarity when considering liability associated with CCS operations. A level of precision is required in defining the various forms of liability that are to be borne by all parties throughout the lifetime of a storage project. Clarity is essential for ensuring proponents are able to assess the magnitude of their exposure, as well as affording policymakers and regulators a means of offering targeted and practical approaches to delivering solutions.

The Institute has undertaken significant work in this space and previously noted the potentially broad range of liabilities that will be applicable throughout the CCS project lifecycle. A review of the various CCS-specific legal regimes developed to date reveals three largely distinct forms of liability.

The first, civil liability, refers to those liabilities that may occur where damage is caused by CCS operations to the interests of a third-party and compensation for that damage is sought. Termed 'tortious liability' in common law jurisdictions, these liabilities have been determined in legislation, or through principles developed under decisions of the courts.

A second category, administrative liability, stems from an authority's statutory powers, which may compel an operator to undertake a specified action. In the case of CCS operations, these liabilities may be borne by an operator under a CCS-specific license or permit, or under wider energy-related and environmental protection legislation.

The third category, greenhouse emissions/climate change liability, occurs where an operator is obliged to account for any subsequent leakage of CO_2, in instances where a credit has been previously awarded for permanent geological storage.

The impact of these individual forms of liability upon operators, however, will likely vary considerably when considered individually. As such, their allocation and management will require careful consideration by policymakers and regulators.

> Several jurisdictions globally have now developed comprehensive CCS-specific regimes, which include provisions aimed at managing the liabilities associated with the geological storage of CO_2 throughout the entirety of the project lifecycle.

National approaches to managing liability

Several jurisdictions globally have now developed comprehensive CCS-specific regimes, which include provisions aimed at managing the liabilities associated with the geological storage of CO_2 throughout the entirety of the project lifecycle. While many of these early regimes front-load their regulatory requirements, to reduce the risks of CCS operations, they also include provisions that formally channel liabilities to an operator in instances where storage may be compromised. Policymakers and regulators have created these operational models through the introduction of new provisions, as well as amendments to existing regimes.

In the EU, for example, the Storage Directive requires an operator to take preventative and remedial action in accordance with the Environmental Liability Directive. In other jurisdictions the current position is less clear, with regulators yet to address the topic in national frameworks. The absence of a clear approach consequently exposes industry, investors and the public to uncertainties around the management of these liabilities.

In the United States, where the federal regulator has a limited legal responsibility for addressing long-term liability, several states are now developing regimes for the management of liability following the cessation of injection activities. Some states have proposed models that afford extensive post-closure relief to operators, a move that has been met with consternation from some parties and positivity from others.

Critical considerations

Several early CCS-specific regimes offer the opportunity for operators to transfer liability for a storage site or stored CO_2 from the operator to a state's competent authority. Examples of this approach have been implemented in frameworks in Canada, Australia and under the European Union's CCS Directive.

Other policymakers and regulators are now also considering whether this approach should be adopted in their jurisdictions. While potentially an important factor in recognising the temporal challenges of liabilities and one that may encourage the wider deployment of a critical climate mitigation technology, it is important to ensure that the use of this mechanism does not abrogate an operator's wider responsibilities to risk management and the environment.

The approach to financial security, similarly, remains an important consideration for many governments when considering their management of liability. Successful examples demonstrate the importance of carefully balancing competing issues, to ensure that project deployment is not jeopardised. These examples model an approach where more financial/operational risks are carried by the operator during the operational phase of the project, when such risks can be better managed than during deployment, and away from the public purse.

5.6 STORAGE RESOURCE DEVELOPMENT PROGRESS

Historically, CCS facilities were vertically integrated, capturing CO_2 from a single facility and transporting and storing that CO_2 as part of a single chain. The first such facility utilising a dedicated geological storage resource, Equinor's Sleipner, has operated in the North Sea, Norway, since 1996. Vertically integrated facilities develop enough storage resources to match the required capture rate over the lifetime of a project.

However, disaggregated CCS value chains are rapidly emerging as a common structure for CCS projects in development. As discussed in Section 5.3, operators are now developing facilities focused solely on CO_2 transport and storage without a dedicated, integrated capture source, such as Equinor's Northern Lights.

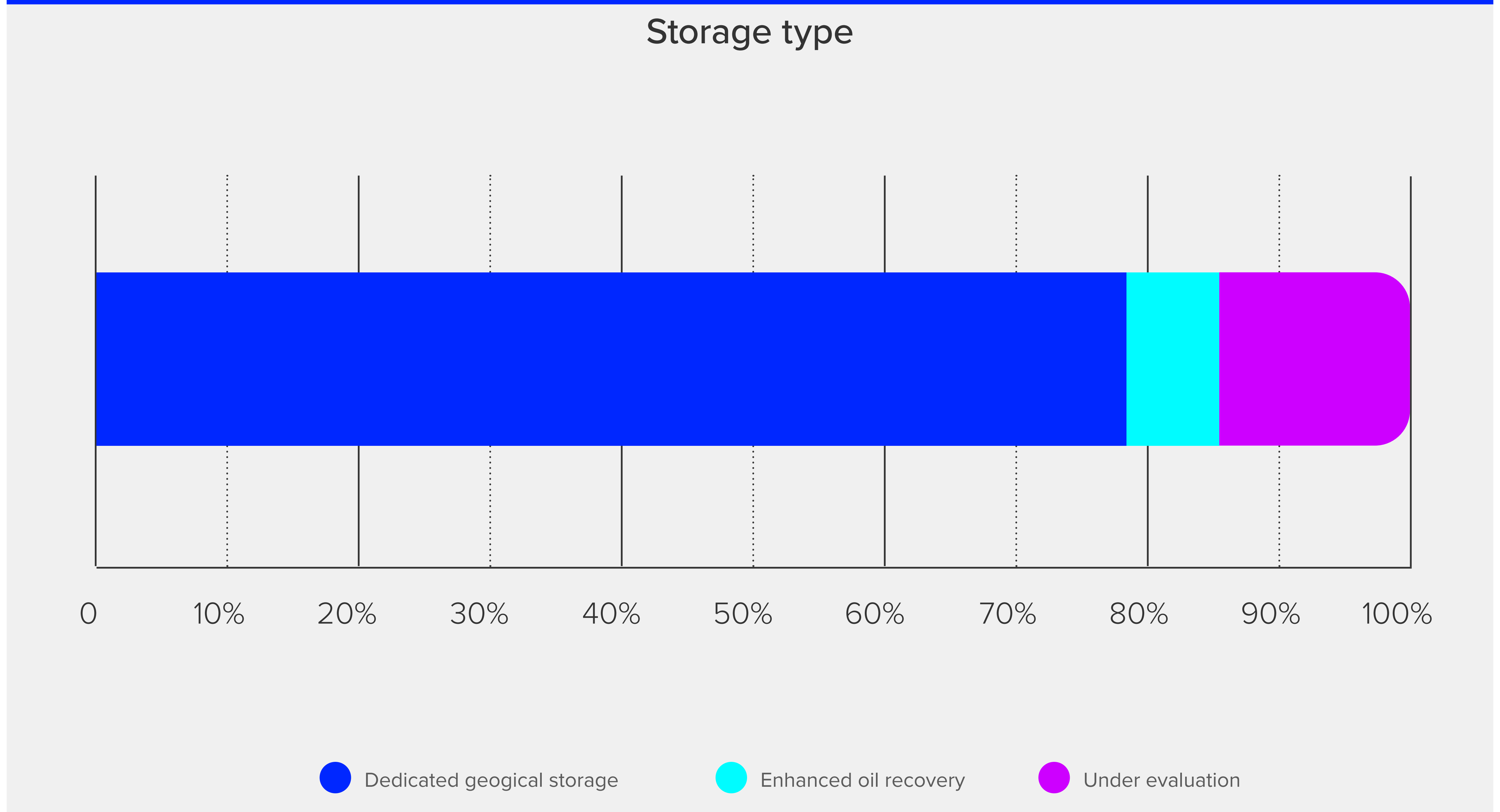
As of 31 July 2023, 101 CO_2 transport and storage facilities were operational or in the development pipeline. All but seven of these facilities were announced between 2020 and 2023. Almost all of these plan to connect into or establish CCS networks as they seek to receive CO_2 from multiple sources for transport and/or storage for a fee. More than 100 separate CCS networks are now in development. The rise of networks continues, now clearly driven by projects that plan to transport and/or store CO_2 for profit.

In addition to the rise of CCS networks, another clear trend is the development of dedicated geological storage resources as opposed to CO_2 storage through enhanced oil recovery; 78% of the total capacity of CCS facilities in development or in construction have stated they will use dedicated geological storage (15% of facilities by capacity have not yet announced if they will use dedicated geological storage or enhanced oil recovery).

This is significant for two reasons. The first is that it demonstrates that revenues from enhanced oil recovery are generally becoming less important to the commercial viability of CCS investments. The second is that developers of dedicated geological storage resources will seek to maximise their capacity to increase their economic value. This financial incentive is critical to drive increased rates of storage resource development.

Whilst the number of CCS projects and geological storage resources being developed has grown rapidly in recent years, it is clear that storage resource development must accelerate to help achieve net-zero emissions by mid-century.

Figure 5.6–1: Total capacity of CCS facilities in development, construction or operation by storage type



Projections of how much CO_2 must be geologically stored to achieve net zero emissions vary considerably depending upon the assumptions of the scenario or model. For example, the average total mass of CO_2 stored between 2020 and 2050, across the 90 scenarios considered in the IPCC Special Report on Global Warming of 1.5° Celsius exceeds 100 Gt (the annual CO_2 storage rate reaches 10 Gtpa in 2050). In comparison, if all the CCS facilities in the CCS project pipeline commenced operations on time and operated at full capacity, they could theoretically store a total of 12 Gt of CO_2 between now and 2050. The gap between the geological storage capacity in development and the geological storage capacity required to meet climate targets is an order of magnitude.

This simple analysis illustrates that the rate of geological storage resource development must accelerate rapidly to achieve net-zero targets.

It is important to note that total global geological storage capacity is not the limiting factor. The IPCC states that the world's total theoretical storage resource potential is conservatively estimated at 1,000 Gt of CO_2 – more than enough to meet the world's ambitious climate targets.

In order to ensure that storage resources are available for utilisation when required, more must be done to incentivise and bring forward investment in storage resource identification and appraisal. The development of sufficient geological storage resources to meet national net-zero emission targets should be a high priority for governments.

Like grid scale energy storage or transmission lines for renewable electricity, sufficient investment in this essential infrastructure to help meet net-zero commitments requires targeted polices and planning by governments.

Figure 5.6–2: Comparison of total mass of CO_2 required to be stored by 2050 with the maximum theoretical potential of the current CCS project pipeline

6.0
FACILITIES LIST

2023 FACILITIES LIST

Operational

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Occidental Terrell	USA	1972	Natural Gas Processing	0.5	Enhanced Oil Recovery
Enid Fertilizer	USA	1982	Hydrogen / Ammonia / Fertiliser	0.2	Enhanced Oil Recovery
ExxonMobil Shute Creek Gas	USA	1986	Natural Gas Processing	7	Enhanced Oil Recovery
MOL Szank Field	Hungary	1992	Natural Gas Processing	0.16	Enhanced Oil Recovery
Equinor Sleipner	Norway	1996	Natural Gas Processing	1	Dedicated Geological Storage
Great Plains Synfuels Plant and Weyburn-Midale	USA	2000	Hydrogen / Ammonia / Fertiliser	3	Enhanced Oil Recovery
Core Energy CO_2-EOR South Chester plant	USA	2003	Natural Gas Processing	0.35	Enhanced Oil Recovery
Equinor Snohvit	Norway	2008	Natural Gas Processing	0.7	Dedicated Geological Storage
Petrobras Santos Basin Pre-Salt Oil Field	Brazil	2008	Natural Gas Processing	10.6	Enhanced Oil Recovery
Arkalon CO_2 Compression Facility	USA	2009	Ethanol	0.5	Enhanced Oil Recovery
Longfellow WTO Century Plant	USA	2010	Natural Gas Processing	5	Enhanced Oil Recovery
Gary Climate Solutions Bonanza BioEnergy	USA	2012	Ethanol	0.1	Enhanced Oil Recovery
Yanchang Integrated Demonstration	China	2012	Chemical	0.05	Enhanced Oil Recovery
Air Products and Chemicals Valero Port Arthur Refinery	USA	2013	Hydrogen / Ammonia / Fertiliser	0.9	Enhanced Oil Recovery
Contango Lost Cabin Gas Plant	USA	2013	Natural Gas Processing	0.9	Enhanced Oil Recovery
Coffeyville Gasification Plant	USA	2013	Hydrogen / Ammonia / Fertiliser	0.9	Enhanced Oil Recovery
PCS Nitrogen Geismar Plant	USA	2013	Hydrogen / Ammonia / Fertiliser	0.3	Enhanced Oil Recovery
SaskPower Boundary Dam	Canada	2014	Power Generation and Heat	1	Enhanced Oil Recovery
Saudi Aramco Uthmaniyah	Saudi Arabia	2015	Natural Gas Processing	0.8	Enhanced Oil Recovery
Shell Quest	Canada	2015	Hydrogen / Ammonia / Fertiliser	1.3	Dedicated Geological Storage

Operational

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Xinjiang Dunhua Karamay	China	2015	Chemical	0.1	Enhanced Oil Recovery
ADNOC Al-Reyadah	United Arab Emirates	2016	Iron and Steel Production	0.8	Enhanced Oil Recovery
ADM Illinois Industrial	USA	2017	Ethanol	1	Dedicated Geological Storage
CNPC Jilin Oil Field	China	2018	Natural Gas Processing	0.6	Enhanced Oil Recovery
Chevron Gorgon	Australia	2019	Natural Gas Processing	4	Dedicated Geological Storage
Qatargas Qatar LNG	Qatar	2019	Natural Gas Processing	2.2	Dedicated Geological Storage
Enhance Clive Oil Field	Canada	2020	CO_2 Transport / Storage	1.12	Enhanced Oil Recovery
NWR Sturgeon Refinery	Canada	2020	Oil Refining	1.6	Enhanced Oil Recovery
WCS Redwater	Canada	2020	Hydrogen / Ammonia / Fertiliser	0.3	Enhanced Oil Recovery
Wolf Alberta Carbon Trunk Line	Canada	2020	CO_2 Transport / Storage	14.6	Enhanced Oil Recovery
China National Energy Guohua Jinjie	China	2021	Power Generation and Heat	0.15	Dedicated Geological Storage
Climeworks Orca	Iceland	2021	Direct Air Capture	0.004	Dedicated Geological Storage
Sinopec Nanjing Chemical	China	2021	Chemical	0.2	Enhanced Oil Recovery
Yangchang Yan'an CO_2-EOR	China	2021	Chemical	0.1	Enhanced Oil Recovery
Entropy Glacier Gas Plant	Canada	2022	Natural Gas Processing	0.2	Dedicated Geological Storage
Red Trail Energy Richardton Ethanol	USA	2022	Ethanol	0.18	Dedicated Geological Storage
Sinopec Qilu-Shengli	China	2022	Chemical	1	Enhanced Oil Recovery
Yangchang Yulin CO_2-EOR	China	2022	Chemical	0.3	Dedicated Geological Storage
China National Energy Taizhou	China	2023	Power Generation and Heat	0.5	Enhanced Oil Recovery
CNOOC Enping	China	2023	Natural Gas Processing	0.3	Dedicated Geological Storage
Sinopec Jinling Petrochemical (Nanjing Refinery)	China	2023	Oil Refining	0.3	Enhanced Oil Recovery

In construction

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Guanghui Energy Methanol Plant	China	2023	Chemical	0.1	Enhanced Oil Recovery
Targa Red Hills natural gas processing complex	USA	2023	Natural Gas Processing	0.36	Dedicated Geological Storage
44.01 Project Hajar	Oman	2024	Direct Air Capture	Under Evaluation	Dedicated Geological Storage
Air Product Blue But Better	Canada	2024	Hydrogen / Ammonia / Fertiliser	3	Enhanced Oil Recovery
Hafslund Oslo Celsio Waste-to-Energy Plant	Norway	2024	Biomass to Power and Heat	0.4	Dedicated Geological Storage
Heidelberg Materials Brevik Cement Plant	Norway	2024	Cement	0.4	Dedicated Geological Storage
Northern Lights Transport and Storage	Norway	2024	CO_2 Transport / Storage	1.5	Dedicated Geological Storage
Shell Energy and Chemicals Park Rotterdam	Netherlands	2024	Biomass to Power and Heat	0.38	Dedicated Geological Storage
CarbFix Mammoth	Iceland	2024	Direct Air Capture	0.03	Dedicated Geological Storage
China National Energy Ningxia	China	2024	Chemical	3	Enhanced Oil Recovery
Santos Cooper Basin	Australia	2024	Natural Gas Processing	1.7	Dedicated Geological Storage
OCI Iowa Fertiliser Company	USA	2025	Hydrogen / Ammonia / Fertiliser	0.45	Dedicated Geological Storage
CF Industries Donaldsonville	USA	2025	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
Huaneng Longdong Energy Base	China	2025	Power Generation and Heat	1.5	Dedicated Geological Storage
Linde Beaumont hydrogen plant	USA	2025	Hydrogen / Ammonia / Fertiliser	2.2	Dedicated Geological Storage
Petronas Kasawari	Malaysia	2025	Natural Gas Processing	3.3	Dedicated Geological Storage
Qatar Petroleum North Field East	Qatar	2025	Natural Gas Processing	2.1	Under Evaluation
Silverstone	Iceland	2025	Power Generation and Heat	0.03	Dedicated Geological Storage
STRATOS (1PointFive Direct Air Capture)	USA	2025	Direct Air Capture	0.5	Dedicated Geological Storage
Air Products and Chemical Louisiana Clean Energy Complex	USA	2026	Hydrogen / Ammonia / Fertiliser	5	Dedicated Geological Storage
QAFCO Ammonia-7 Blue Ammonia Facility	Qatar	2026	Hydrogen / Ammonia / Fertiliser	1.5	Dedicated Geological Storage
CapturePoint Solutions Central Louisiana Regional Carbon Storage (CENLA) Hub	USA	2027	CO_2 Transport / Storage	10	Dedicated Geological Storage
Energy Transfer Haynesville Gas Processing (CENLA Hub)	USA	2027	Natural Gas Processing	Under Evaluation	Dedicated Geological Storage
Baotou Steel	China	Under Evaluation	Iron and Steel Production	0.5	Dedicated Geological Storage
Xinjiang Jinlong Shenwu	China	Under Evaluation	Power Generation and Heat	0.2	Enhanced Oil Recovery
Yulin Integrated Coal-to-Liquification	China	Under Evaluation	Chemical	4	Enhanced Oil Recovery

Advanced development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Bridgeport Energy Moonie	Australia	2024	CO_2 Transport / Storage	0.2	Enhanced Oil Recovery
HeidelbergCement	USA	2024	Cement	2	Dedicated Geological Storage
Aemetis Keyes Ethanol	USA	2024	Ethanol	0.4	Dedicated Geological Storage
Air Liquide Refinery Rotterdam	Netherlands	2024	Hydrogen / Ammonia / Fertiliser	0.5	Dedicated Geological Storage
Bushmills Biorefinery	USA	2024	Ethanol	0.24	Dedicated Geological Storage
ExxonMobil Benelux Refinery	Netherlands	2024	Hydrogen / Ammonia / Fertiliser	Under Evaluation	Dedicated Geological Storage
FCL Regina Refinery	Canada	2024	Oil Refining	0.25	Dedicated Geological Storage
Horisont Energi Polaris Carbon Storage	Norway	2024	CO_2 Transport / Storage	2	Dedicated Geological Storage
Summit Aberdeen Biorefinery	USA	2024	Ethanol	0.14	Dedicated Geological Storage
Summit Atkinson Biorefinery	USA	2024	Ethanol	0.16	Dedicated Geological Storage
Summit Casselton Biorefinery	USA	2024	Ethanol	0.5	Dedicated Geological Storage
Summit Central City Biorefinery	USA	2024	Ethanol	0.33	Dedicated Geological Storage
Summit Fairmont Biorefinery	USA	2024	Ethanol	0.34	Dedicated Geological Storage
Summit Galva Biorefinery	USA	2024	Ethanol	0.11	Dedicated Geological Storage
Summit Goldfield Biorefinery	USA	2024	Ethanol	0.22	Dedicated Geological Storage
Summit Grand Junction Biorefinery	USA	2024	Ethanol	0.34	Dedicated Geological Storage
Summit Granite Falls Biorefinery	USA	2024	Ethanol	0.18	Dedicated Geological Storage
Summit Heron Lake Biorefinery	USA	2024	Ethanol	0.19	Dedicated Geological Storage
Summit Huron Biorefinery	USA	2024	Ethanol	0.09	Dedicated Geological Storage
Summit Lamberton Biorefinery	USA	2024	Ethanol	0.16	Dedicated Geological Storage
Summit Lawler Biorefinery	USA	2024	Ethanol	0.57	Dedicated Geological Storage
Summit Madison Biorefinery	USA	2024	Ethanol	0.25	Dedicated Geological Storage
Summit Marcus Biorefinery	USA	2024	Ethanol	0.46	Dedicated Geological Storage
Summit Mason City Biorefinery	USA	2024	Ethanol	0.34	Dedicated Geological Storage
Summit Merrill Biorefinery	USA	2024	Ethanol	0.16	Dedicated Geological Storage
Summit Mid West Express Storage	USA	2024	CO_2 Transport / Storage	12	Dedicated Geological Storage

Advanced development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Summit Mid West Express Trunk Pipeline	USA	2024	CO_2 Transport / Storage	20	Dedicated Geological Storage
Summit Mina Biorefinery	USA	2024	Ethanol	0.4	Dedicated Geological Storage
Summit Mount Vernon Biorefinery	USA	2024	Ethanol	0.25	Dedicated Geological Storage
Summit Nevada Biorefinery	USA	2024	Ethanol	0.26	Dedicated Geological Storage
Venture Global LNG CP2	USA	2024	Natural Gas Processing	0.5	Dedicated Geological Storage
Summit Norfolk Biorefinery	USA	2024	Ethanol	0.15	Dedicated Geological Storage
Summit Obion Biorefinery	USA	2024	Ethanol	0.34	Dedicated Geological Storage
Summit Onida Biorefinery	USA	2024	Ethanol	0.23	Dedicated Geological Storage
Summit Otter Tail Biorefinery	USA	2024	Ethanol	0.17	Dedicated Geological Storage
Summit Plainview Biorefinery	USA	2024	Ethanol	0.32	Dedicated Geological Storage
Summit Redfield Biorefinery	USA	2024	Ethanol	0.17	Dedicated Geological Storage
Summit Shenandoah Biorefinery	USA	2024	Ethanol	0.24	Dedicated Geological Storage
Summit Sioux Center Biorefinery	USA	2024	Ethanol	0.19	Dedicated Geological Storage
Summit Steamboat Rock Biorefinery	USA	2024	Ethanol	0.23	Dedicated Geological Storage
Summit Superior Biorefinery	USA	2024	Ethanol	0.17	Dedicated Geological Storage
Summit Watertown Biorefinery	USA	2024	Ethanol	0.37	Dedicated Geological Storage
Summit Wentworth Biorefinery	USA	2024	Ethanol	0.26	Dedicated Geological Storage
Summit Wood River Biorefinery	USA	2024	Ethanol	0.35	Dedicated Geological Storage
Summit York Biorefinery	USA	2024	Ethanol	0.14	Dedicated Geological Storage
Whitecap Resources Southeast Saskatchewan Hub	Canada	2024	CO_2 Transport / Storage	2.5	Dedicated Geological Storage
8 Rivers Coyote Clean Power	USA	2025	Power Generation and Heat	0.86	Under Evaluation
ADNOC Ghasha Concession Fields	United Arab Emirates	2025	Natural Gas Processing	Under Evaluation	Dedicated Geological Storage
ADNOC Natural gas processing plant	United Arab Emirates	2025	Natural Gas Processing	2.3	Enhanced Oil Recovery
G2 Net-Zero	USA	2025	Natural Gas Processing	4	Under Evaluation
Gerald Gentleman Station	USA	2025	Power Generation and Heat	4.3	Enhanced Oil Recovery
Golden Spread Electric Mustang Station	USA	2025	Power Generation and Heat	1.5	Dedicated Geological Storage

Advanced development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Lake Charles Methanol	USA	2025	Chemical	4	Dedicated Geological Storage
One Earth Energy Ethanol	USA	2025	Ethanol	0.5	Dedicated Geological Storage
Sinopec Shengli Power Plant	China	2025	Power Generation and Heat	1	Enhanced Oil Recovery
Amager Bakke Waste to Energy	Denmark	2025	Biomass to Power and Heat	0.5	Dedicated Geological Storage
East Coast Cluster Humber Pipeline	United Kingdom	2025	CO_2 Transport / Storage	17	Dedicated Geological Storage
East Coast Cluster Teesside Pipeline	United Kingdom	2025	CO_2 Transport / Storage	10	Dedicated Geological Storage
Hafslund Oslo Celsio - Truck Route	Norway	2025	CO_2 Transport / Storage	0.4	Dedicated Geological Storage
LafargeHolcim Cement	USA	2025	Cement	1.6	Under Evaluation
Northern Endurance Storage Site	United Kingdom	2025	CO_2 Transport / Storage	27	Dedicated Geological Storage
Orsted Asnaes CHP Plant	Denmark	2025	Power Generation and Heat	0.2	Under Evaluation
Orsted Avedore CHP Plant	Denmark	2025	Power Generation and Heat	0.2	Under Evaluation
Pilot Energy Cliff Head (Mid West Clean Energy)	Australia	2025	CO_2 Transport / Storage	3	Dedicated Geological Storage
Project Greensand	Denmark	2025	CO_2 Transport / Storage	8	Dedicated Geological Storage
Shell Polaris (Scotford Complex)	Canada	2025	Hydrogen / Ammonia / Fertiliser	0.75	Dedicated Geological Storage
Wolf Lamont Carbon Hub	Canada	2025	CO_2 Transport / Storage	4	Dedicated Geological Storage
Yara Sluiskil	Netherlands	2025	Hydrogen / Ammonia / Fertiliser	0.8	Dedicated Geological Storage
BP Tangguh LNG	Indonesia	2026	Natural Gas Processing	3	Enhanced Oil Recovery
Minnkota Power Project Tundra	USA	2026	Power Generation and Heat	4	Dedicated Geological Storage
Project Interseqt - Hereford Ethanol Plant	USA	2026	Ethanol	0.35	Enhanced Oil Recovery
Project Interseqt - Plainview Ethanol Plant	USA	2026	Ethanol	0.35	Enhanced Oil Recovery
PTTEP Lang Lebah	Malaysia	2026	Natural Gas Processing	Under Evaluation	Dedicated Geological Storage
Repsol Sakakemang	Indonesia	2026	Natural Gas Processing	2	Dedicated Geological Storage
Capital Power Genesee CCS	Canada	2026	Power Generation and Heat	3	Dedicated Geological Storage
CarbFix CODA Transport and Storage	Iceland	2026	CO_2 Transport / Storage	0.3	Dedicated Geological Storage
Chevron Bayou Bend	USA	2026	CO_2 Transport / Storage	20	Dedicated Geological Storage
Porthos CO_2 Transport and Storage	Netherlands	2026	CO_2 Transport / Storage	2.5	Dedicated Geological Storage

Advanced development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Wabash Valley Resources West Terre Haute fertilizer plant	USA	2026	Hydrogen / Ammonia / Fertiliser	1.65	Dedicated Geological Storage
Vertex HyNet Hydrogen	United Kingdom	2026	Hydrogen / Ammonia / Fertiliser	1.8	Dedicated Geological Storage
Cal Capture	USA	2027	Power Generation and Heat	1.55	Dedicated Geological Storage
St. Charles Clean Fuels Hydrogen Louisiana	USA	2027	Hydrogen / Ammonia / Fertiliser	Under Evaluation	Under Evaluation
BOC Teesside Hydrogen	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	0.2	Dedicated Geological Storage
Drax BECCS	United Kingdom	2027	Power Generation and Heat	8	Dedicated Geological Storage
ExxonMobil Baytown Low Carbon Hydrogen	USA	2027	Hydrogen / Ammonia / Fertiliser	7	Dedicated Geological Storage
FCL Belle Plaine Ethanol Complex	Canada	2027	Ethanol	0.25	Enhanced Oil Recovery
Harbour Energy Viking Transport and Storage	United Kingdom	2027	CO_2 Transport / Storage	8	Dedicated Geological Storage
Hydrogen to Humber Saltend	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	0.89	Dedicated Geological Storage
Phillips 66 Humber Refinery	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	0.5	Dedicated Geological Storage
Santos Bayu-Undan	Timor-Leste	2027	Natural Gas Processing	10	Dedicated Geological Storage
Saudi Aramco Jubail Hub	Saudi Arabia	2027	Natural Gas Processing	9	Dedicated Geological Storage
SSE Thermal Keadby 3 Power Station	United Kingdom	2027	Power Generation and Heat	2.6	Dedicated Geological Storage
Stockholm Exergi BECCS	Sweden	2027	Biomass to Power and Heat	0.8	Dedicated Geological Storage
Stockholm Exergi BECCS Shipping Route	Sweden	2027	CO_2 Transport / Storage	0.8	Dedicated Geological Storage
VPI Immingham Power Plant	United Kingdom	2027	Power Generation and Heat	7.1	Dedicated Geological Storage
Yara Hydrogen Texas	USA	2027	Hydrogen / Ammonia / Fertiliser	Under Evaluation	Dedicated Geological Storage
Cleco Diamond Vault	USA	2028	Power Generation and Heat	4	Dedicated Geological Storage
Heidelberg Materials Padeswood Cement	United Kingdom	2028	Cement	0.8	Dedicated Geological Storage
Prax Lindsey Carbon Capture (PLCCP)	United Kingdom	2028	Oil Refining	1	Dedicated Geological Storage
GE James M. Barry Electric Generating Plant	USA	2030	Power Generation and Heat	0.6	Under Evaluation
BASF Antwerp (Kairos@C)	Belgium	2030	Chemical	1.42	Dedicated Geological Storage
Pathways Alliance Oil Sands Pathways to Net Zero	Canada	2030	CO_2 Transport / Storage	12	Dedicated Geological Storage
ION Polk Power Station	USA	2040	Power Generation and Heat	3.7	Dedicated Geological Storage
Calpine Baytown Energy Center	USA	Under Evaluation	Power Generation and Heat	2.5	Dedicated Geological Storage

Advanced development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Calpine Project Delta	USA	Under Evaluation	Power Generation and Heat	2.36	Dedicated Geological Storage
CPV Shay Energy Center (CPV West Virginia Natural Gas Power Station)	USA	Under Evaluation	Power Generation and Heat	Under Evaluation	Under Evaluation
EPRI Cane Run	USA	Under Evaluation	Power Generation and Heat	1.7	Dedicated Geological Storage
LafargeHolcim Ste. Genevieve Cement Plant	USA	Under Evaluation	Cement	2.9	Under Evaluation
Pertamina Jatibarang	Indonesia	Under Evaluation	Natural Gas Processing	Under Evaluation	Enhanced Oil Recovery
Prairie State Generating Station	USA	Under Evaluation	Power Generation and Heat	7.6	Dedicated Geological Storage
PTTEP Arthit	Thailand	Under Evaluation	Natural Gas Processing	1	Dedicated Geological Storage
Southern Company Farley DAC	USA	Under Evaluation	Direct Air Capture	0.005	Under Evaluation
Southern Company Plant Daniel Carbon Capture	USA	Under Evaluation	Power Generation and Heat	1.8	Dedicated Geological Storage
Calpine Texas Deer Park Energy Centre	USA	Under Evaluation	Power Generation and Heat	5	Dedicated Geological Storage
CRC Elk Hills Power	USA	Under Evaluation	Power Generation and Heat	1.4	Dedicated Geological Storage
Northern Plains Nitrogen Grand Forks Blue Ammonia	USA	Under Evaluation	Natural Gas Processing	0.5	Dedicated Geological Storage
NuGen Ethanol Plant	USA	Under Evaluation	Ethanol	0.45	Dedicated Geological Storage
Sumitomo Hydrogen Energy Supply Chain (HESC)	Australia	Under Evaluation	Hydrogen / Ammonia / Fertiliser	5	Dedicated Geological Storage
Venture Global LNG Calcasieu Pass	USA	Under Evaluation	Natural Gas Processing	0.5	Dedicated Geological Storage
Venture Global LNG Plaquemines	USA	Under Evaluation	Natural Gas Processing	0.5	Dedicated Geological Storage
Victorian Government CarbonNet	Australia	Under Evaluation	CO_2 Transport / Storage	5	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Harvestone Blue Flint Ethanol	USA	2024	Ethanol	0.2	Dedicated Geological Storage
CF Fertilisers Billingham Ammonia CCS	United Kingdom	2024	Hydrogen / Ammonia / Fertiliser	Under Evaluation	Under Evaluation
DUC Bifrost	Denmark	2024	CO_2 Transport / Storage	3	Dedicated Geological Storage
Singleton Birch ZerCaL250	United Kingdom	2024	Cement	Under Evaluation	Dedicated Geological Storage
Aemetis Riverbank Ethanol	USA	2024	Ethanol	0.4	Dedicated Geological Storage
Equinor Hydrogen 2 Magnum	Netherlands	2024	Power Generation and Heat	2	Dedicated Geological Storage
Imperial Oil Strathcona refinery	Canada	2024	Hydrogen / Ammonia / Fertiliser	0.5	Under Evaluation
Frontier Carbon Solutions Holdings Sweetwater Carbon Storage Hub	USA	2024	CO_2 Transport / Storage	2	Dedicated Geological Storage
Gulf Cryo MEG Plant	Saudi Arabia	2024	Chemical	Under Evaluation	Under Evaluation
Storegga Acorn Transport and Storage	United Kingdom	2024	CO_2 Transport / Storage	5	Dedicated Geological Storage
Tarmac Buxton Lime Net Zero	United Kingdom	2024	Cement	0.02	Dedicated Geological Storage
Wolf Central Storage Hub Edmonton	Canada	2024	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Tallgrass Energy Eastern Wyoming Sequestration Hub	USA	2024	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
8 Rivers Capital Saskatchewan NET Power Plant	Canada	2025	Power Generation and Heat	0.95	Dedicated Geological Storage
Adams Fork Energy Clean Ammonia	USA	2025	Hydrogen / Ammonia / Fertiliser	2.9	Dedicated Geological Storage
ADNOC TA'ZIZ Blue Ammonia	United Arab Emirates	2025	Hydrogen / Ammonia / Fertiliser	0.8	Under Evaluation
Basin Electric Dry Fork	USA	2025	Power Generation and Heat	3	Dedicated Geological Storage
ADM Cedar Rapids	USA	2025	Ethanol	Under Evaluation	Dedicated Geological Storage
ADM Clinton	USA	2025	Ethanol	Under Evaluation	Dedicated Geological Storage
Air Liquide Normandy	France	2025	Hydrogen / Ammonia / Fertiliser	0.6	Dedicated Geological Storage
Aker BP Poseidon	Norway	2025	CO_2 Transport / Storage	8	Dedicated Geological Storage
Bison Meadowbrook Storage Hub	Canada	2025	CO_2 Transport / Storage	3	Dedicated Geological Storage
Cadent Hydrogen Production	United Kingdom	2025	Hydrogen / Ammonia / Fertiliser	3	Dedicated Geological Storage
Cadent Hynet CO_2 Transport and Storage	United Kingdom	2025	CO_2 Transport / Storage	4.5	Dedicated Geological Storage
Clean Energy Systems Carbon Negative Energy Plant - Central Valley	USA	2025	Power Generation and Heat	0.32	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Clean Energy Systems Mendota BECCS	USA	2025	Biomass to Power and Heat	0.3	Dedicated Geological Storage
CNPC Junggar Basin Hub	China	2025	CO_2 Transport / Storage	1.5	Enhanced Oil Recovery
CNPC Songliao Basin Hub	China	2025	Chemical	3	Under Evaluation
CRC Carbon TerraVault I	USA	2025	CO_2 Transport / Storage	1.24	Dedicated Geological Storage
Denbury Leo Sequestration Site	USA	2025	CO_2 Transport / Storage	10	Dedicated Geological Storage
Energean Prinos Sigma plant	Greece	2025	Natural Gas Processing	1	Dedicated Geological Storage
Energean Prinos Transport and Storage	Greece	2025	CO_2 Transport / Storage	3	Dedicated Geological Storage
Equinor North Sea Pipeline Zeebrugge	Belgium	2025	CO_2 Transport / Storage	40	Dedicated Geological Storage
ExxonMobil South East Australia Carbon Capture Hub	Australia	2025	Natural Gas Processing	2	Dedicated Geological Storage
Holcim Milaki Plant	Greece	2025	Cement	1	Dedicated Geological Storage
Horisont Energi AS Barents Blue	Norway	2025	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
INEOS Greenport Scandinavia	Denmark	2025	Biomass to Power and Heat	1.5	Dedicated Geological Storage
Liberty CCUS hub	USA	2025	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Lone Cypress Hydrogen	USA	2025	Hydrogen / Ammonia / Fertiliser	0.1	Under Evaluation
Mitsui Mid West Modern Energy Hub	Australia	2025	Hydrogen / Ammonia / Fertiliser	Under Evaluation	Dedicated Geological Storage
Navigator Heartland Greenway CO_2 Transport and Storage	USA	2025	CO_2 Transport / Storage	15	Dedicated Geological Storage
NET Power Plant	United Kingdom	2025	Power Generation and Heat	Under Evaluation	Under Evaluation
Net Zero Teesside - CCGT Facility	United Kingdom	2025	Power Generation and Heat	2	Dedicated Geological Storage
Pembina Alberta Carbon Grid	Canada	2025	CO_2 Transport / Storage	20	Dedicated Geological Storage
Poet Arthur, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
KEPCO Korea-CCS 1 & 2	South Korea	2025	Power Generation and Heat	1	Dedicated Geological Storage
Poet Ashton, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Big Stone, SD	USA	2025	Ethanol	0.28	Dedicated Geological Storage
KNOC Donghae	South Korea	2025	CO_2 Transport / Storage	1.2	Dedicated Geological Storage
Poet Chancellor, SD	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Coon Rapids, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Lehigh Cement Plant	Canada	2025	Cement	0.78	Under Evaluation

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Poet Corning, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Emmetsburg, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Fairbank, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Fairmont, NE	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Gowrie, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Groton, SD	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Hanlontown, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Hudson, SD	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Iowa Falls, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Jewell, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
NextDecade Rio Grande LNG	USA	2025	Natural Gas Processing	5.5	Dedicated Geological Storage
Poet Menlo, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Mitchell, SD	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Poet Shell Rock, IA	USA	2025	Ethanol	0.28	Dedicated Geological Storage
Preem Lysekil Refinery	Sweden	2025	Hydrogen / Ammonia / Fertiliser	0.5	Dedicated Geological Storage
Progressive Energy Vertex Hydrogen	United Kingdom	2025	Oil Refining	1.8	Dedicated Geological Storage
Redcar Energy Centre	United Kingdom	2025	Biomass to Power and Heat	0.4	Under Evaluation
PacifiCorp Dave Johnston Plant	USA	2025	Power Generation and Heat	Under Evaluation	Enhanced Oil Recovery
PAU Central Sulawesi Clean Fuel Ammonia	Indonesia	2025	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
Pieridae Energy Caroline Power	Canada	2025	Power Generation and Heat	3	Dedicated Geological Storage
Shell Atlas Carbon Storage Hub	Canada	2025	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Storegga Acorn Hydrogen	United Kingdom	2025	Hydrogen / Ammonia / Fertiliser	0.4	Dedicated Geological Storage
Wolf Mt. Simon Hub (Iowa Illinois Carbon Pipeline)	USA	2025	CO_2 Transport / Storage	12	Dedicated Geological Storage
Starwood Energy Power Plant	USA	2025	Power Generation and Heat	Under Evaluation	Enhanced Oil Recovery
The Illinois Clean Fuels	USA	2025	Chemical	8.13	Dedicated Geological Storage
1PointFive Bluebonnet Hub	USA	2026	CO_2 Transport / Storage	8	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Beach Energy Otway Natural Gas Plant	Australia	2026	Natural Gas Processing	0.2	Dedicated Geological Storage
Acorn Direct Air Capture	United Kingdom	2026	Direct Air Capture	1	Dedicated Geological Storage
Air Liquide Zeeland Refinery Azur	Netherlands	2026	Hydrogen / Ammonia / Fertiliser	0.8	Under Evaluation
Carbon Clean CEMEX	Germany	2026	Cement	0.03	Under Evaluation
Cinfracap Transport	Sweden	2026	CO_2 Transport / Storage	4	Dedicated Geological Storage
Denbury Orion Sequestration Site	USA	2026	CO_2 Transport / Storage	10	Dedicated Geological Storage
Enbridge Open Access Wabamun Carbon Hub	Canada	2026	CO_2 Transport / Storage	4	Dedicated Geological Storage
Enhance Energy Origins Carbon Storage Hub	Canada	2026	CO_2 Transport / Storage	20	Dedicated Geological Storage
ENI Structures A&E	Libya	2026	Natural Gas Processing	Under Evaluation	Dedicated Geological Storage
Fidelis Norne Carbon Storage Hub	Denmark	2026	CO_2 Transport / Storage	10	Dedicated Geological Storage
FREVAR Waste to Energy	Norway	2026	Biomass to Power and Heat	0.06	Dedicated Geological Storage
Höegh LNG Stella Maris	Under Evaluation	2026	CO_2 Transport / Storage	10	Under Evaluation
Horisont Energi Errai	Norway	2026	CO_2 Transport / Storage	8	Dedicated Geological Storage
INPEX CCS Darwin	Australia	2026	Natural Gas Processing	2	Dedicated Geological Storage
Kvitebjørn Varme Kvitebjørn Waste to Energy	Norway	2026	Biomass to Power and Heat	0.06	Dedicated Geological Storage
Neptune Energy L10	Netherlands	2026	CO_2 Transport / Storage	9	Dedicated Geological Storage
KeyState Natural Gas Synthesis	USA	2026	Natural Gas Processing	0.3	Dedicated Geological Storage
Lapis Energy El Dorado	USA	2026	Hydrogen / Ammonia / Fertiliser	0.45	Dedicated Geological Storage
Port of Rotterdam Delta Corridor Pipeline Network	Netherlands	2026	CO_2 Transport / Storage	22	Dedicated Geological Storage
Nucor Steel DRI	USA	2026	Iron and Steel Production	0.8	Under Evaluation
SUEZ Tees Valley Energy Recovery Facility (TVERF)	United Kingdom	2026	Biomass to Power and Heat	Under Evaluation	Dedicated Geological Storage
Synergia Energy Damhead Pipeline	United Kingdom	2026	CO_2 Transport / Storage	7.6	Dedicated Geological Storage
Synergia Energy Damhead Power Station	United Kingdom	2026	Power Generation and Heat	Under Evaluation	Dedicated Geological Storage
Synergia Energy Grain Power Station	United Kingdom	2026	Power Generation and Heat	Under Evaluation	Dedicated Geological Storage
Synergia Energy Isle of Grain Transport	United Kingdom	2026	CO_2 Transport / Storage	1.2	Dedicated Geological Storage
Synergia Energy Medway Transport and Storage	United Kingdom	2026	CO_2 Transport / Storage	7.6	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Talos Coastal Bend	USA	2026	CO_2 Transport / Storage	1.5	Dedicated Geological Storage
Talos Harvest Bend Louisiana Transport and Storage	USA	2026	CO_2 Transport / Storage	5	Dedicated Geological Storage
Whitecap Resources Rolling Hills Hub	Canada	2026	CO_2 Transport / Storage	2	Dedicated Geological Storage
Yosemite Hydrogen Project	USA	2026	Hydrogen / Ammonia / Fertiliser	4	Dedicated Geological Storage
Velocys Bayou Fuels Negative Emission	USA	2026	Chemical	1.5	Dedicated Geological Storage
Aramis Hub	Netherlands	2027	CO_2 Transport / Storage	5	Dedicated Geological Storage
BP H2Teesside	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
Clean Energy Systems BiCRS Plant - Madera County	USA	2027	Power Generation and Heat	0.6	Dedicated Geological Storage
Clean Hydrogen Works Ascension Clean Energy	USA	2027	Hydrogen / Ammonia / Fertiliser	6	Dedicated Geological Storage
ENI Ravenna Hub	Italy	2027	CO_2 Transport / Storage	4	Dedicated Geological Storage
Fluxys Ghent Carbon Hub	Netherlands	2027	CO_2 Transport / Storage	6	Dedicated Geological Storage
Grannus Blue	USA	2027	Hydrogen / Ammonia / Fertiliser	0.37	Under Evaluation
Kellas Midstream H2NorthEast	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
Lafarge Cement GO4ECOPLANET	Poland	2027	Cement	1	Dedicated Geological Storage
Novatek Yamal LNG	Russia	2027	Natural Gas Processing	10	Dedicated Geological Storage
SSE Thermal Peterhead Power Station	United Kingdom	2027	Power Generation and Heat	1.5	Dedicated Geological Storage
Suez Waste to Energy	United Kingdom	2027	Biomass to Power and Heat	0.24	Dedicated Geological Storage
Uniper Humber Hub Blue Project	United Kingdom	2027	Hydrogen / Ammonia / Fertiliser	1.6	Dedicated Geological Storage
Växjö Energi CHP Sandviksverket	Sweden	2027	Biomass to Power and Heat	0.18	Under Evaluation
TotalEnergies Papua LNG	Papua New Guinea	2027	Natural Gas Processing	1	Dedicated Geological Storage
Air Liquide CalCC	France	2028	Cement	0.6	Dedicated Geological Storage
Equinor Smeaheia (Norway)	Norway	2028	CO_2 Transport / Storage	20	Dedicated Geological Storage
EQIOM K6	France	2028	Cement	0.8	Under Evaluation
Ervia Cork	Ireland	2028	Power Generation and Heat	2.5	Dedicated Geological Storage
Holcim GO4ZERO Obourg Plant	Belgium	2028	Cement	1.1	Dedicated Geological Storage
HeidelbergCement ANRAV	Bulgaria	2028	Cement	0.8	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
Holcim KOdeCO Koromačno Plant	Croatia	2028	Cement	0.37	Dedicated Geological Storage
Pertamina Sukowati	Indonesia	2028	Oil Refining	1.4	Enhanced Oil Recovery
Santos Reindeer	Australia	2028	CO_2 Transport / Storage	4	Dedicated Geological Storage
Suncor and ATCO Heartland Hydrogen	Canada	2028	Hydrogen / Ammonia / Fertiliser	2	Under Evaluation
Carbone Aceh Arun Hub	Indonesia	2029	CO_2 Transport / Storage	1.5	Dedicated Geological Storage
CO_2NTESSA	Croatia	2029	Cement	0.7	Dedicated Geological Storage
Heidelberg Materials GeZero Cement	Germany	2029	Cement	0.7	Dedicated Geological Storage
Borealis Antwerp	Belgium	2030	Chemical	Under Evaluation	Dedicated Geological Storage
Cementa Slite Cement Plant	Sweden	2030	Cement	1.8	Dedicated Geological Storage
ENEOS Northern to Western Kyushu Offshore	Japan	2030	CO_2 Transport / Storage	3	Dedicated Geological Storage
Exxonmobil Antwerp Refinery	Belgium	2030	Chemical	Under Evaluation	Dedicated Geological Storage
ExxonMobil Houston Ship Channel Innovation Zone	USA	2030	CO_2 Transport / Storage	50	Dedicated Geological Storage
ExxonMobil Blue Hydrogen Fawley Refinery	United Kingdom	2030	Hydrogen / Ammonia / Fertiliser	2	Dedicated Geological Storage
Ineos Antwerp	Belgium	2030	Chemical	Under Evaluation	Dedicated Geological Storage
Grand Ouest CO_2	France	2030	CO_2 Transport / Storage	2.6	Dedicated Geological Storage
INPEX Metropolitan Area	Japan	2030	CO_2 Transport / Storage	1	Dedicated Geological Storage
ITOCHU Tohoku Region West Coast	Japan	2030	CO_2 Transport / Storage	2	Dedicated Geological Storage
JAPEX East Niigata Area	Japan	2030	CO_2 Transport / Storage	1.5	Dedicated Geological Storage
JAPEX Tomakomai Area	Japan	2030	CO_2 Transport / Storage	1.5	Dedicated Geological Storage
Mitsubishi Corp Oceania	Japan	2030	CO_2 Transport / Storage	2	Dedicated Geological Storage
Mitsui Offshore Malay	Japan	2030	CO_2 Transport / Storage	2	Dedicated Geological Storage
RWE Pembroke Power Station	United Kingdom	2030	Power Generation and Heat	5	Under Evaluation
Wintershall Dea CO_2nnectNow	Germany	2032	CO_2 Transport / Storage	40	Under Evaluation
ArcelorMittal Texas (formerly voestalpine Texas)	USA	Under Evaluation	Iron and Steel Production	Under Evaluation	Under Evaluation
Bakken Energy Resources Heartland Hydrogen Hub	USA	Under Evaluation	Power Generation and Heat	Under Evaluation	Under Evaluation
8 Rivers Whitetail Clean Energy	United Kingdom	Under Evaluation	Power Generation and Heat	0.8	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
ARC Resources Greenview Region	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Bison North Drumheller Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Borg CO_2	Norway	Under Evaluation	CO_2 Transport / Storage	0.63	Dedicated Geological Storage
C.GEN North Killingholme Power	United Kingdom	Under Evaluation	Power Generation and Heat	Under Evaluation	Dedicated Geological Storage
Chevron San Joaquin	USA	Under Evaluation	Power Generation and Heat	1	Under Evaluation
Cementir Aalborg Plant	Denmark	Under Evaluation	Cement	0.4	Dedicated Geological Storage
City of Medicine Hat Project Clear Horizon	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
CRC InEnTec Bioenergy	USA	Under Evaluation	Ethanol	0.1	Dedicated Geological Storage
Crescent Midstream Louisiana Offshore Hub	USA	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Daya Bay Hub	China	Under Evaluation	CO_2 Transport / Storage	10	Under Evaluation
Encyclis Protos Energy Recovery Facility	United Kingdom	Under Evaluation	Biomass to Power and Heat	0.38	Dedicated Geological Storage
Enhance Grand Prairie Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Entropy Bow River Hub	Canada	Under Evaluation	CO_2 Transport / Storage	5	Dedicated Geological Storage
ExxonMobil Indonesia Regional Storage Hub	Indonesia	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Under Evaluation
Heartland Generation Battle River Carbon Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Fidelis New Energy Cyclus Power Generation	USA	Under Evaluation	Biomass to Power and Heat	2	Under Evaluation
Fjernvarme Fyn Odense CHP plant	Denmark	Under Evaluation	Biomass to Power and Heat	Under Evaluation	Under Evaluation
Fortum Waste Nyborg	Denmark	Under Evaluation	Biomass to Power and Heat	Under Evaluation	Under Evaluation
FS Lucas do Rio Verde BECCS	Brazil	Under Evaluation	Ethanol	0.4	Under Evaluation
IPL Alberta Hub	Canada	Under Evaluation	CO_2 Transport / Storage	6	Dedicated Geological Storage
Harvestone Dakota Spirit AgEnergy	USA	Under Evaluation	Ethanol	0.2	Dedicated Geological Storage
Holcim Exshaw Cement	Canada	Under Evaluation	Cement	1	Dedicated Geological Storage
Kiwetinohk Maskwa Swan Hills Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Kiwetinohk Opal Carbon Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Idku Egypt	Egypt	Under Evaluation	Natural Gas Processing	Under Evaluation	Under Evaluation
Motor Oil Hellas IRIS	Greece	Under Evaluation	Hydrogen / Ammonia / Fertiliser	0.5	Dedicated Geological Storage

Early development

Facility	Country	Operational date	Facility industry	Capture, transport and/or storage capacity (Mtpa CO_2)	Facility storage code
NorthRiver Grand Prairie Net Zero Gateway Storage Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Onyx Power Blue Hydrogen Production Plant	Netherlands	Under Evaluation	Hydrogen / Ammonia / Fertiliser	2.5	Under Evaluation
RETI East Calgary Region Carbon Sequestration Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
RWE Stallingborough	United Kingdom	Under Evaluation	Power Generation and Heat	2	Dedicated Geological Storage
RWE Straythorpe	United Kingdom	Under Evaluation	Power Generation and Heat	4	Dedicated Geological Storage
SNOC Sharjah	United Arab Emirates	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Synergy Energy Medway Power Station	United Kingdom	Under Evaluation	Power Generation and Heat	Under Evaluation	Dedicated Geological Storage
Tidewater Brazeau Carbon Sequestration Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Tidewater Ram River Carbon Sequestration Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Titan Cement IFESTOS	Greece	Under Evaluation	Cement	1.9	Dedicated Geological Storage
Tourmaline Clearwater	Canada	Under Evaluation	CO_2 Transport / Storage	10	Under Evaluation
Vault 44.01 Rocky Mountain Carbon Vault	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Vault 44.01 Athabasca Banks Carbon Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Viridor Runcorn Waste Incineration	United Kingdom	Under Evaluation	Biomass to Power and Heat	0.9	Dedicated Geological Storage
West Lake Pincher Creek Carbon Sequestration Hub	Canada	Under Evaluation	CO_2 Transport / Storage	2.7	Dedicated Geological Storage
Wintershall Dea Havstjerne	Norway	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Wintershall Dea Luna	Norway	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
SaskPower The Shand	Canada	Under Evaluation	Power Generation and Heat	2	Enhanced Oil Recovery
Wolf Central Alberta Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Sempra Hackberry Carbon Sequestration	USA	Under Evaluation	Natural Gas Processing	2	Dedicated Geological Storage
Wolf East Calgary Region Carbon Sequestration Hub	Canada	Under Evaluation	CO_2 Transport / Storage	Under Evaluation	Dedicated Geological Storage
Woodside Burrup Hub	Australia	Under Evaluation	CO_2 Transport / Storage	5	Under Evaluation

7.0 APPENDIX

ACRONYMS

ACCU Australian Carbon Credit Unit
ADNOC Abu Dhabi National Oil Company
BECCS Bioenergy with CCS
CCS Carbon Capture and Storage
CCUS Carbon Capture Utilisation and Storage
CDR Carbon Dioxide Removal
CO_2 Carbon Dioxide
COP Conference of the Parties
DAC Direct Air Capture
DACCS Direct Air Capture with Carbon Storage
DOE US Department of Energy
EC European Commission
EOR Enhanced Oil Recovery
EPA Environmental Protection Agency
EPC Engineer, Procure, Construct
EPSs Emission Performance Standards
ESG Environmental, Social and Corporate Governance
ETS Emissions Trading System
EU European Union
FEED Front-End Engineering Design
FFS Fee for Service
GFC The Green Climate Fund
GHG Greenhouse Gas
Gt Gigatonne
GW Gigawatt
IEA International Energy Agency
IEA-SDS IEA's Sustainable Development Scenario
IMO International Maritime Organisation
IPCC Intergovernmental Panel on Climate Change
IRS Treasury and Internal Revenue Service
JCM Joint Crediting Mechanism
JOGMEC Japan Oil, Gas and Metals National Corporation
LCFS Low Carbon Fuel Standard
LEDS Long Term Low Greenhouse Gas Development Strategies
LNG Liquified Natural Gas
MEE Ministry of Ecology and Environment
MMV Monitoring, Measurement and Verification
Mt Million Metric Tonnes
MTPA Million tonnes per annum
MW Megawatt
NDC Nationally Determined Contribution
NET Negative Emissions Technology
NETL National Energy Technology Laboratory
NPV Net present value
NZE Net zero emissions
PV Photovoltaic
R&D Research and Development
RD&D Research, Development and Demonstration
SDS Sustainable Development Scenario
SLL Sustainability Linked Loan
SMR Steam Methane Reforming
SOE State Owned Enterprise
TWH Terrawatt Hour
UNFCCC United Nations Framework Convention on Climate Change
UAE United Arab Emirates
UN SDGs UN's Sustainable Development Goals
VCM Voluntary Carbon Market
WTE Waste to Energy

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Section 3.3 Status of CCS finance

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Find out more

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Any questions

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