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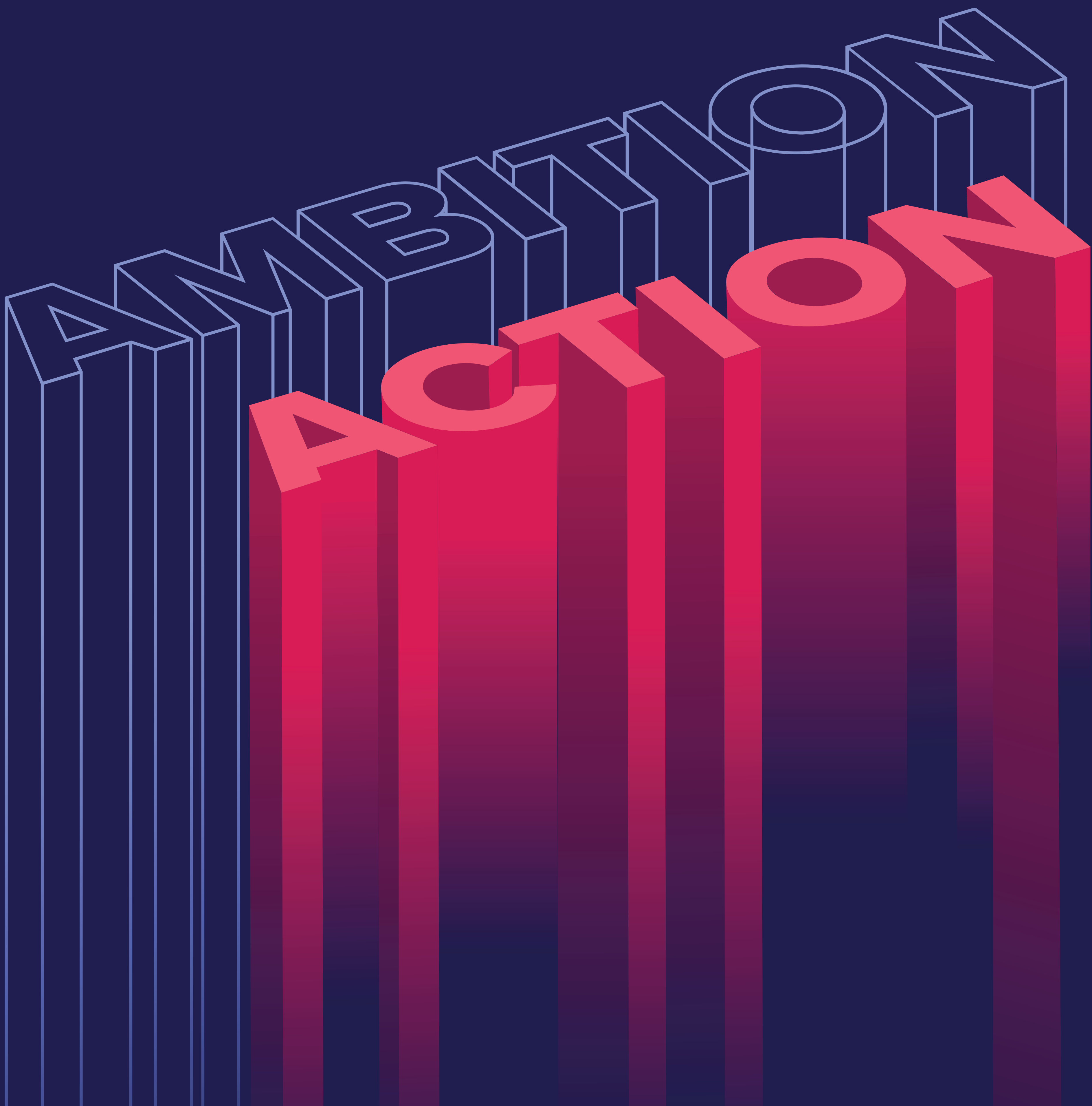
GLOBAL STATUS OF CCS 2022

GLOBAL CCS INSTITUTE REPORT



GLOBAL CCS INSTITUTE

BUILDING MOMENTUM AS WE SHIFT INTO A PHASE OF ACTION

CONTENTS

FROM THE CEO

CHAPTER 1

GLOBAL CCS INSTITUTE

INTRODUCTION

"AMBITION MUST NOW TRANSLATE TO URGENT, BROAD, AND LARGE-SCALE ACTION IF WE ARE TO MAINTAIN A LIVABLE CLIMATE."

JARAD DANIELS
CEO, Global CCS Institute

As we deliver the Global Status of CCS 2022, it is clearer than ever that CCS is one of the critical tools we must use now to address the climate crisis. In fact, without CCS, reaching our shared climate goals is practically impossible.

When it comes to limiting global warming, the last few years have been marked by growing ambition from both countries and companies alike. That ambition must now translate to urgent, broad, and large-scale action if we are to maintain a livable climate.

In the solution space, the momentum behind carbon capture and storage has continued to build. As a mature, well-understood technology, companies seeking to deploy CCS have embraced robust policy to strengthen the business case for doing so.

As we publish the Global Status of CCS report this year, there are over 190 facilities in the project pipeline.

In 2022, we've seen CCS becoming increasingly commercial and competitive in many countries. We expect to see more strategic partnerships and collaboration driving deployment, particularly through CCS networks.

Clean hydrogen and other low-carbon fuels are also part of the CCS growth story, with dozens of blue hydrogen projects now in development around the world.

This year we've also seen unprecedented interest and engagement in direct air capture with CCS or DACCS, with billions of dollars in funding allocated to scale-up this essential technology.

The outlook for CCS has never been more positive, which is good news more broadly for climate change mitigation.

However, global efforts to reduce emissions, including investment in CCS, are still grossly inadequate. Private capital must be met with government policy to unlock the full potential of CCS and keep global warming below 1.5 degrees. Put simply, we must move from ambition to action.

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AMBITION TO ACTION

CHAPTER 2

SECTION 2

2.1

AMBITION TO ACTION

The past few years have witnessed an escalation in the language of climate change. Transforming the global economy to achieve net-zero greenhouse gas emissions by mid-century is now accepted as the objective in the global climate change discourse. This level of ambition, essential to avoid dangerous anthropogenic interference with the climate system, requires an acceleration in investment in near-zero emissions technologies of all types across all sectors.

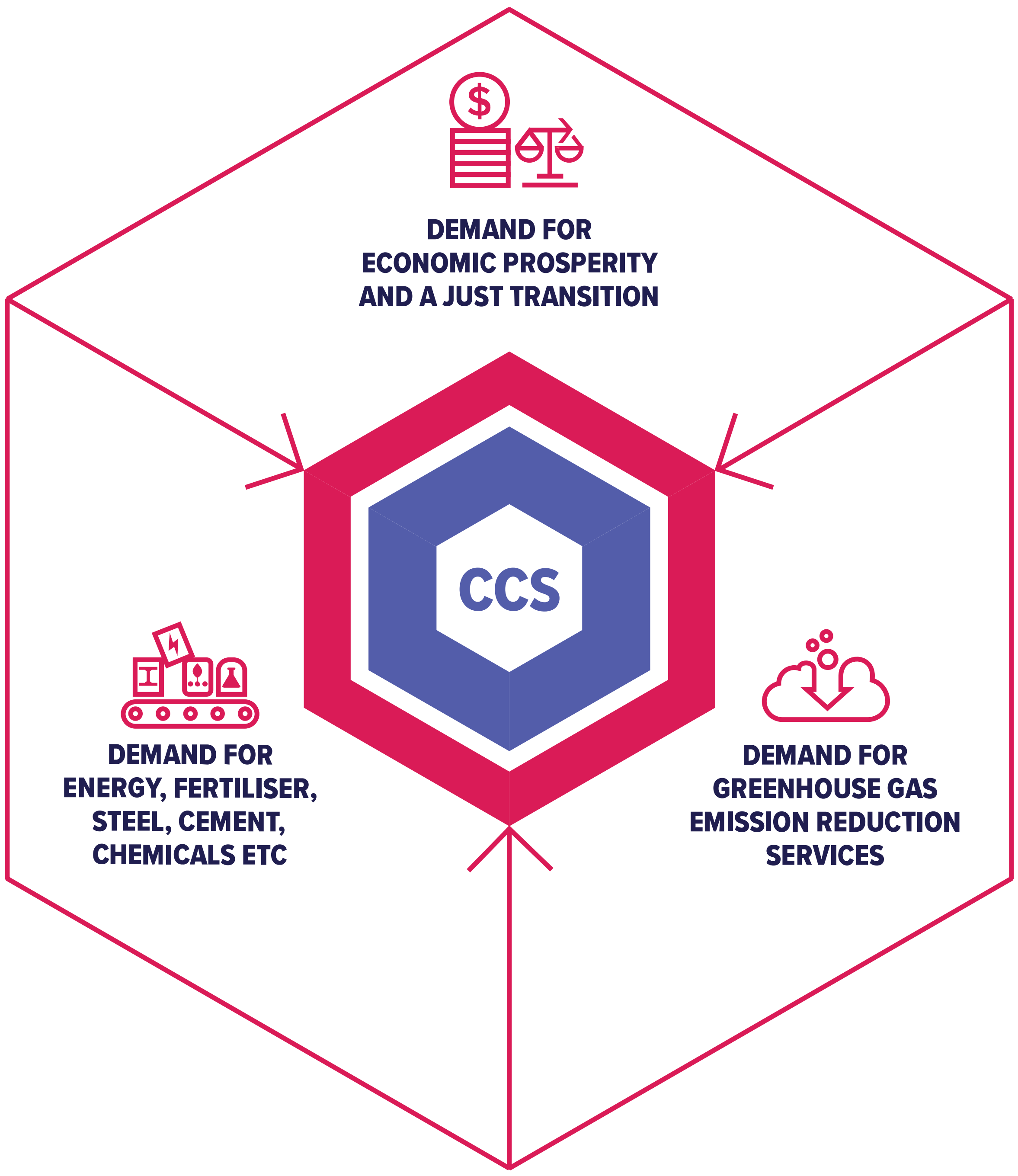
Put simply, the global response to climate change is advancing from ambition to action and this is clearly evident in data on the level of investment in carbon capture and storage (CCS). The significant increase in activity to develop carbon capture and storage projects reported in the *Global Status of CCS 2021* report has continued throughout this reporting period. As of September 2022, the total capacity of commercial CCS projects in the pipeline (operational, in development, and two with operations suspended) was 243.97 million tonnes per annum (Mtpa) of carbon dioxide (CO_2) – an increase of 44 per cent over the past 12 months, as shown in Figure 1.

__Figure 1:__ Commercial CCS Facilities 2021 – 2022

This growth arises from the private sector's response to the rising expectations of civil society to move to a net-zero emissions future and the evolution of government policy and regulation that is strengthening the business case for investment in CCS. The business risks and opportunities created by climate change are receiving closer analysis. For some businesses, CCS is a critical tool in reducing their exposure to CO_2 emissions, either directly or in their value chain, mitigating a strategic business risk. For others, CCS is an opportunity to supply a new and growing industry. Similarly, governments seeking to chart the lowest-cost, most efficient pathway toward net-zero are identifying CCS alongside all other mitigation options as essential to meeting climate targets, while ensuring a just transition for their communities.

If the provision of emission reduction services is considered in the same way as the market for any other service, investment in CCS would be expected to continue to grow. Demand for emission reduction services is rising as the carbon budget consistent with climate targets is depleted. Future demand is projected to rise even more steeply, creating an expectation of a rapidly growing industry to meet that demand. Simultaneously, demand for energy and the essential materials and products upon which modern society is built, such as fertiliser, steel, chemicals and cement, is also rising as emerging economies develop and their standard of living moves toward developed economies. CCS is at the centre of the Venn diagram of these demand drivers and economic growth, delivering emission reduction services in essential industries while supporting employment and economic prosperity.

FIGURE 2: *Demand drivers for CCS*



Recognising the potential of CCS, government policy continues to strengthen, which is incentivising greater levels of investment by the private sector. North America, Europe and the UK, regions containing established leaders in CCS-relevant policy, maintained or strengthened their positions over the past 12 months. Developments are described in greater detail in later sections of this report, but here are a few examples. In the US, the Infrastructure Investment and Jobs Act (US) passed into law, providing over US$12 billion for CCS and related activities, including:

- $2.5 billion for carbon storage validation
- $8 billion for hydrogen hubs, including blue hydrogen
- over $200 million announced or awarded by the US Department of Energy for CCS technology development.

The US also enacted the historic Inflation Reduction Act, which includes enhancements to the 45Q tax credit and accelerates the deployment of CCS by extending the start of construction timing, lowering capture thresholds, and expanding transferability. US states, notably Pennsylvania, West Virginia, North Dakota, and California, advanced legislation related to CO_2 storage, and/or proposed or established programs to support CCS.

Canada established a C$2.6 billion tax credit for CCS projects and Saskatchewan extended its 20 per cent tax credit under the province's Oil Infrastructure Investment Program to pipelines carrying CO_2.

In Europe, Denmark announced €5 billion in subsidies for CCS, Norway announced NOK1 billion (US$100 million) to support three large blue hydrogen projects, and four of the seven projects selected for grant preparation under the first call of the European Union's Innovation Fund were CCS projects. These projects are a bioenergy with CCS facility in Stockholm; a cement facility in France; a hydrogen production facility in Finland; and a hydrogen, ammonia and ethylene plant in Belgium. A further seven CCS projects were selected in the second call of the Innovation Fund.

The UK Government released its *CCUS Investor Roadmap* setting out its approach to delivering four CCUS low-carbon industrial clusters by 2030, and selected the first two clusters – East Coast and HyNet.

North America and Europe host the most robust climate and CCS policy mechanisms, but policy is also advancing in the Asia-Pacific region. The Australian Government released additional acreage for geological storage of CO_2, approved a method to allow CCS to create Australian carbon credits, and announced over A$200 million in funding to support CCS. The Japanese Government approved its *Sixth Strategic Energy Plan* describing how Japan will achieve net-zero emissions by 2050, in which CCS has a prominent role. The Chinese State Council has now issued more than 10 national policies and guidelines promoting CCS, including the *Outline of the 14th Five-Year Plan (2021–2025) for National Economic and Social Development and Vision 2035 of China.* Both Indonesia and Malaysia took steps to develop legislation for the geological storage of carbon dioxide and the government of Thailand indicated that it will also develop legislation.

This observed ramp-up of policy and legislation by national governments is consistent with a growing sense of urgency to drastically reduce greenhouse gas emissions. In charting a course to net-zero greenhouse gas emissions by 2050, the year 2030 has become a significant milestone in international climate negotiations and national emission reduction target setting. In addition to the fundamental relationship between atmospheric CO_2 concentration and global average temperature, these challenging targets recognise that achieving net-zero emissions by 2050 requires a nation's emissions to be well on that glide path by 2030. Whereas historically, public discussion of emission reduction targets was almost exclusively concerned with 2050, the end of this decade is now receiving greater focus. In some respects, 2030 has become the new 2050.

The outlook for CCS has never been more positive. However, global efforts to reduce emissions, including investment in CCS, remain grossly inadequate. Following the COVID shock to the global economy, emissions have returned to trend. Near-zero emission technologies must be deployed at unprecedented rates to cease the steady rise in emissions. While the private sector has the capital, the resources, and the expertise to meet that challenge, governments have the capacity to unleash that potential and drive investment in CCS through policy.

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GLOBAL STATUS OF CCS

CHAPTER 3

SECTION 3

NEW CCS PROJECTS HAVE BEEN ANNOUNCED EACH MONTH IN 2022. AS OF SEPTEMBER 2022, THERE ARE 196 PROJECTS IN THE CCS FACILITIES PIPELINE.

3.1

FACILITIES AND TRENDS

New CCS projects have been announced each month in 2022. As of September 2022, there are 196 (including two suspended) projects in the CCS facilities pipeline. This is an impressive growth of 44 per cent in the number of CCS facilities since the Global Status of CCS 2021 report and continues the upward momentum in CCS projects in development since 2017.

FIGURE 3 *– Pipeline of Commercial facilities since 2010 by capture capacity (Mtpa)*
*2021 capacities adjusted to reflect this year's change to how capacity tonnages are interpreted, to facilitate comparison with 2022 figures.

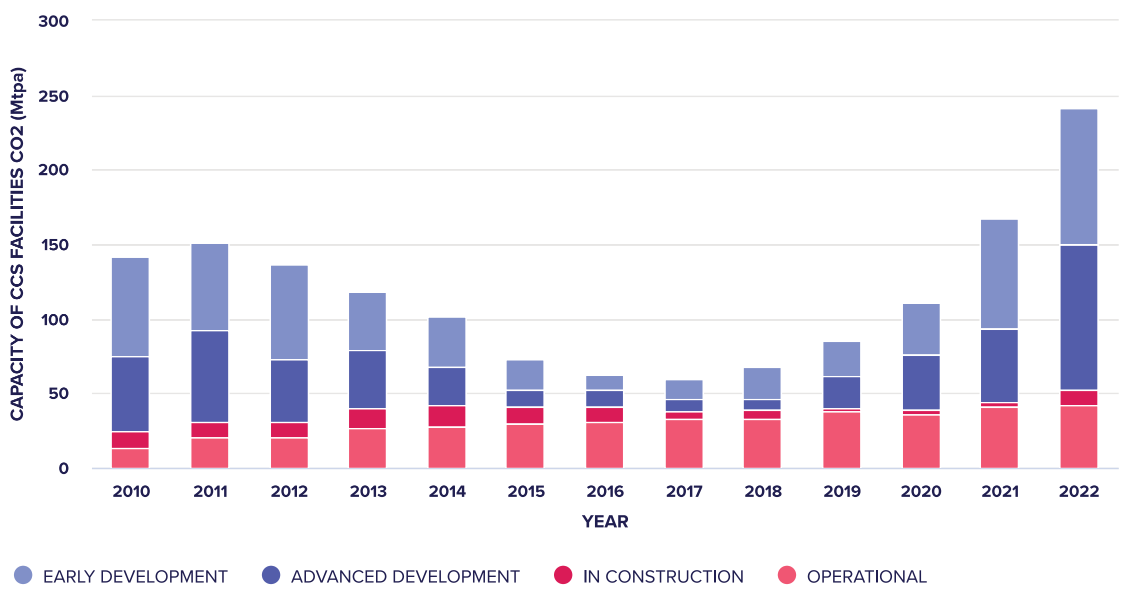


Figure 3 shows the increase in the capacity of CCS projects from 2010 until September 2022 (the final bar represents the project development status as of mid-September 2022). In 2022, the Institute has formally adopted a revised approach to estimating total CCS capacity (see below).

FIGURE 4 *– Commercial CCS Facilities by number and total CO_2 capture capacity (mid-September 2022)*

	OPERATIONAL	IN CONSTRUCTION	ADVANCED DEVELOPMENT	EARLY DEVELOPMENT	OPERATION SUSPENDED	TOTAL
NUMBER OF FACILITIES	30	11	78	75	2	196
CAPTURE CAPACITY	42.58	9.63	97.6	91.86	2.3	243.97

The facility counts in Figure 4 also include transport and storage projects that do not include capture. These provide essential infrastructure for the industry to develop. As explained in the notes below, they do not contribute to capture capacity tonnage figures, to avoid double-counting of project capacities.

Notable project developments in the 12 months since the last Global Status report include:

- Drax Power Station in the UK announced the world's single largest bioenergy with CCS (BECCS) project, with a world-scale 8.0 Mtpa capacity across two units.
- The Klemetsrud Waste-to-Energy CCS project in Norway moved to In Construction, having secured funding. This is the first commercial-scale CCS project applied to a waste-to-energy facility.
- Glacier CCS Project – capture technology firm, Entropy, commissioned a CO_2 capture facility on a natural gas-fired reciprocating engine, the first of its kind at commercial scale and an important milestone given the importance of future capture from natural gas combustion streams worldwide.
- Air Products announced its world-scale blue hydrogen project in Louisiana, incorporating autothermal reforming hydrogen production to facilitate CO_2
- ORCA, the world's first commercial direct air capture with carbon storage (DACCS) facility, was commissioned in Iceland. Its follow-up, the MAMMOTH project, was then announced.
  In Australia, the Bayu-Undan project by Santos has moved into Front End Engineering and Design (FEED). This project will capture CO_2 from LNG production in Darwin and transport it via pipeline across the maritime border between Australia and Timor-Leste for

offshore geological storage. A key feature of this project is repurposing an existing natural gas pipeline for CO_2
Occidental, in partnership with DACCS technology company Carbon Engineering, announced that construction will commence on a 500 ktpa direct air capture project in the Permian Basin in the US. The plant is said to be capable of scaling up to a 1 Mtpa capacity. This is in the context of Occidental's stated plans to develop a fleet of up to 70 such facilities around the world by 2035.

MEASURING GLOBAL CCS CAPACITY BY CAPTURE CAPACITY

In prior years, most CCS projects were full-value chain. This means they tended to incorporate a single CO_2 capture plant with its own dedicated CO_2 compression, transport (usually pipeline) and storage systems. This meant that when describing the CO_2 flow capacity (in tonnes per year) of these systems, the capacity of the capture plant, transport and storage systems were all aligned and operating as a single integrated system.

Today, CCS networks are becoming the predominant method of CCS deployment. CCS networks involve the use of shared transport and storage infrastructure. Some CCS-related developments, such as shipping projects, pipelines, or new storage facilities, do not involve CO_2 capture at all, and handle CO_2 captured by third parties.

If the CO_2 flow capacities of these non-capture sites were counted in our statistics, there would potentially be a double-counting of global CCS capacity, as CO_2 capacity would have already been included in our figures for capture plants upstream.

To avoid this problem, and ensure compatibility with our historical capacity statistics, only CO_2 capture capacity will be included when determining global CCS system capacity (Mtpa). This is why project pipeline charts and figures now explicitly refer to 'by capture capacity', a change from the earlier title "Capacity of CCS facilities".

Dedicated transport and/or storage projects will still be counted in total facility numbers, but will not contribute to global CCS system capacity. Facility counts can be somewhat arbitrary depending upon where the boundaries between transport and storage facilities in networks are drawn. Therefore, total system capacity is a better guide to the growth of the CCS sector than facility counts.

NOTE ON THE CHANGE TO THE INTERPRETATION OF CAPACITY TONNAGES IN 2022

Historically, *Global Status of CCS* reports have reported tonnage in millions of tonnes per annum (Mtpa) based on the mean of the proponent-reported range of plant capacities. For example, if a proponent said it was targeting 1–1.3 Mtpa for its project, our reports have stated this as 1.15 Mtpa.

For projects in the Early Development stage, such ranges are often provided because there is uncertainty about the final specifications for the project. However, as projects progress to later stages and to construction, design capacities are typically locked into a single design capacity figure. This can make these ranges misleading, especially if the lower-end estimate is carried over from earlier project stages. The effect has been an overall understatement of CO_2 capture capacity for the sector as a whole.

Beginning with this report, design capacities (upper end of ranges, if given) will be used. If a range is revised when moving from Early Development to Advanced Development, for example, the new capacity figure will be used and the facility entry updated accordingly. This may mean a given project's stated capacity will be adjusted one or more times over the project life cycle.

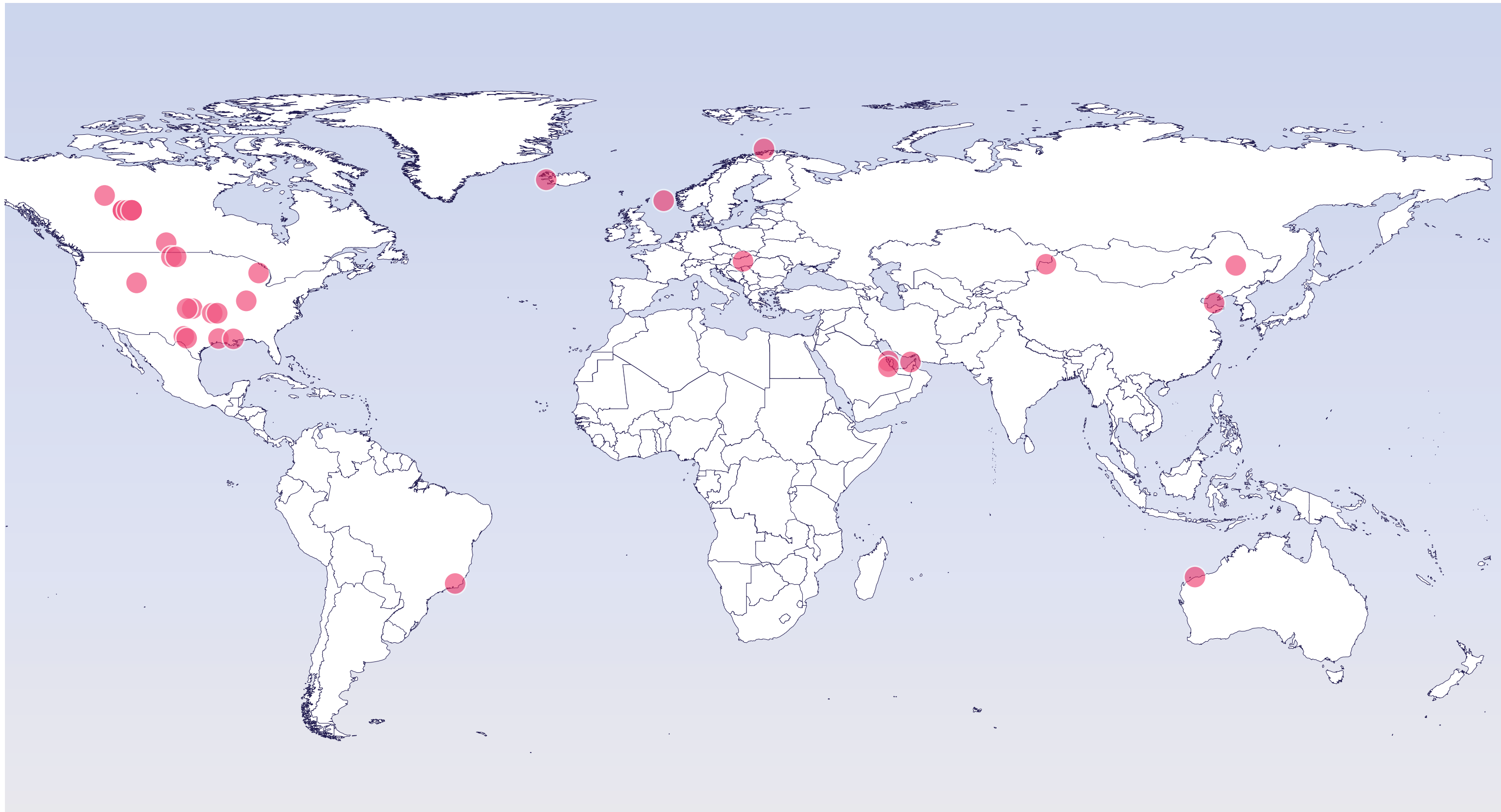
One effect of this change is that the 2022 capture capacity in the project pipeline bar chart is not directly comparable with previous capture capacities. A portion of the increase from 2021 to 2022 is due to this measurement change, and a portion is due to growth in projects.

The project pipeline, in terms of facility numbers and capture capacity, is now at a record high. Since 2017, capture capacity has grown at a compound rate of over 34 per cent per annum.

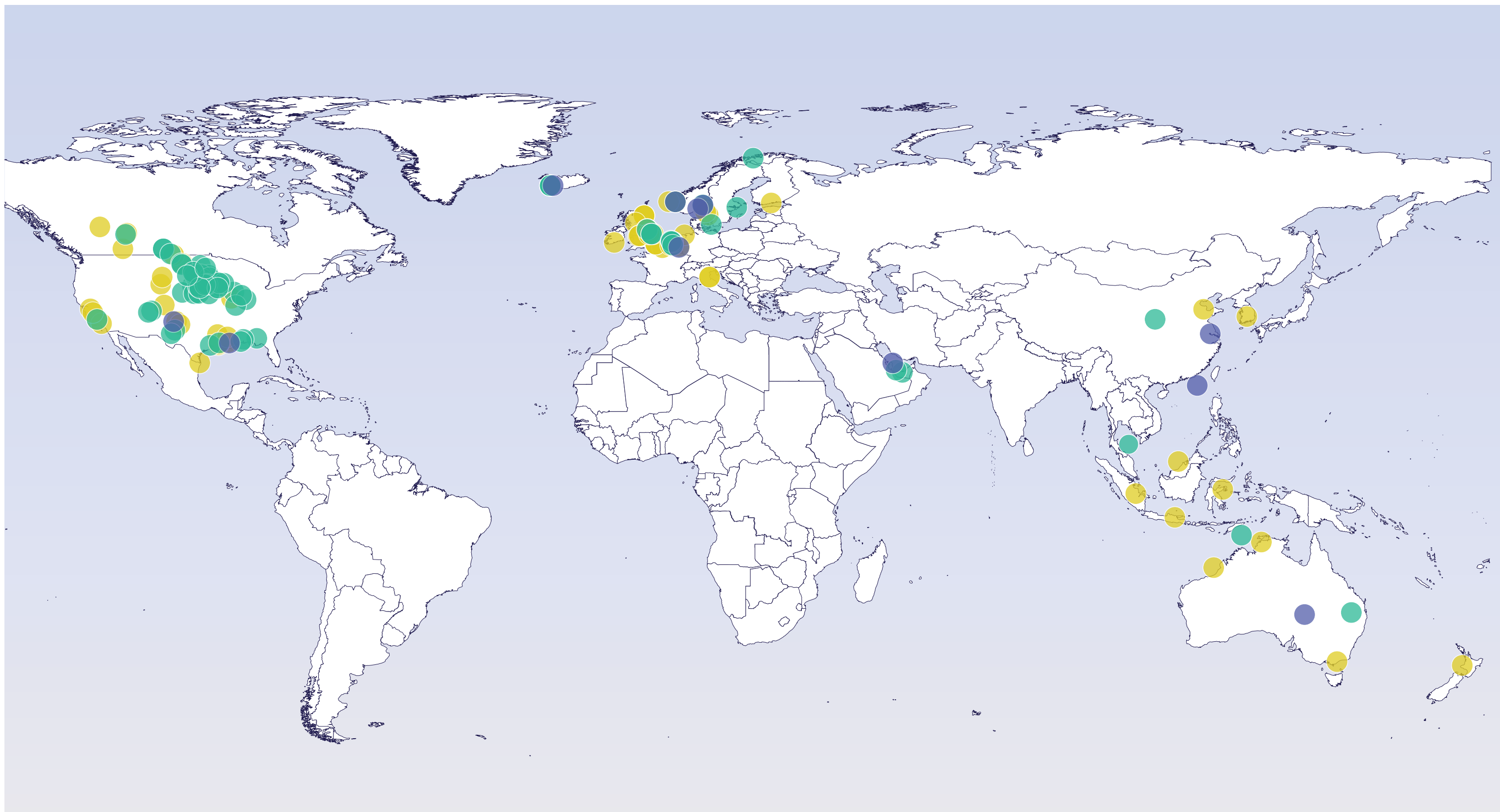
Capture capacity (on a 2022 basis – see explanatory note above) in the pipeline has grown substantially in the past 12 months. This includes an impressive near-doubling of capture capacity in the Advanced Development state (projects undergoing Front End Engineering Design), from 49.4 Mtpa in 2021 to 97.6 Mtpa in 2022. Advanced Development means projects have received significant funds for engineering development, demonstrating a higher level of commitment to project development and a higher probability of moving to funding approval and construction, so this increase is significant for future project growth.

By facility count growth, the US continues to lead the way globally, with 34 new projects since 2021[1]. Other leading countries in the past year include Canada (19 new projects), the UK (13), Norway (8), and Australia, the Netherlands and Iceland (6 each).

__FIGURE 5:__ World Map of CCS Facilities at Various Stages of Development



● OPERATIONAL



● EARLY DEVELOPMENT ● ADVANCED DEVELOPMENT ● IN CONSTRUCTION

Significant contributors to the growth of Early Development and Advanced Development pipelines are featured in the tables below.

__FIGURE 6__ – Significant contributors to Early Development growth in 2021–22

	COUNTRY	INDUSTRY	CAPTURE CAPACITY (MTPA)
THE ILLINOIS CLEAN FUELS PROJECT	US	Chemical Production	8.1
DRAX PROJECT BECCS	UK	Power Generation	8
MEDWAY HUB POWER STATIONS	UK	Power Generation	7.6
NET ZERO TEESSIDE – BP H2TEESSIDE	UK	Hydrogen Production	2
CYCLUS POWER GENERATION	US	Bioenergy	2
SOUTH EAST AUSTRALIA CARBON CAPTURE HUB	Australia	Natural Gas Processing	2

FIGURE 7 – Significant contributors to Advanced Development growth in 2021–22

	COUNTRY	INDUSTRY	CAPTURE CAPACITY (MTPA)
BAYU-UNDAN CCS	Timor-Leste	Natural Gas Processing	10
DEER PARK ENERGY CENTRE CCS PROJECT	US	Power Generation	5
FEDERATED CO-OPERATIVES LIMITED	Canada	Ethanol Production	3
HUANENG LONGDONG ENERGY BASE CARBON CAPTURE AND STORAGE	China	Power Generation	1.5
FEDERATED CO-OPERATIVES LIMITED (REFINERY)	Canada	Oil Refining	1

FOOTNOTES

1. This includes dedicated transport and storage projects.

3.2

POLICY, LEGAL, AND REGULATORY TRENDS

The global policy, legal and regulatory environment for CCS remains dynamic, with significant developments in many jurisdictions over the past year. While a number of early-mover nations have adopted a renewed focus toward addressing these issues, several countries are now in the initial stages of developing their policy response to support and facilitate the technology's deployment.

CLIMATE POLICY TRENDS AND ANALYSIS

The publication of the much anticipated Intergovernmental Panel on Climate Change (IPCC) Working Group III (WG3) Report, *Mitigation of Climate Change*, has increased awareness of the need for CCS, illustrating its effectiveness and viability through widescale deployment across various scenarios and sectors. However, while large-scale fossil-based energy and industry sources are posed to increasingly include CCS in modelled pathways to limit warming to 1.5°C, current rates of deployment are far below those found in the modelled pathways. The relationship between CCS and technology-based carbon dioxide removal (CDR) is highlighted in counterbalancing emissions where they cannot be mitigated. Widening the lens to consider overall social, environmental and economic impacts across mitigation options, an analysis of the relationship of CCS to the sustainable development goals (SDG) found synergies in goals 3, 7, 8, 9 and 12. A brief published by the Global CCS Institute discusses in further detail the key takeaways for CCS in the WG3 report (1).

FIGURE 8: The UN Sustainable Development Goals (source: The United Nations)

In current international climate negotiations, Articles 6 (market mechanisms and non-market approaches) and 14 (global stocktake) of the Paris Agreement remain the most relevant for CCS. As Article 6 matures with significant developments in the technical work and the establishment of its supervisory body, clarity is still needed on the transfer of existing CCS methodologies from the Clean Development Mechanism (CDM) to the upcoming mechanism under Article 6. Looking at Article 14, the global stocktake (GST) – which runs until 2023 and repeats in five-year cycles – presents a timely opportunity for CCS experts to engage in technical dialogues (TD) with parties that could inform updated nationally determined contributions (NDC) at the heart of achieving the objectives of the Paris Agreement.

FIGURE 9: *CCS in Country NDCs and CCS International Legislation*

YEAR	INDC	FIRST NDC	FIRST NDC UPDATE	SECOND NDC
AUSTRALIA	NOT AVAILABLE	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS	
BAHRAIN	NOT AVAILABLE	NDC MENTIONS CCS	NDC MENTIONS CCS	
CANADA	NDC MENTIONS CCS	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS	
CHINA	NDC MENTIONS CCS	NDC MENTIONS CCS	NDC MENTIONS CCS	
EGYPT	NOT AVAILABLE	NDC MENTIONS CCS		
EL SALVADOR	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
ICELAND	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
IRAN	NDC MENTIONS CCS			
IRAQ	NDC MENTIONS CCS			
JAPAN	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
MALAWI	NDC MENTIONS CCS	NDC MENTIONS CCS	NDC MENTIONS CCS	
MONGOLIA	NDC DOES NOT MENTION CCS	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS	
NORWAY	NOT AVAILABLE	NDC MENTIONS CCS	NDC MENTIONS CCS	
PAKISTAN	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
QATAR	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
SAUDI ARABIA	NDC MENTIONS CCS	NDC MENTIONS CCS	NDC MENTIONS CCS	
SOUTH AFRICA	NDC MENTIONS CCS	NDC MENTIONS CCS	NDC DOES NOT MENTION CCS	
UAE	NOT AVAILABLE	NDC MENTIONS CCS	NOT AVAILABLE	NDC MENTIONS CCS
UNITED STATES	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS		
KUWAIT	NOT AVAILABLE	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS	
TOGO	NOT AVAILABLE	NOT AVAILABLE	NDC MENTIONS CCS	
TUNISIA	NOT AVAILABLE	NDC DOES NOT MENTION CCS	NDC MENTIONS CCS	

■ NDC MENTIONS CCS ■ NDC DOES NOT MENTION CCS ■ NOT AVAILABLE

TOWARD CLOSER REGIONAL COOPERATION

The role of closer, regionally focused cooperation in achieving CCS deployment has arisen as a further and important consideration for both governments and industry over the past 12 months. The emergence of new markets and applications for CCS technologies, enhanced national commitments to achieving net-zero and the commercial opportunities posed by the deployment of CCS networks, has led to greater scrutiny of opportunities beyond national boundaries. Further progress with projects under development in the North Sea, as well as proposed activities in Southeast Asia and the wider Asia-Pacific region, are indicative of this approach.

To support this ambition, attention has inevitably turned to the requirements necessary for achieving them and, in particular, the development of a supportive policy, legal and regulatory landscape. National governments and corporations with an interest in developing projects with a transnational element are now actively considering and promoting issues surrounding transboundary regulation, as well as the development of regional frameworks and mechanisms that will support the development of CCS networks.

The challenges associated with a more regionally focused approach are particularly significant where CO_2 is transported from one country for storage in another nation's territory. The ability of project proponents to fully recognise the contribution of these transboundary storage activities within national and international accounting and crediting schemes has been raised by several government and industry parties as an important issue to be addressed. Similarly, the absence of detailed legal and regulatory regimes for the technology in many nations worldwide also creates uncertainty as to how storage operations will be regulated. In addition, these transboundary storage projects will also call into play several wider international, regional and domestic legal frameworks that will all require careful navigation to ensure they do not unwittingly pose further barriers to proposed activities.

Few examples exist where these CCS-specific issues have been addressed. However, the consideration of transboundary issues within the international marine agreements provides an important model. The amendments to the London Protocol and the approach adopted by the parties to date, are indicative of the need to swiftly address these challenges. The 2019 agreement by the parties to the protocol, to allow for the provisional application of a 2009 amendment to Article 6, finally enables parties to avail themselves of provisions explicitly aimed at supporting the transboundary transportation of CO_2 for the purposes of geological storage. To date, however, only the Republic of Korea, Denmark, the Netherlands and Norway have formally submitted a declaration on the provisional application of the 2009 amendment. The Institute's own analysis demonstrates there is significant potential for further activity within the auspices of the London Protocol to address these challenges and drive regional collaboration (2). An increasing focus on the development of regional networks or individual projects, which in many instances will require the transportation of CO_2 across international maritime boundaries, emphasises the need for a renewed focus on the role of the treaty and the national frameworks in supporting deployment.

REGIONAL POLICY, LEGAL AND REGULATORY DEVELOPMENTS

The global policy, legal and regulatory environment for CCS remains dynamic, with significant developments in many jurisdictions over the past year. While a number of early-mover nations have adopted a renewed focus toward addressing these issues, several countries are now in the initial stages of developing their policy response to support and facilitate the technology's deployment.

In North America, regulators and policymakers have continued to strengthen their existing CCS-specific frameworks to offer further financial incentives and provide new and additional regulatory frameworks. Canada's robust policy and regulatory environment has been further strengthened by a proposed federal investment tax credit for CCS, while in the US, the federal government has committed further project-specific and infrastructure funding through its Infrastructure Investment and Jobs Act (US). Additional enhancements to the US's successful 45Q tax credit scheme were made through the introduction of the Inflation Reduction Act (US) of 2022, while expansion of the nation's CCS-specific legislation also continues, with planned state-level legislation and new federal legislation to regulate leasing and provide oversight of offshore CCS operations.

The announcement of project support through the EU's Innovation fund for CCS, coupled with a buoyant EU Emissions Trading Scheme (EU ETS) and further policy initiatives from individual member states, continues to strengthen the supportive policy environment for the technology in Europe. Several countries within the region have sought to build upon this momentum, announcing new initiatives and committing further support to projects. In the UK, the government has progressed its post-Brexit plan for energy transition, announcing two initial hubs and further refining its business model for transport and storage. Norway and the Netherlands have also sought to strengthen policy and regulatory commitments to the technology and the two nations were the first to deposit declarations on the provisional application of the London Protocol amendments. On another positive note, several other member states are also seeking to re-engage with CCS, to complete regulatory frameworks, remove barriers and provide policy support.

Recent policy, legal and regulatory developments across the Asia-Pacific region highlight the increasing focus of government and industry on the technology as well as the significance of these issues in supporting its more widespread deployment. In Australia, the new Labor government has committed to strengthening baselines for major emitters under the existing safeguard mechanism, a decision that may offer further support to CCS projects. The development complements the earlier release of the CCS-specific methodology under the national Emission Reduction Fund, which will provide a formal revenue pathway through the generation of carbon credit units. The governments of Japan and China have also taken further steps in the past year, introducing new climate and energy policies and in the case of Japan, announcing a commitment to the development of a CCS-specific regulatory framework.

Significant regional potential for the technology has led to several important developments in Southeast Asia. The governments of Indonesia and Malaysia have made several policy announcements in line with their commitments to supporting more widespread deployment. The government of Indonesia has released a draft of its region-first CCS-specific legal and regulatory framework, with Malaysia also indicating that it too is in the process of developing a CCS-specific regulatory regime. While other countries within the region have announced projects or taken tentative steps toward deployment, their policy and regulatory regimes remain underdeveloped and will require further intervention to support more widespread deployment.

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2. Havercroft, I. and Consoli, C. (2022) *Developments and Opportunities – A Review of National Responses to CCS Under the London Protocol.*

GLOBAL CCS INSTITUTE

REGIONAL OVERVIEW

CHAPTER 4

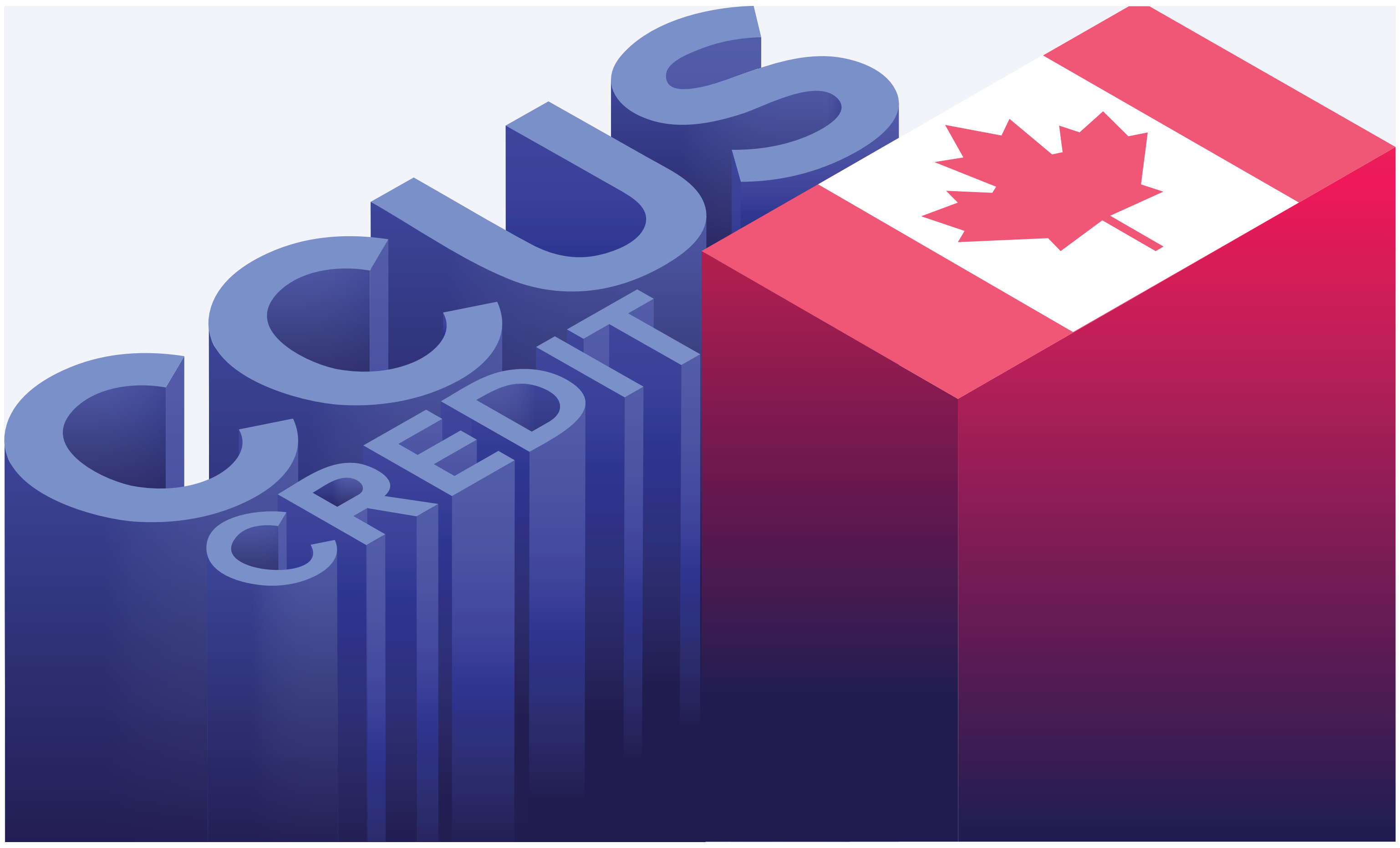
SECTION 4

4.1

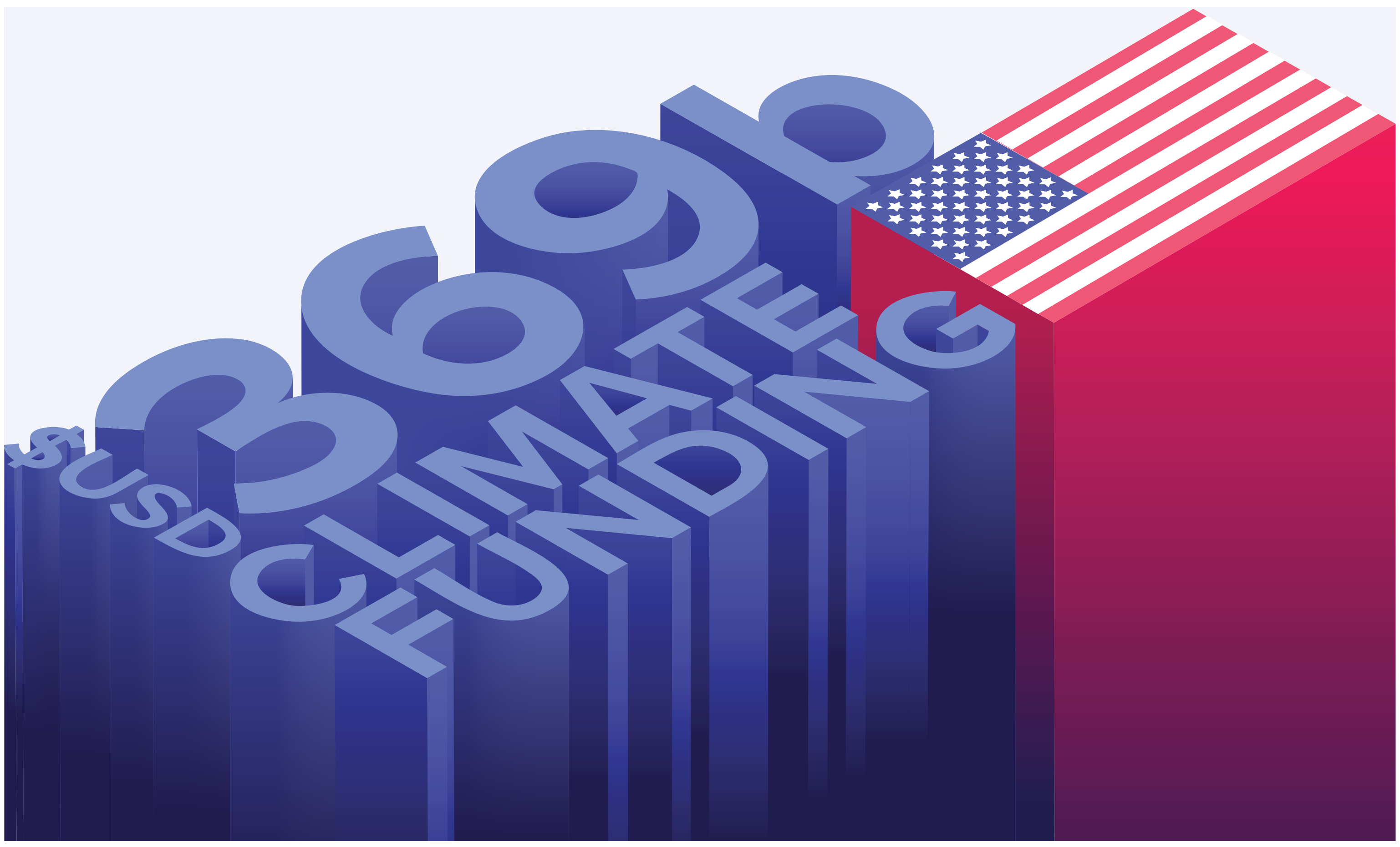
THE AMERICAS

The Americas, particularly North America, continue leading the world in CCS deployment. In the US, the Biden administration finds that achieving an equitable transition to a net-zero economy by 2050 must include policies that provide significant funding for cutting-edge technologies to safely and efficiently capture, remove, and store carbon dioxide. Carbon capture and storage has bipartisan political support in the US. Likewise, in Canada, CCUS is critical in its economic and environmental path to meeting its net-zero by 2050 objective. The role of environmental, social, and governance (ESG) principles continues to increase.

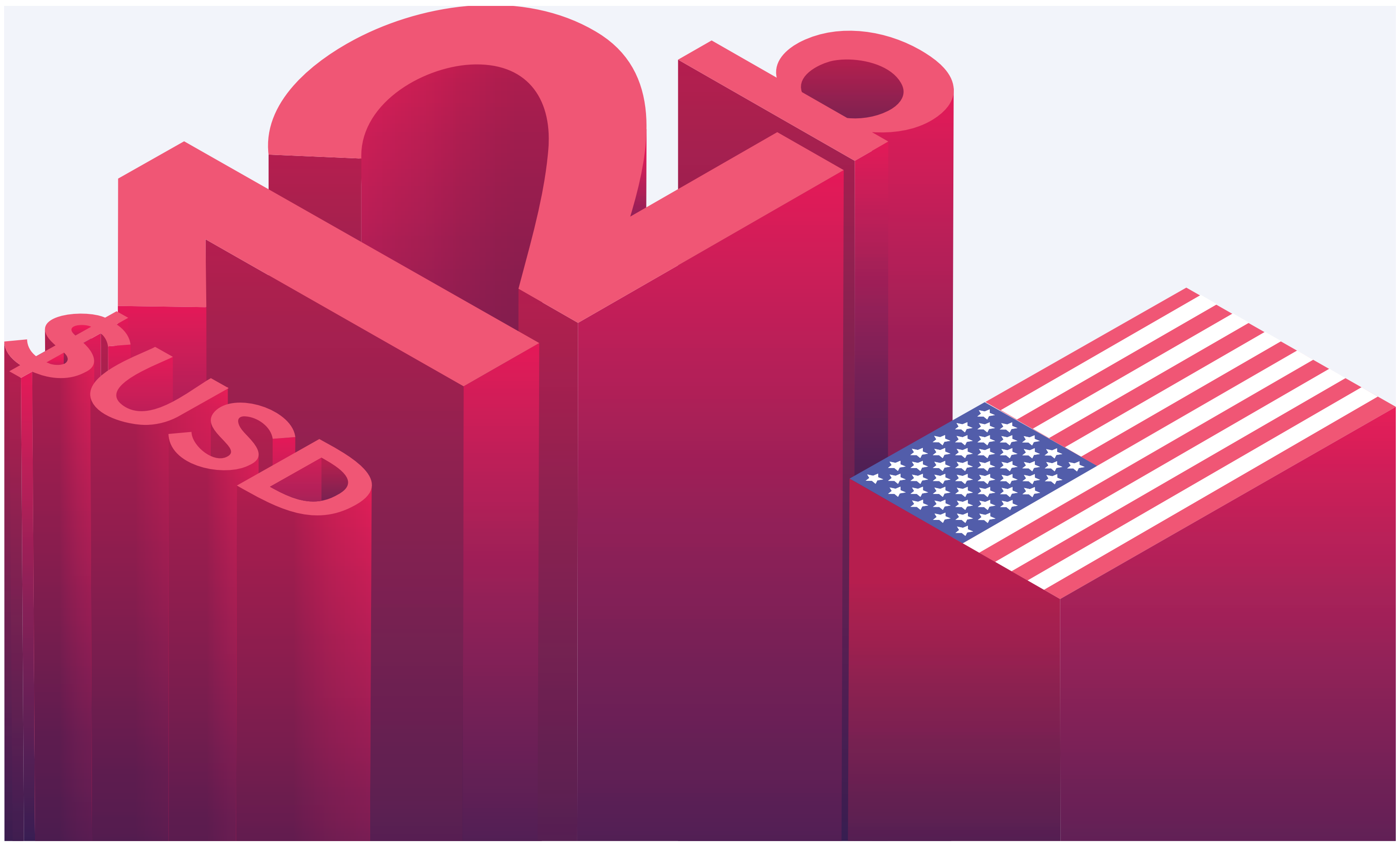
OVERVIEW



CANADA'S 2022 FEDERAL BUDGET STRONGLY SUPPORTS CCUS VIA AN INVESTMENT TAX CREDIT. THE TAX CREDIT RATE IS 60 PER CENT FOR DIRECT AIR CAPTURE PROJECTS, 50 PER CENT FOR ALL OTHER CARBON CAPTURE PROJECTS, AND 37.5 PER CENT FOR TRANSPORTATION, STORAGE, AND USE.



THE US ENACTED THE HISTORIC INFLATION REDUCTION ACT (US) OF 2022, WHICH INCLUDES ENHANCEMENTS TO INTERNAL REVENUE SERVICE SECTION 45Q AND US$369 BILLION IN FUNDING FOR CLIMATE AND ENERGY.



INFRASTRUCTURE INVESTMENT AND JOBS ACT INCLUDES OVER US$12 BILLION TO BE SPENT ON CCS OVER THE NEXT FIVE YEARS.

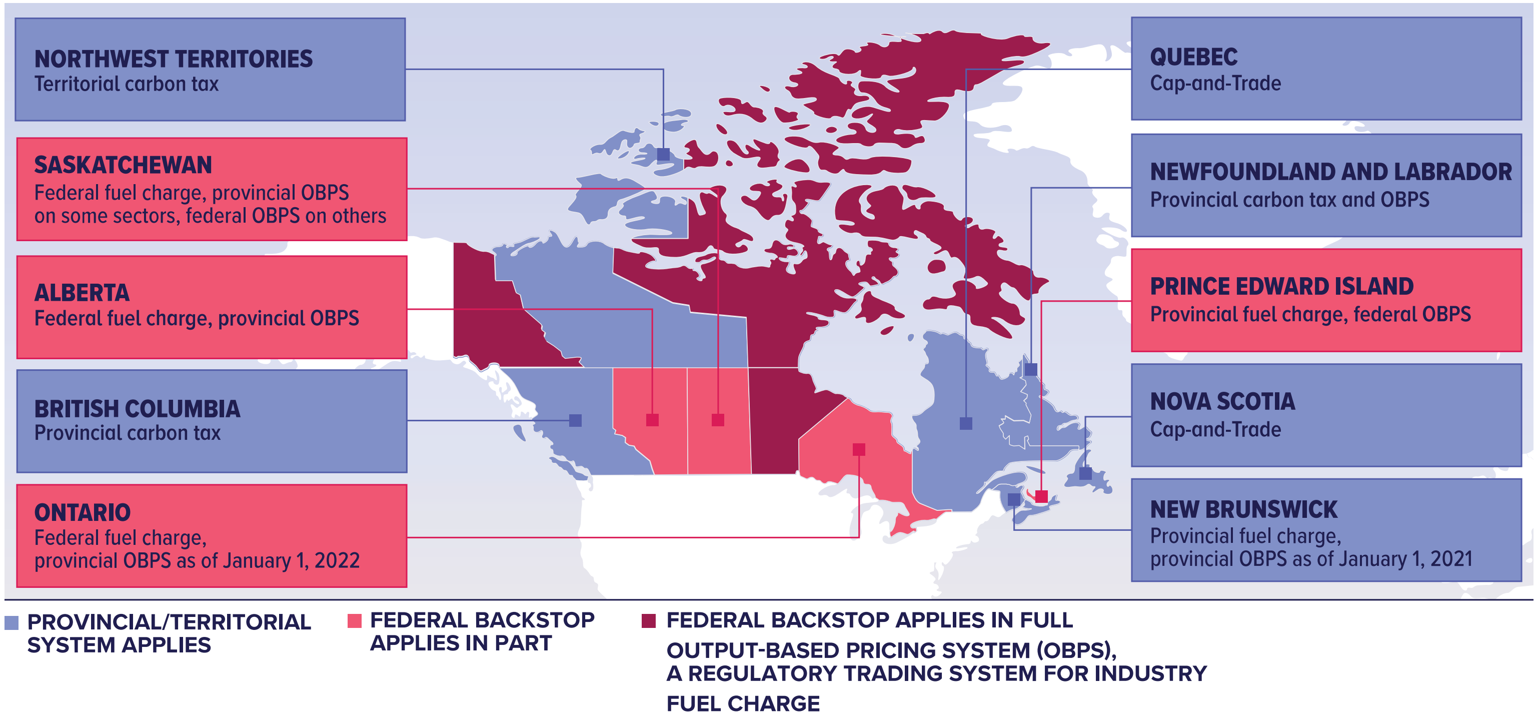
BRAZIL CONTINUES PROGRESSING TOWARD ITS GOAL OF INJECTING 40 MILLION TONNES OF CO_2 BY 2025.

CANADA

POLICY

In November 2021, the Province of Saskatchewan announced the eligibility of pipelines transporting CO_2, whether for CCUS or enhanced oil recovery (EOR), for the provincial oil infrastructure investment program (OIIP) (1). The province of Alberta also announced in the fourth quarter of 2021 the Alberta Hydrogen Roadmap, outlining Alberta's intention to become an international leader in clean hydrogen. CCUS is key in the roadmap (2). In the first quarter of 2022, the government of Canada released its 2030 Emissions Reduction Plan (3). Canada's goal is to position its industries to be green and competitive, which includes developing a CCUS strategy to incentivise the development and adoption of this technology. The plan provides a roadmap for how Canada will meet its enhanced Paris Agreement nationally determined contributions (NDC) target to reduce greenhouse gas emissions to 40–45 per cent below 2005 levels by 2030 across the Canadian economy, and puts the country on a path to achieving net-zero emissions by 2050.

FIGURE 10: Carbon Pricing Across Canada



Following the release of the plan, Canada issued its 2022 federal budget, which strongly supports CCUS via an investment tax credit (4). The tax credit rate is 60 per cent for direct air capture projects, 50 per cent for all other carbon capture projects, and 37.5 per cent for transportation, storage, and use from 2022 through 2030. After that, from 2031 to 2040, the tax rates drop to 30 per cent, 25 per cent, and 18.75 per cent, respectively. The tax credit can be claimed by businesses that, beginning 1 January 2022, incur eligible expenses related to purchasing and installing equipment used in a suitable new project that captures CO_2 emissions. Companies can claim the tax credit only if they agree to abide by a validation and verification process, prove that the project meets CO_2 storage requirements, and produce a climate-related financial disclosure report.

ENVIRONMENTAL, SOCIAL AND GOVERNANCE

In December 2021, Canada's Prime Minister, Justin Trudeau, directed Cabinet ministers to move toward mandatory climate-related financial disclosures as part of Canada's strategy to transition to net-zero by 2050 (5). The 2022 Budget included this mandatory reporting requirement across a broad spectrum of the Canadian economy, based on the international Task Force on Climate-related Financial Disclosures (TCFD) framework (6).

OTHER PROVINCES – ONTARIO

Hard-to-decarbonise sectors of Ontario's economy, such as steelmaking and cement, do not have obvious paths to a carbon-neutral future. In these sectors, CCS likely provides the most viable decarbonisation option. Therefore, the government is evaluating CO_2 storage as a decarbonisation option. The likely storage area will be in the western part of the province in saline aquifers. But existing laws prohibit storage, so the province must revise the governing statutes by narrowing the prohibition on the injection of CO_2 into a well regulated under the Oil, Gas, and Salt Resources Act (Canada), and by enabling authorisation to store carbon on Crown land under the Mining Act (Canada) (7).

PROJECTS

A large percentage of CCUS-specific action and strategy lies in the provinces of Alberta and Saskatchewan. Alberta is developing Canada's first carbon storage hubs to help cut climate-warming emissions by permanently sequestering CO_2 underground. In March 2022, the province selected six proposals to move forward with developing Canada's first carbon storage hubs servicing Alberta's industrial heartland region near Edmonton. The selected proposals came from: Enbridge Inc.; Shell Canada Limited; ATCO Energy Solutions Ltd; Suncor Energy Inc.; Wolf Carbons Solutions; Bison Low Carbon Ventures; Enhance Energy; and a joint-venture project from TC Energy and Pembina Pipeline Corp. (8,9). Alberta's abundance of geological formations for CO_2 storage makes it an ideal location to develop a series of CCUS hubs (10).

Entropy Inc. announced that it has begun commissioning its first post-combustion CCS project at the Glacier Gas Plant in Alberta. Permanent geologic carbon injection will likely start during the summer of 2022. The project is considered to be the world's first commercial project to capture and store carbon dioxide from the combustion of natural gas (11).

The government of Saskatchewan's Ministry of Energy and Resources and others will support a study, developed by the Transition Accelerator and the Saskatchewan Research Council, to provide investors with an analysis of commercial-scale hydrogen opportunities and synergies with CCUS infrastructure in Saskatchewan.

UNITED STATES

POLICY

The national climate goals of 100 per cent clean electricity by 2035 and achieving a net-zero emissions economy by 2050 involve significant reliance on CCS. Through enacted legislation in late 2021 and during 2022, the US committed to record investments into carbon capture technologies, while also addressing environmental justice concerns.

LEGISLATIVE

In November 2021, the US enacted the Infrastructure Investment and Jobs Act (IIJA) (US), which included over US$12 billion to be spent on CCS over the next five years. The legislation includes funding for CCUS research, development, and demonstration, CO_2 transport and storage infrastructure, carbon utilisation market development and four regional direct air capture with carbon storage (DACCS) hubs, and DACCS competition (12).

The US enacted the bipartisan Creating Helpful Incentives to Produce Semiconductors for America fund in 2022, or the CHIPS Act (US). CHIPS provides funding for increased carbon removal research, development and demonstration (13).

The US also enacted the historic Inflation Reduction Act (US) of 2022, which includes enhancements to Internal Revenue Service section 45Q. The legislation accelerates CCS deployment by extending the start of construction timing to the end of 2032; lowering capture thresholds, including direct pay; and expanding transferability. The Act also increases the credit amount per tonne for entities satisfying prevailing wage and apprentice requirements (14,15).

POLICY GUIDANCE AND ANNOUNCEMENTS

The Council on Environmental Quality (CEQ) issued guidance to promote the responsible development and permitting of CCUS projects. Guidance elements include facilitating federal decision making on CCUS projects and CO_2 pipelines, public engagement, understanding of environmental impacts, and carbon dioxide removal (16).

The Department of Energy Office of Fossil Energy and Carbon Management (FECM) published its strategy for advancing CCS. The Strategic Vision establishes a framework for making informed carbon management decisions regarding deep decarbonisation and addressing legacy emissions. FECM prioritises justice, labour and engagement; carbon management approaches toward deep decarbonisation; and technologies that lead to sustainable energy (17).

The Pipeline and Hazardous Materials Safety Administration (PHMSA) announced new safety measures for CO_2 pipelines and initiated new rulemaking. PHMSA also issued an updated advisory bulletin addressing issues resulting from geological hazards (18).

The Bureau of Land Management (BLM) issued guidance for CO_2 storage in line with the Federal Land Management Policy Act (US). BLM's instruction memorandum addressed carbon storage on public lands, including pore space managed by BLM (19).

OFFSHORE STORAGE

The IIJA legislation amends the Outer Continental Shelf Lands Act (US), directing the Department of Interior to develop regulations for establishing a permitting framework for offshore CO_2 storage.

ENVIRONMENTAL, SOCIAL AND GOVERNANCE

The Securities and Exchange Commission proposed a rule addressing climate-related disclosures. The proposed rule would require company disclosure on how it plans to attain climate-related targets (such as investing in renewable energy or carbon capture technology). The proposal recognises that CCS will likely have a role to play in the governance of some companies regarding ESG (20).

JUDICIAL

The US Supreme Court issued its decision in *West Virginia v United States Environmental Protection Agency* (USEPA), a case challenging the 2015 Obama administration's Clean Power Plan's (CPP) rule. The court held that the USEPA exceeded its statutory authority under the Clean Air Act (US) in attempting to regulate the nation's energy sector by adopting the CPP. The court ruled that the agency could not "force a nationwide transition away from the use of coal" (21). The decision limits the USEPA's ability to regulate greenhouse gases. States will likely use their authority to regulate GHGs.

STATES

Several states are progressing carbon management policies. The California Air Resources Board (CARB) released its *Draft 2022 Scoping Plan* for comment. The Scoping Plan presents a path for carbon neutrality by 2045, while supporting economic, environmental, energy security, justice, and health priorities. The Scoping Plan calls for the deployment of CCS technology in sectors where non-combustion options are not technically or economically viable for meeting 2045 goals (22).

Several other states have enacted legislation or policies covering CO_2 storage. These include Indiana, West Virginia, and Wyoming. States continue to face permitting concerns where only two states, Wyoming and North Dakota, have primacy for issuing permits under the Underground Injection Control Program, which covers injection wells for geologic storage of CO_2. The existing permitting process can take years. The state of Louisiana has a primacy permit application pending. Texas, Arizona, and West Virginia are in the pre-application primacy application process.

DIVERSE PARTNERSHIPS PROMOTE CCS DEPLOYMENT

Significant momentum for CCS project developments and announcements in various sectors continues. The high level of activity related to CCS project developments is likely due to a number of reasons that include collaboration and partnerships between companies with differing capabilities and requirements in the CCS value chain; policy changes such as enhanced 45Q tax credits; and innovative pipeline service changes from natural gas to CO_2 transport conversions. Examples of some these innovative projects include:

- Talos Energy, Carbonvert, and Chevron announced an expanded joint venture to develop the Bayou Bend CCS hub, with Talos being the operator (23).
- NEXT Carbon Solutions and California Resources Corporation jointly announced an agreement to explore further the decarbonisation of CRC's Elk Hills Power Plant. The companies seek to capture and utilise the emissions from the Elk Hills Power Plant for permanent storage in oil-producing reservoirs (24).
- Carbon America will finance and operate systems in Colorado ethanol plants to capture and store underground 95 per cent of CO_2 emissions from two Colorado plants (25).
- Tallgrass plans to convert its Trailblazer natural gas pipeline to transport CO_2 captured from a carbon capture project at an ADM corn processing complex in Nebraska. The 400 mile (644 km) pipeline expands the reach of its Eastern Wyoming Sequestration Hub (26).
- The Red Trail Energy CCS project at its ethanol facility near Richardton, North Dakota, is officially operating. The project is the first in the US to operate under a state-led regulatory authority for carbon storage. Red Trail is advancing the project utilising the 45Q tax credit (27).
- More companies announced support for the massive proposed carbon capture and storage hub in the Houston Ship Channel, bringing the number of industrial facilities to 14 (28).
- Occidental will build 70 carbon capture facilities by 2035. The facilities are expected to each remove as much as 1 Mtpa of CO_2 directly from the atmosphere (29).

DEVELOPMEMNTS IN BRAZIL

Brazil hosts an operating CCS facility in the Santos Basin where Petrobras continues progressing toward its goal of injecting 40 million tonnes of CO_2 by 2025. Significant policy developments regarding CCS deployment occurred in 2021 and 2022 in Brazil. In addition to updating its NDC, significant legislation was introduced into Brazil's legislature (30). Bill 1.425/2022 establishes a legal framework for the geological storage of carbon dioxide, addressing pore space property rights, long-term responsibilities and its transfer from private to public agent, the definition of regulatory agencies, and the period of monitoring. (31)

Additionally, Decreto 11.075/2022 establishes the procedures for the preparation of "Sectoral Plans for Mitigation of Climate Change" and sets the National System for the Reduction of Greenhouse Gas Emissions (31).

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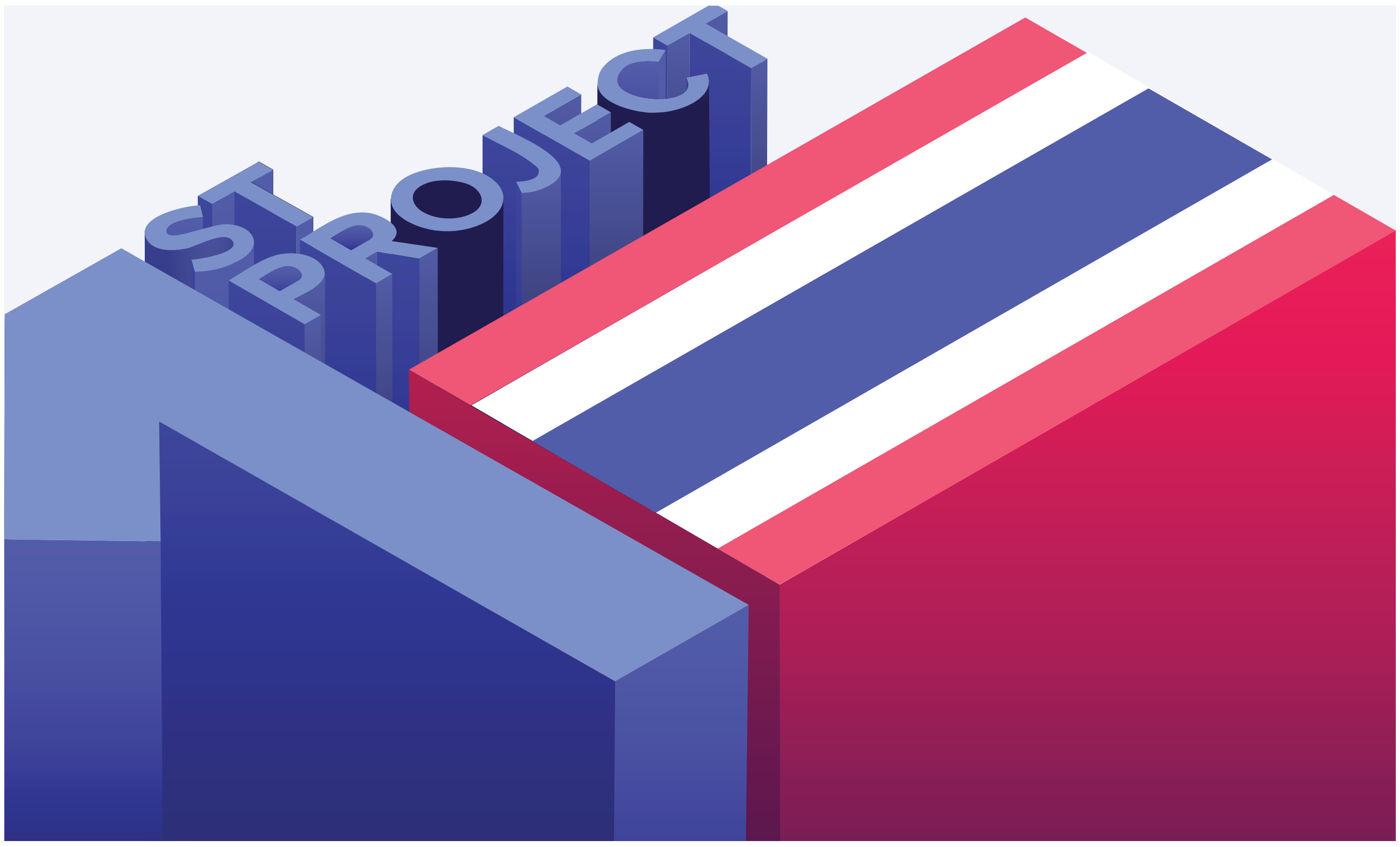
4.2

ASIA PACIFIC

CCS in the Asia-Pacific region, as part of broader climate mitigation, remains a continuing contrast between significant development and lagging deployment. While the public and private sectors across the region continue to release climate mitigation plans and ramp up decarbonisation efforts, much more is required and soon (1).

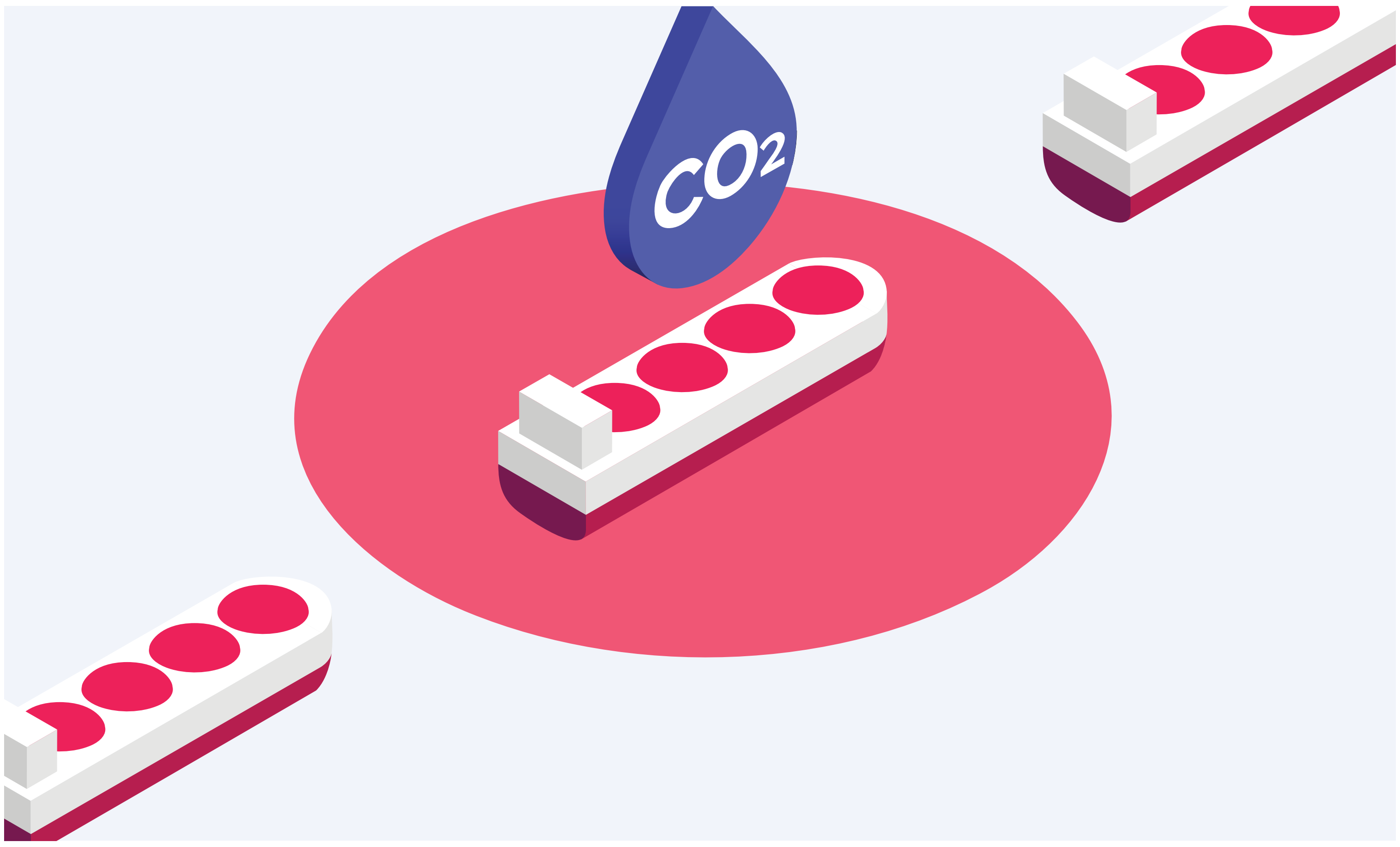
OVERVIEW



THE FIRST COMMERCIAL PROJECT WAS ANNOUNCED IN THAILAND.

ON 25 FEBRUARY 2022, THE WORLD'S FIRST SHIPMENT OF LIQUID HYDROGEN IN A PURPOSE-BUILT SHIP, FROM THE PORT OF HASTINGS IN VICTORIA, AUSTRALIA, WAS SUCCESSFULLY UNLOADED IN KOBE JAPAN SUCCESSFULLY COMPLETING THE HYDROGEN ENERGY SUPPLY CHAIN PROJECT.

CHINA'S FIRST MILLION-TONNE CCUS PROJECT COMMENCED OPERATION.

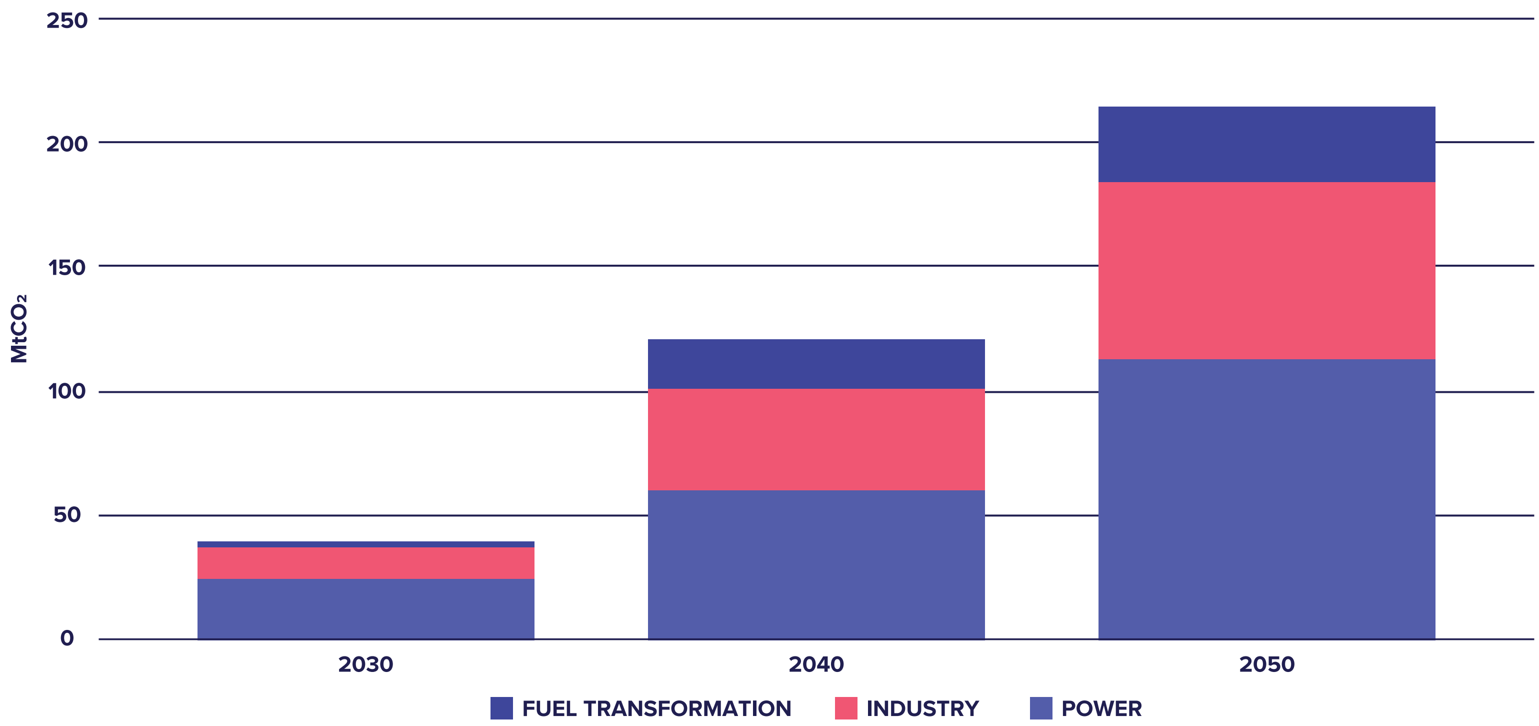


JAPANESE SHIPPING COMPANIES ARE INCREASINGLY ACTIVE IN LIQUIFIED CO_2 TRANSPORTATION FOR CCS, WORKING ON SHIPPING TECHNOLOGY AND DEMONSTRATION PROJECTS.

Part of the complexity of regional climate ambition is that many Asian economies, particularly those in Southeast Asia, are reliant on fossil fuels to drive their growth. Many also remain home to a substantial portion of the world's emissions-intense industries, highlighting the necessity of CCS in managing the dual challenge of growth and decarbonisation.

Some notable progress has been made over the past 12 months. Several new projects have been announced, including the first commercial project in Thailand, and institutional momentum is clear as CCS regulations and policy mechanisms have begun to emerge at national and sub-national levels. Collaboration continues to accelerate, with MOUs proliferating across both the private and public sectors. However, three broad barriers to CCS remain across the region to varying extents – geological storage resource data, legal and regulatory frameworks, and incentivising policy.

FIGURE 11: *CCUS Deployment in Southeast Asia in the Sustainable Development Scenario (Source: International Energy Agency 2021) (note: values shown are from the IEA Sustainable Development Scenario; corresponding CCUS deployment levels are generally higher in the Net Zero 2050 roadmap)*



MALAYSIA

OVERVIEW

Malaysia, in large part through its well-established oil and gas industry, is positioning itself to be a CCS leader in Southeast Asia. At a Global CCS Institute event in April, a representative from Malaysian national oil and gas operator, Petronas, stated that the national vision was to become an offshore storage hub by the end of the decade (2). MPM Senior Vice President, Mohamed Firouz Asnan, publicly said that “sixty per cent of storage capacity will be allocated to Malaysia – for Petronas and our partners – while the remaining 40 per cent will be made available to other users” (3).

PROJECTS

More information has been released regarding the Kasawari CCS project, located offshore from Sarawak. Linked to the Kasawari Ph2 Field, the project forms part of a strategy to monetise high CO_2 gas resources and part of the organisation’s broader objective of achieving net-zero by 2050. The project seeks to capture approximately 4.5 Mtpa CO_2, beginning in 2025, transported via pipeline 135 km to a depleted reservoir in the M1 field (2).

The second project emerging in Malaysia is the Lang Lebah CCS project. Offshore from Sarawak, Lang Lebah is the largest discovery from PTTEP, Thailand’s national oil operator (4). The reservoir is estimated to contain 17 per cent CO_2, necessitating CCS (5).

POLICY

In September 2021, during the release of the *12th Malaysia Plan 2021–2025*, the Malaysian Government committed to achieving net-zero by 2050 ‘at the earliest’, with a commitment to a 45 per cent reduction in emissions by 2030, based on 2005 levels (6). The national commitment, in line with the same commitment from Petronas, highlights a necessary role for CCS for the world’s fourth-largest liqufied natural gas (LNG) producer (7).

In the same plan, the President announced the introduction of a carbon pricing mechanism (6). However, little information has been released as to rates and administration. A national climate change legal framework is expected near the end of 2022. CCUS regulations are believed to be under development.

INDONESIA

OVERVIEW

Indonesia remains a CCS proponent and appears to be a deployment frontrunner in Southeast Asia. Like Malaysia, the broad vision for Indonesian CCS is delivering project-level abatement, while also opening the opportunity for the country to become a storage facility in the region. The Indonesian Government is progressing policy and regulatory development as foreign oil and gas operators drive projects.

PROJECTS

In late 2021, BP announced that the Indonesian oil and gas regulator, SKK Migas, had approved the expansion of the Tangguh LNG project and the development of the Vorwata CCUS project (8). The project, slated for completion by 2026 or 2027, will inject up to 4 Mtpa for incremental gas recovery and permanent storage (9).

Repsol is planning its first injection at its Sakekamang CCS project by 2027, which is estimated to be able to permanently store 2.5 Mtpa.

In May, Pertamina announced it would collaborate with Air Liquide Indonesia to develop CCUS technology at the Balikpapan Refinery Processing Unity, with CO_2 utilised or stored in the Kutai Basin (10). Elsewhere, four organisations, Japan Oil, Gas and Metals National Corporation (JOGMEC); Mitsubishi Corporation (MC); Bandung Institute of Technology (ITB); and PT Panca Amara Utama (PAU), have agreed to conduct a joint study on the production of ammonia with CCS.

POLICY AND REGULATORY DEVELOPMENTS

Indonesia established a taskforce in mid-2021, coordinated by the Ministry of Energy and Mineral Resources, to draft CCUS regulations. The regulations are expected to be disseminated by the end of 2022. The Presidential Regulation 98/201 on the Instrument for the Economic Value of Carbon for the Achievement of the NDC and Control, a carbon pricing mechanism, was meant to launch in early 2022, but has been delayed several times. The mechanism effectively sets up a legal framework for both domestic pricing and trading of carbon and will operate in conjunction with the carbon tax set to be imposed on coal-fired power plants (at US$2.09 per tonne).

AUSTRALIA

PROJECTS — NEW AND UPDATED

Perhaps the most significant development in the Australian CCS project landscape has been the progress of the Middle Arm Sustainable Development Precinct, a natural gas processing and low-carbon manufacturing hub in the Northern Territory. The Middle Arm hub is now in the early planning phases, having received project commitments from the previous federal government, as well as major natural gas operators INPEX and Santos, in the past 12 months.

In November 2021, Santos announced a final investment decision on its Moomba CCS project, which will commence operations in 2024 and inject 1.7 Mtpa (11). Santos entered into the FEED phase in March for the proposed Bayu-Undan CCS project, located offshore from Timor-Leste (12). Bayu-Undan could store up to 10 Mtpa CO_2, acting as a regional storage hub (12).

In April, ExxonMobil, through Esso Australia, signalled it was undertaking pre-FEED studies to determine the potential for a CCS hub in the Gippsland Basin (13). Woodside, BP, and Japan Australia LNG are undertaking feasibility studies for a CCS network on the Burup Peninsula in North-West Australia. (14) Mitsui E&P Australia is assessing the feasibility of commercialising the Mid-West Modern Energy Hub, a natural gas processing and blue hydrogen facility (15).

POLICY AND REGULATORY DEVELOPMENTS

Notably, a new Australian Government was elected in May. The Labor Government has pledged to strengthen baselines for major emitters under the existing safeguards mechanism, effectively meaning that companies will be able to emit less each year or else pay for offsets. Significantly for CCS, deployment may be spurred in hard-to-abate industrial sectors as a result.

In late 2021, a CCS methodology was included under the Emissions Reduction Fund, allowing projects to generate Australian carbon credit units (ACCU) and thereby generate income (16). In June, the Minister for Climate Change and Energy, Chris Bowen, announced an independent review into the Emissions Reduction Fund, highlighting CCS among several recently adopted methodologies for specific scrutiny.

In March, the Western Australian Minister for Mines and Petroleum, Bill Johnston, approved the drafting of the Greenhouse Gas Storage and Transport Bill, which will underpin the regulatory regime for CCS in the state (17).

JAPAN

OVERVIEW

A reliance on energy imports and limited CO_2 storage capacity, coupled with a net-zero by 2050 commitment and associated decarbonisation targets, has driven Japan to act as a convenor for climate and energy in the region. In line with this, Japan continues to promote bilateral and multilateral CCUS collaboration in the Asia-Pacific region.

PROJECTS AND NOTABLE UPDATES

Japanese shipping companies are increasingly active in liquefied CO_2 transportation for CCS. Japan CCS is working with Kansai Electric Power on a demonstration project to transport CO_2 from Kansai Electric Power's coal-fired power complex in Kyoto to the Tomokomai CCS project, commencing operation in 2027 (18). NYK and the Knutsen Group have established a new business for liquefied CO_2 transportation and storage; Mitsubishi Shipbuilding is working on the construction of a CO_2 demonstration ship; and MOL and Petronas have signed an MOU on liquefied CO_2 transportation for CCUS (19–21).

In January, the *Suiso Frontier*, the world's first liquefied hydrogen carrier, arrived in Victoria, Australia to transport hydrogen to Japan (22). The shipment marked an important milestone for the Hydrogen Energy Supply Chain (HESC), a coal gasification hydrogen pilot project. If the HESC moves to the commercial phase, captured CO_2 will be stored at the CarbonNet CCS project. Elsewhere in Australia, INPEX is playing a leading role in the development of the Middle Arm CCS hub in Darwin.

J-POWER and ENEOS have announced a feasibility study for a domestic CCS project, with a potential final investment decision (FID) projected for 2026 and subsequent commencement in 2030 (23). The project aims to decarbonise oil refining and coal-fired and biomass-fired plants and stored CO_2 in western Japan.

POLICY AND REGULATORY DEVELOPMENTS

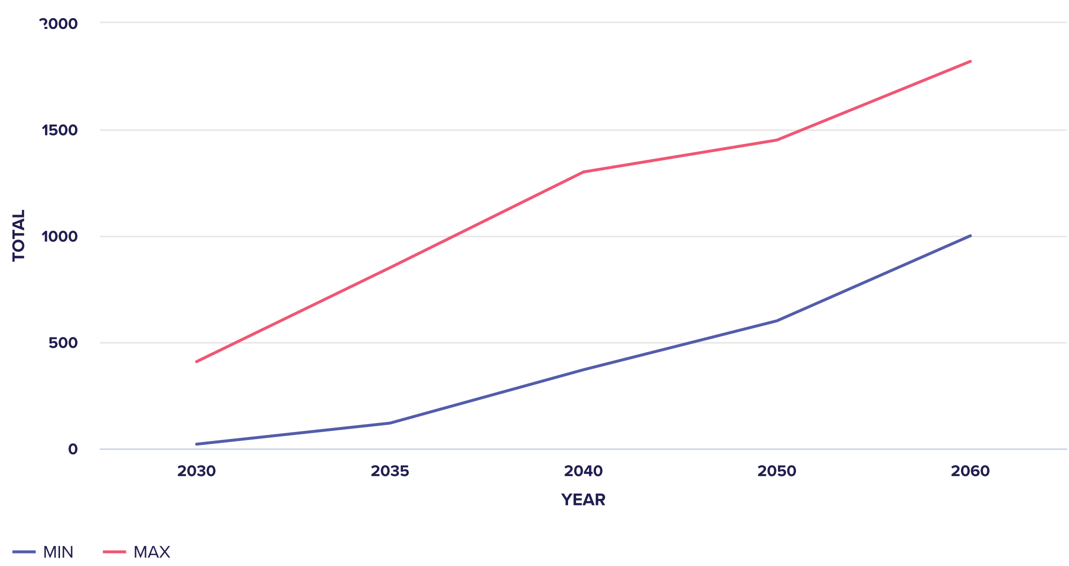
A new strategic energy plan was approved by Cabinet in late 2021, mapping a pathway toward a 46 per cent greenhouse gas emissions reduction by 2030 (based on 2013 levels) and carbon neutrality by 2050. Hydrogen is expected to play a key role in achieving the plan. The Ministry of Economy, Trade and Industry has drafted a long-term CCS roadmap, aiming to store 120–240 Mt CO_2 offshore from Japan by 2050.

CHINA

OVERVIEW

CCUS has been the subject of increasing attention in China over the past 12 months. Research has highlighted the potential role for CCUS under the carbon neutrality target, suggesting the technology suite may account for reductions of 0.6–1.45 billion tonnes of CO_2 per annum by 2050 and 1–1.82 billion tonnes per annum by 2060 (24).

FIGURE 12: *Potential CCUS deployment China (24)*



PROJECTS

Major state-owned energy companies are leading project development. China's first integrated million tonne (1 Mtpa) CCUS project, developed by SINOPEC, came into full operation at the end of August 2022. The captured CO_2 from Qilu Petrochemical plant is transported to the Shengli Oil Field for Enhanced Oil Recovery. Huaneng has commenced construction on a 1.5 Mtpa coal-fired power CCUS project in the Ordos basin, widely anticipated to be the world's largest coal power CCUS project. CNPC plans to begin injecting up to 5 Mtpa CO_2 from 2025. CNOOC is starting China's first CO_2 offshore storage in the mouth of the Pearl River. On June 27, ExxonMobil, Shell and CNOOC signed a MoU with Guangdong Provincial Government to evaluate a world-scale hub project in Dayawan Petrochemical Industry Park. Additionally, several private companies, including Guanghui and Hengli, have announced CCUS projects.[1]

POLICY AND REGULATORY DEVELOPMENTS

In 2021, China announced its 30/60 climate policy framework, outlining a goal of achieving carbon peaking by 2030 and climate neutrality before 2060.[2] The 1+N framework lays some of the groundwork for CCUS policy directions. The People's Bank of China launched a carbon emissions reduction facility, a structural monetary policy instrument providing financial institutions with low-cost loans to support decarbonisation projects, in which CCUS was included (25). Despite progress and some policy documents outlining a role for CCUS, lack of a policy-based, sustainable business model for CCUS remains a deployment hurdle.

REST OF ASIA PACIFIC

THAILAND

In June, Thailand's national oil and gas operator, PTTEP, announced the country's first CCS project[3] (26). The project, located at the Arthit offshore gas field, has entered FEED and is expected to commence operations in 2026. PTTEP has also signed an MOU with Japan's JGC Holdings and INPEX on the *Thailand Carbon Capture and Storage Initiative*, a feasibility study investigating the potential for deployment across oil and gas, hard-to-abate industrial sectors, and power generation (27).

SINGAPORE

Shell and ExxonMobil (the latter through its Low Carbon Solutions business unit), both with oil refining and petrochemical manufacturing plants in Singapore, are investigating regional CCS hubs to capture CO_2 and transport it to nearby storage (28). Capture could span petrochemicals, biofuels, refineries, and hydrogen development (28).

THE REPUBLIC OF KOREA

Korean energy company, SK E&S, signed an MOU with Australia's Santos to support and collaborate on the development of CCS projects and hubs in Australia and at Bayu-Undan (29). Korea's domestic petrochemical industry continues to investigate and deploy CCUS at feasibility study and pilot demonstration levels.

FOOTNOTES

[1]. Guanghui Industry Investment is mainly engaged in automobile dealership, energy, real estate, and logistics businesses. Hengli Group produces and sells crude oils, aromatics, purified terephthalic acids, polyester, and other products. Hengli Group also produces textile materials.

[2]. "30/60" refers to current China's climate targets – peaking its emissions before 2030 and achieving carbon neutrality by 2060. The "1" refers to the "guiding opinions" that set out the overarching principles of all forthcoming climate policies that aim to facilitate China's 30/60 goal. The "N" stands for a combination of sub-plans, starting with the *Action Plan for Carbon Dioxide Peaking by 2030*.

[3] The Arthit project was added to the database after project number and capacities were finalized for this report and consequently this project is not included in those totals.

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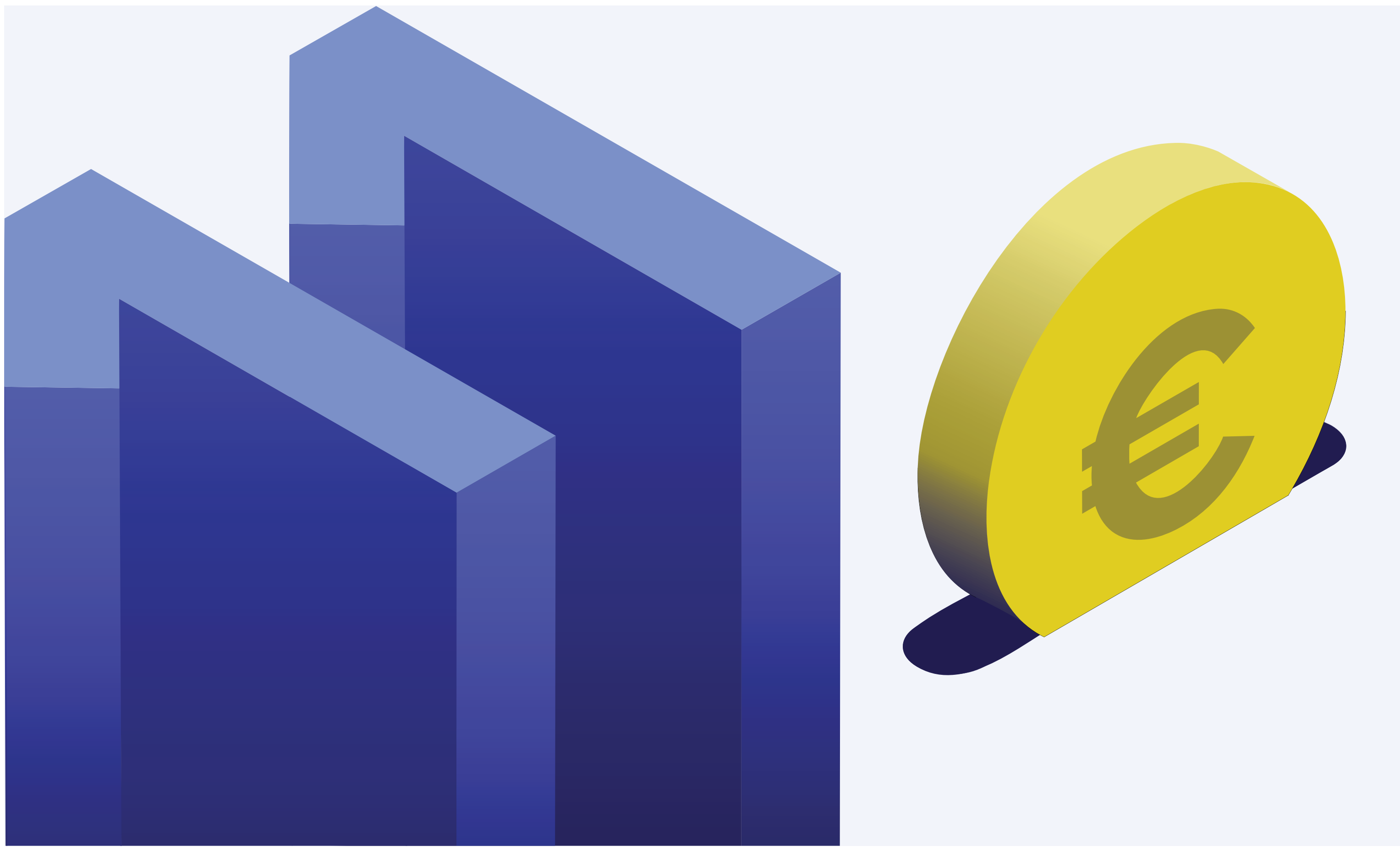
4.3

EUROPE AND THE UK

For yet another year, carbon capture and storage has seen a promising increase in projects across the European region. Today, there are 73 CCS facilities in various stages of development across Europe and the UK.

OVERVIEW



11 CCS/CCUS PROJECTS FUNDED BY THE EU INNOVATION FUND.

DUTCH GOVERNMENT INCREASES SDE++ BUDGET TO €13BN.

UK AWARDS FUNDING FOR TWO CCS CLUSTERS.

Notable factors driving CCS momentum include supportive climate policy programs and measures by the European Commission, including an increase to the number of projects funded through the EU Innovation Fund – a grant program launched in 2020 that aims to support the Commission's 2050 climate neutrality targets (1). Similarly, in the Netherlands, the Sustainable Energy Transition Subsidy Scheme (SDE++), under which CCS projects are eligible for funding, increased from €5 billion to €13 billion over the last year alone (2) In the UK, through its CCUS Infrastructure Fund (CIF), the government committed to establishing two CCS projects by the mid-2020s, and two more by 2030 (3). The past 12 months have illustrated a promising trajectory of industry deploying CCS projects on the foundation of existing policy.

POLICY AND FINANCE DEVELOPMENTS

Legislative proposals are being developed to introduce regulatory mechanisms in the EU that could further support CCS deployment, including carbon removal certification, which remains underway.

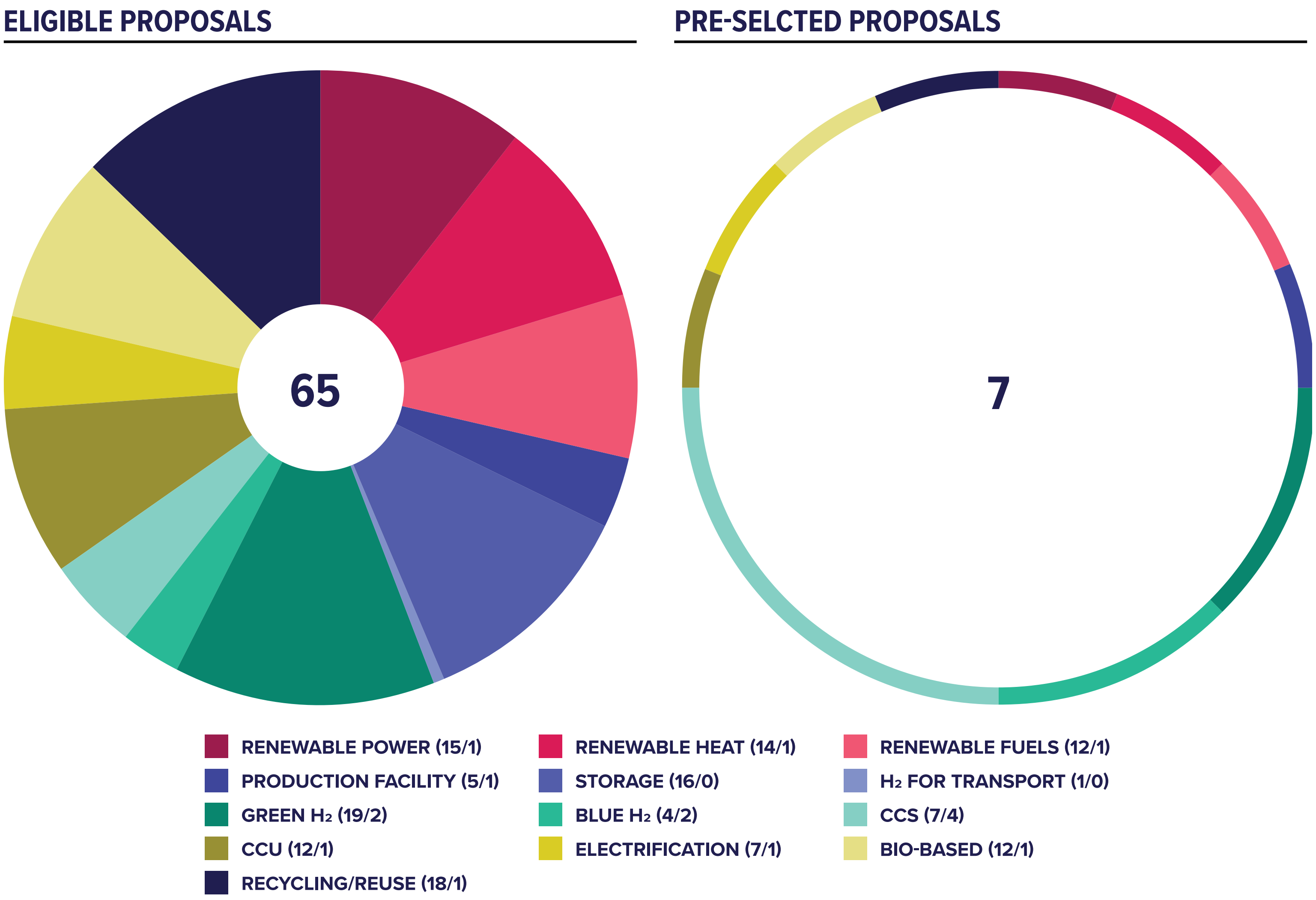
In December 2021, the European Commission released a formal communication on sustainable carbon cycles, which affirmed that reaching climate objectives will require a significant scale-up of carbon removal solutions, particularly within the next 10 years. The Commission further acknowledged that accounting for CO_2 removals accurately and transparently will be needed, and legislated, if carbon removal options are to be further realised. The communication seeks to incorporate CDR into the EU's regulatory and compliance framework, as it relates to Europe's climate neutrality targets (4).

EUROPEAN UNION

CCS FUNDING

The EU Innovation Fund, which aims to invest around €38 billion by 2030 toward innovative clean technologies in Europe (based on the auctioning of 450 million allowances from 2020 to 2030), announced its first successful grant recipients following the first and second call for projects (5). Out of a total seven successful applicants, four projects selected in the 2021 first call had a CCS component. CCS facilities in Finland, Belgium, Sweden and France will all be beneficiaries of funding to support their CCS projects in hydrogen, chemical, bioenergy and cement production, respectively (5). Results of the second call announced in 2022 saw seven CCS and CCU projects awarded with funding. Projects in Bulgaria, Iceland, Poland, France, Sweden and Germany have been selected, ranging from low-carbon cement production, carbon mineral storage site development and sustainable aviation fuel production (6). The upcoming third call will have a funding pool of around €3 billion, up from €1.5 billion for the previous call, in an effort to accelerate green transition (7).

FIGURE 13: *EU Innovation Fund Applications and CCS Contenders – First Call (number of applications/number of pre-selected proposals)*



TRANSPORT MODALITIES

The broadening of CO_2 transport modalities in the Trans-European Energy Networks regulation (TEN-E), which would include shipping, trains and trucks, did not progress further in 2021 (8). As the TEN-E goes under review, CO_2 transport modalities aside from pipelines are not favoured according to a provisional agreement and recent trilogue discussions between the European Commission (EC), the Council of the European Union and the European Parliament (EP). Consequently, CCS efforts looking to be included in the EU's Projects of Common Interest – a designation which eases permitting processes, along with providing access to funding – will not be explicit in legislation.

REPOWEREU

The European Commission has responded to the energy crisis prompted by the Russia-Ukraine conflict through the development of the REPowerEU Plan. Under the plan, the Commission announced aims to end the EU's reliance on Russian energy resources while also tackling climate change. Although carbon capture and storage is not explicitly mentioned in the REPowerEU communication, the commission notes its intention to further support Europe's hydrogen economy.

UNITED KINGDOM

FUNDING PROGRAMS

Following a £1 billion announcement in 2020 to develop CCUS clusters through the UK Government's CCS Infrastructure Fund, the first two recipients of the grant were announced in late 2021, with an expected completion date by the mid-2020s. The HyNet Cluster consortium operating in North West England and North West Wales, and the East Coast Cluster along England's North Sea shore by Humber and Teesside, will enter the Track 1 project negotiations as preferred beneficiaries of the CIF (9). Scotland's CCS project, Acorn, has been placed on the "back-up" to the Track 1 clusters. Through the CIF-selected projects, the UK Government aims to capture and store 20 to 30 Mtpa CO_2 by 2030 onward (10).

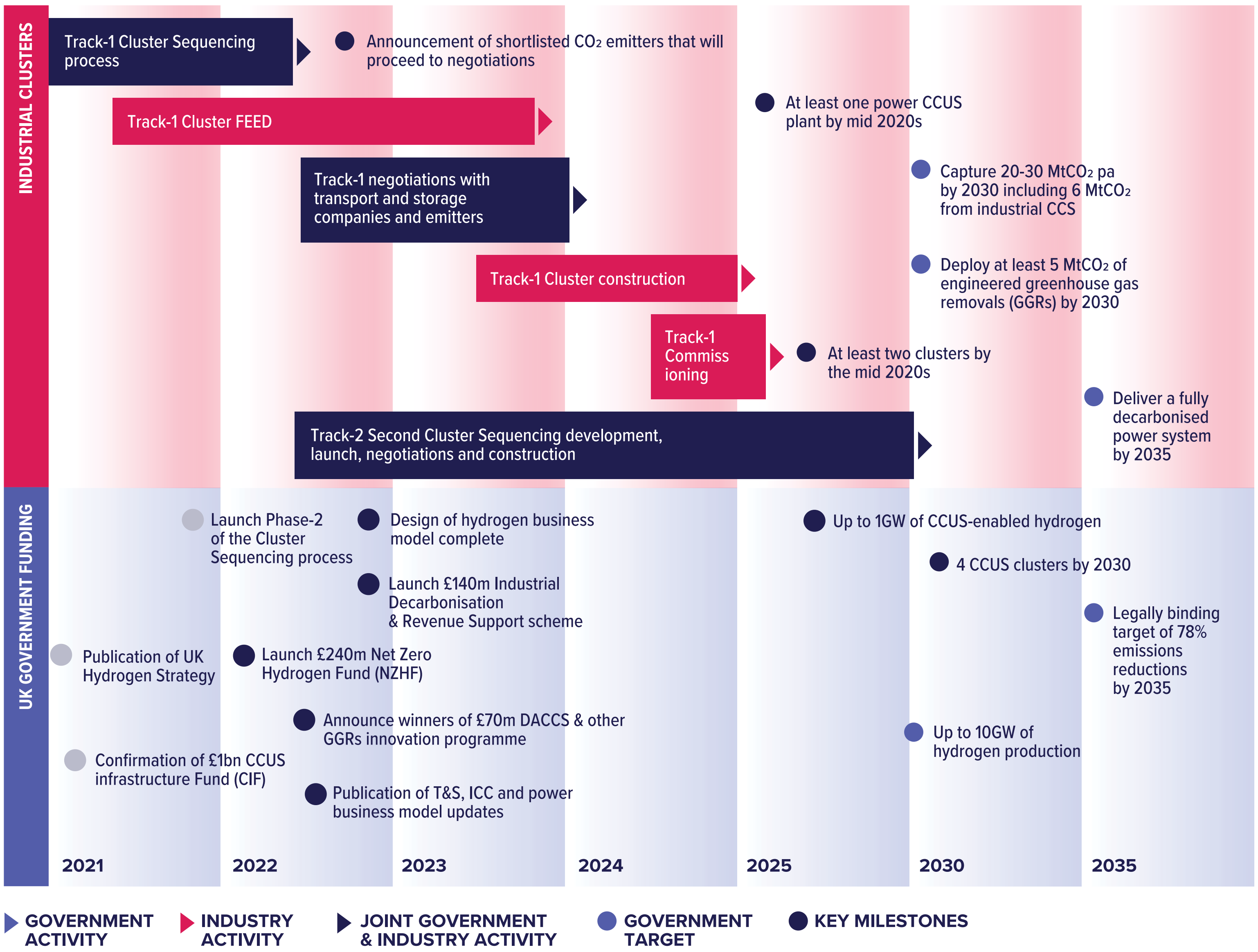
In August 2022, as part of the Track 1 clustering process, the UK Government announced the shortlist of 20 CCUS capture projects that can receive possible support from government, once it has established that the projects represent a "value for money" investment for the taxpayer.

POLICY

Over the last 12 months, the UK Government focused its CCS policy sights on building a cadence around CCS funding programs and policy announcements made in 2020. The government's *10-Point Plan for a Green Industrial Revolution* committed to investing in carbon capture usage and storage. This gave way to a number of CCS-specific policies and funds, including the UK CCUS Innovation Programme, which aims to enhance CCS research and innovation programs along with the CCS Infrastructure Fund, that are intended to support the development of four CCS networks (11).

To further highlight the breadth of public-private partnerships and funding efforts across the UK region – including the CIF, the UK CCUS Innovation Fund and more – the UK Government released a CCUS Investor Roadmap, illustrating its CCUS delivery plan from 2021 to 2035 (12).

FIGURE 14: *UK Government CCUS Delivery Plan*



Following the announcement of CIF recipients in Scotland, where HyNet and East Coast Cluster consortiums were selected to progress as part of Track 1 projects, the national government increased its CCUS funding commitment and ambitions. If selected as part of the CIF-awarded applicants, the Aberdeenshire-based Acorn project will see the Scottish Government provide £80 million to launch the initiative – a project, the government says, that is required if Scotland is to meet its net-zero targets (13).

THE NETHERLANDS

In 2020, the Dutch Government established the Sustainable Energy Transition Subsidy Scheme (SDE++) to support renewable energy projects and CO_2 reduction efforts, such as CCS. In 2022, the Dutch Government announced it would more than double the annual budget for the SDE++, increasing it from €5 billion to €13 billion (14). The Porthos Project, which aims to store CO_2 in the North Sea sub-surface and had previously been announced as a grant recipient, was awarded nearly half of the 2021 budget (15). The SDE++ funding commitment will continue until 2025.

DENMARK

Through three government programs, the Danish Government announced it would invest a total of €5 billion in support of carbon, capture and storage projects (16). Part of the funding will be rolled out across a period of ten years under the Energy Technology Development and Demonstration Programme (EUDP), with Project Greensand and Total Energies-led Bifrost having already received funding from the Danish Government (16). The EUDP aims to support Denmark's target of reducing emissions by 70 per cent by 2030 – Europe's most ambitious 2030 target thus far (17).

In addition to funding support, the Danish Government has entered a bi-lateral agreement with the Belgian Government, along with Flanders, which aims to support cross border CO_2 transport between the two countries (18). The move follows EU Innovation Funding approval of the Kairos@C project – a cross-border CCS effort led by BASF's Belgian operations, alongside Air Liquide (19). The bi-lateral agreement is expected to lead the way for transboundary CCS, both in Europe and beyond.

NEW CCS MARKETS

Several countries in Europe are entering the CCS market for the first time, including Bulgaria, Poland and Finland. Enabling these projects is the EU Innovation Fund's granting program (19, 20).

EU INNOVATION FUND PROJECTS – LARGE-SCALE CCS PROJECTS

- Holcim Deutschland's Carbon2Business project will retrofit its German cement plant with CCS to capture over 1 Mtpa CO_2.
- The full-scale ANRAV project will capture CO_2 from cement facilities in Bulgaria and store it in an offshore storage site in the Black Sea.
- Coda Terminal, by Carbfix, will develop a mineral storage hub in Iceland with the capacity to store 880 million tonnes of CO_2.
- Perstorp's Project Air will develop a full-scale fossil-free methanol plant in Sweden.
- Shell's HySkies project will produce sustainable aviation fuel through waste-to-energy CCUS operations in Sweden.
- The GO4ECOPLANET project in Poland will capture and store CO_2 from Larfarge Cement's Kujawy cement production operations.
- The CalCC project in France will capture CO_2 emissions from exhaust gases, produced during lime production, for permanent storage.
- Kairos-at-C will mitigate 14.2 million tonnes of CO_2 through a cross-border CCS value chain in Belgium, the Netherlands and Norway, which includes CO_2 capture from hydrogen and chemical plants.
- BECCS@STHLM will capture and store 7.8 million tonnes of CO_2 over 10 years from Exergi's Stockholm-based biomass plant.
- The K6 Program in France will capture 8.1 million tonnes of CO_2 from its cement plant, to be stored in the North Sea.
- The SHARC effort in Finland will reduce CO_2 emissions from a diesel refinery through green and blue hydrogen production.

NORTH SEA

With its substantial storage capacity, carbon capture and storage projects are being established with the aim of storing CO_2 beneath the North Sea basin:

- The Norcem Brevik Cement Plant in Norway, operated by HeidelbergCement, will capture and store 0.4 Mtpa CO_2. Once completed, it will be the first cement plant with a full-scale CCS facility (21).
- The UK's largest power station, Drax, seeks to retrofit its biomass-powered facility with CCS. The project will be part of the Zero Carbon Humber consortium operating on England's North Sea coast (22).
- The H21 North of England project will decarbonise power, heating and transport across the north of England, and will be inclusive of CCS. It aims to convert the UK gas grid from natural gas to zero-carbon hydrogen. By 2035, the project will have the potential to have one of the world's largest CCS schemes (23).

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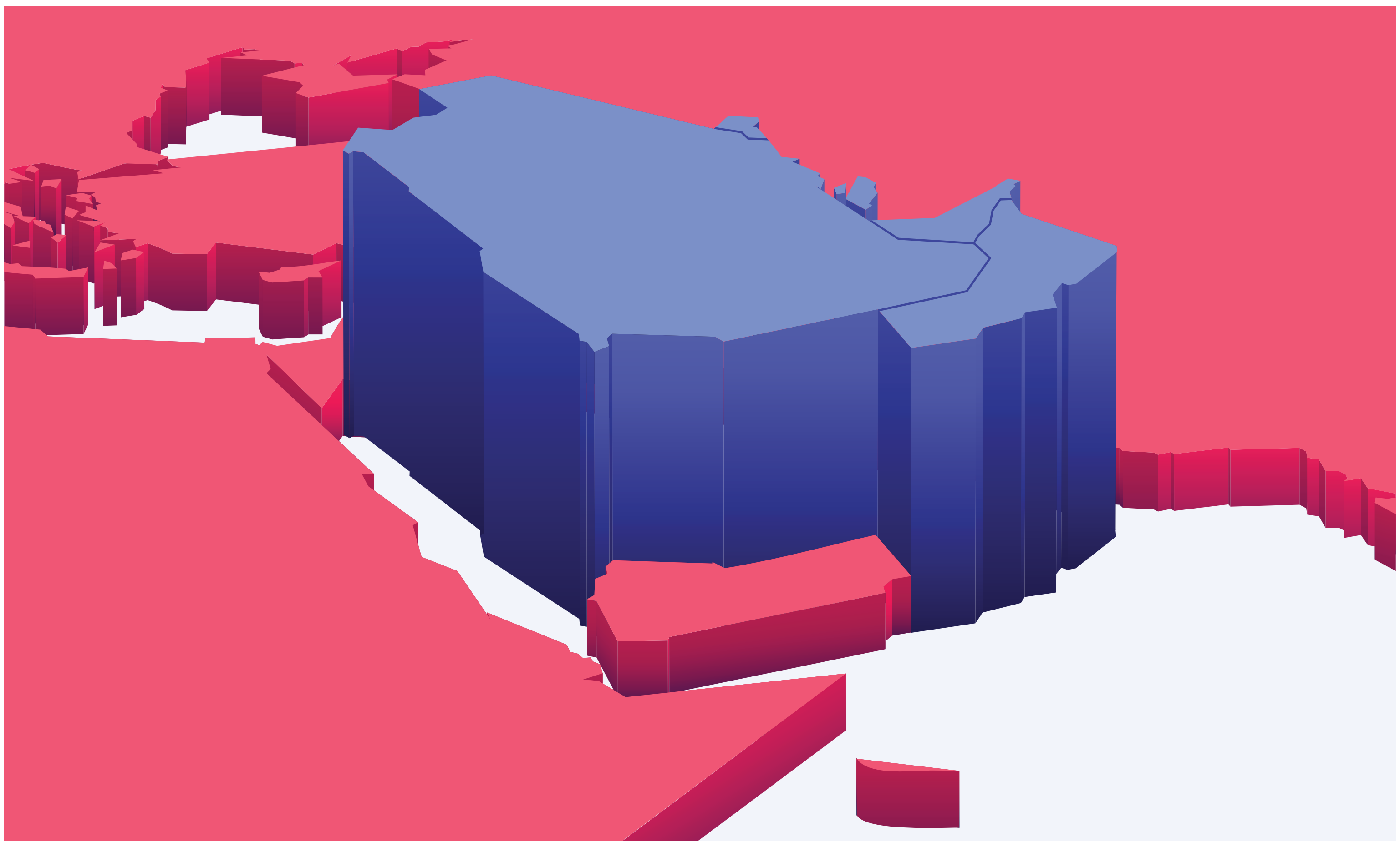
4.4

MIDDLE EAST AND NORTH AFRICA

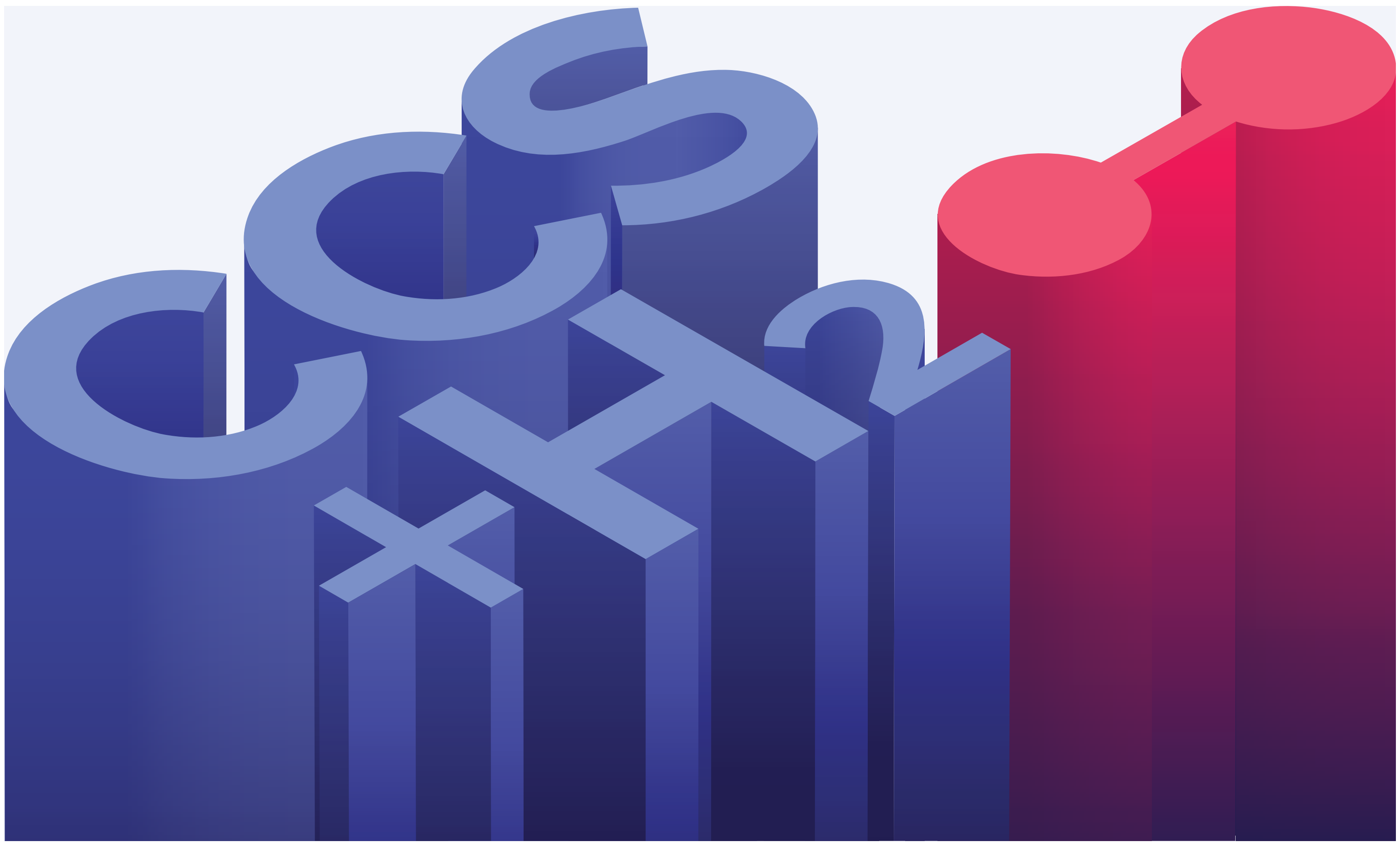
The Middle East and North Africa (MENA) is the largest oil-exporting region in the world. Around 85 per cent of the greenhouse gas (GHG) emissions in the region come from energy production, electricity generation, the industrial sector, and domestic energy consumption.

OVERVIEW



THE GULF COOPERATION COUNCIL STATES ARE POISED TO SEE CCS TAKE OFF IN THE COMING DECADE.

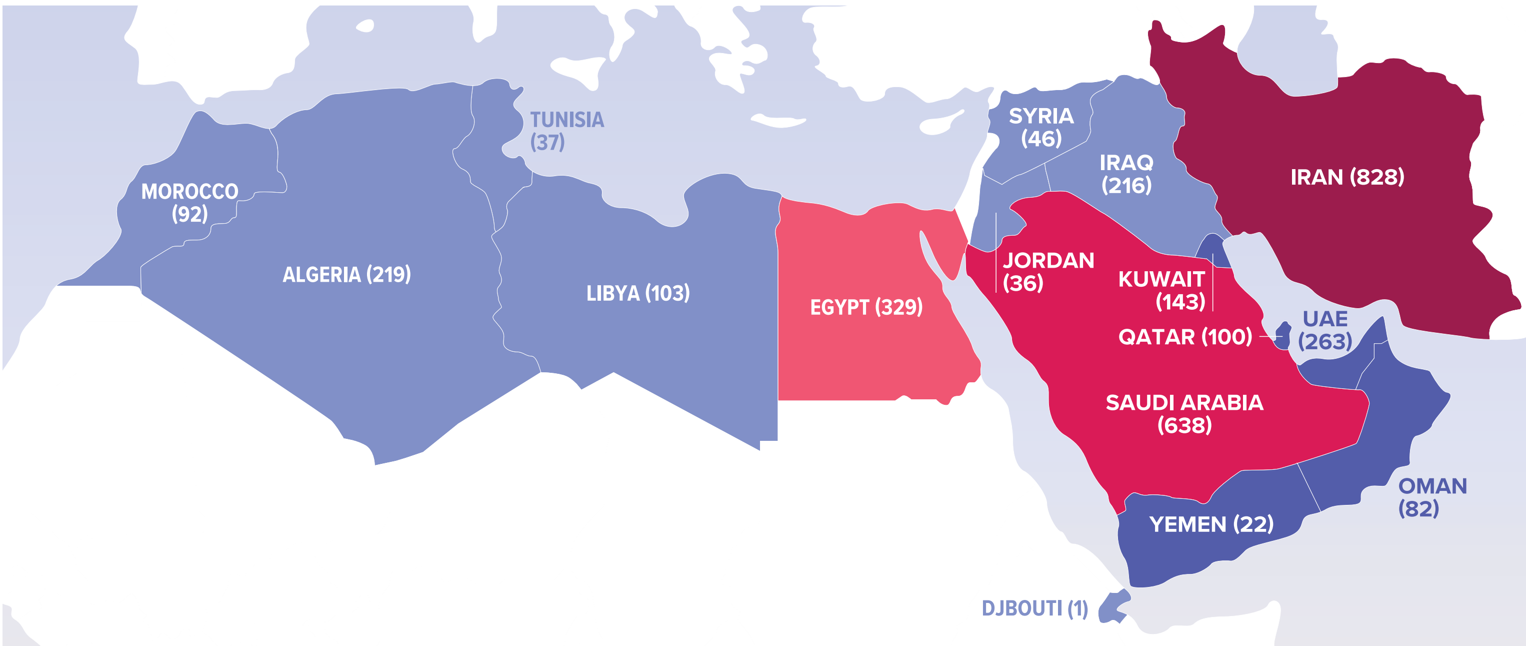
GLOBAL CCS INSTITUTE OPENS OFFICE IN ABU DHABI.



THE POTENTIAL FOR CCS GROWTH IN THE MENA REGION IS BEING DRIVEN BY CLIMATE COMMITMENTS AND THE INCREASING POTENTIAL TO ACT AS A HUB FOR LOW-CARBON HYDROGEN.

The MENA region is considered one of the most carbon-intensive, with countries such as Qatar, Kuwait, the United Arab Emirates (UAE), Bahrain, and Saudi Arabia among the world's top 10 per capita carbon emitters. Without a change in energy policies and energy consumption behaviour, MENA's energy-related GHG emissions will continue to grow (1). The figure below shows the GHG emissions in the individual MENA region countries (2). Moreover, the MENA region holds a major stock of the world's oil and gas reserves and has always been a key player in the geopolitics of energy. To maintain this position, the region is required to invest in decarbonisation and clean energy technological options.

FIGURE 15: *Greenhouse Gas Emissions Across the MENA Region*



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CCS represents an opportunity in the region to reduce carbon dioxide emissions. Three operational CCS facilities in the UAE, Saudi Arabia and Qatar already account for around 10 per cent of global CO_2 captured each year (3). Moreover, the region has extensive experience in CO_2 injection and storage with the In Salah CCS project in central Algeria being a world-pioneering onshore CO_2 capture and storage project, which has built up a wealth of experience highly relevant to CCS projects worldwide (4).

The potential for CCS growth in the MENA region is driven by multiple factors:

- Different MENA countries such as Saudi Arabia, the UAE, Bahrain, Egypt, Iraq, and Iran have explicitly included CCS in their nationally determined contribution (NDC) registry maintained by the United Nations Framework Convention on Climate Change (5).
- The announced commitment to net-zero and emissions targets. The UAE and Saudi Arabia announced their net-zero target by 2050 and 2060, respectively. Oman has set a net-zero target by 2050, Qatar has committed to emissions reductions of 25 per cent by 2030 and Bahrain 30 per cent by 2035 (6).
- The launch of the Saudi Arabian and Middle East Green Initiatives.
- The increasing potential for the MENA region to be a hub of low carbon hydrogen (7).
- Future industrialisation plans with a major focus on clean and sustainable industries (8).
- The region has the required geological formation and expertise in managing subsurface injection of CO_2.

PROJECTS

CCS project activity is spread across Qatar, Saudi Arabia, and the UAE – more specifically in Abu Dhabi. The combined annual capture capacity is around 3.7 Mtpa of CO_2 at three CCS facilities:

- Qatar Gas captures 2.2 Mtpa of CO_2 from the Ras Laffan gas liquefaction plant.
- Saudi Aramco captures 0.8 Mtpa of CO_2 at its Hawiyah Naturals Gas Liquids plant. The CO_2 is used to demonstrate the viability of enhanced oil recovery (EOR) at the Uthmaniyah oil field.
- In Phase I (of at least three phases) of Abu Dhabi National Oil Company's (ADNOC) Al Reyadah project, 0.8 Mtpa of CO_2 is captured at the Emirates Steel plant in Abu Dhabi.

Both the Ras Laffan and Al Reyadah projects are already developing expansion plans:

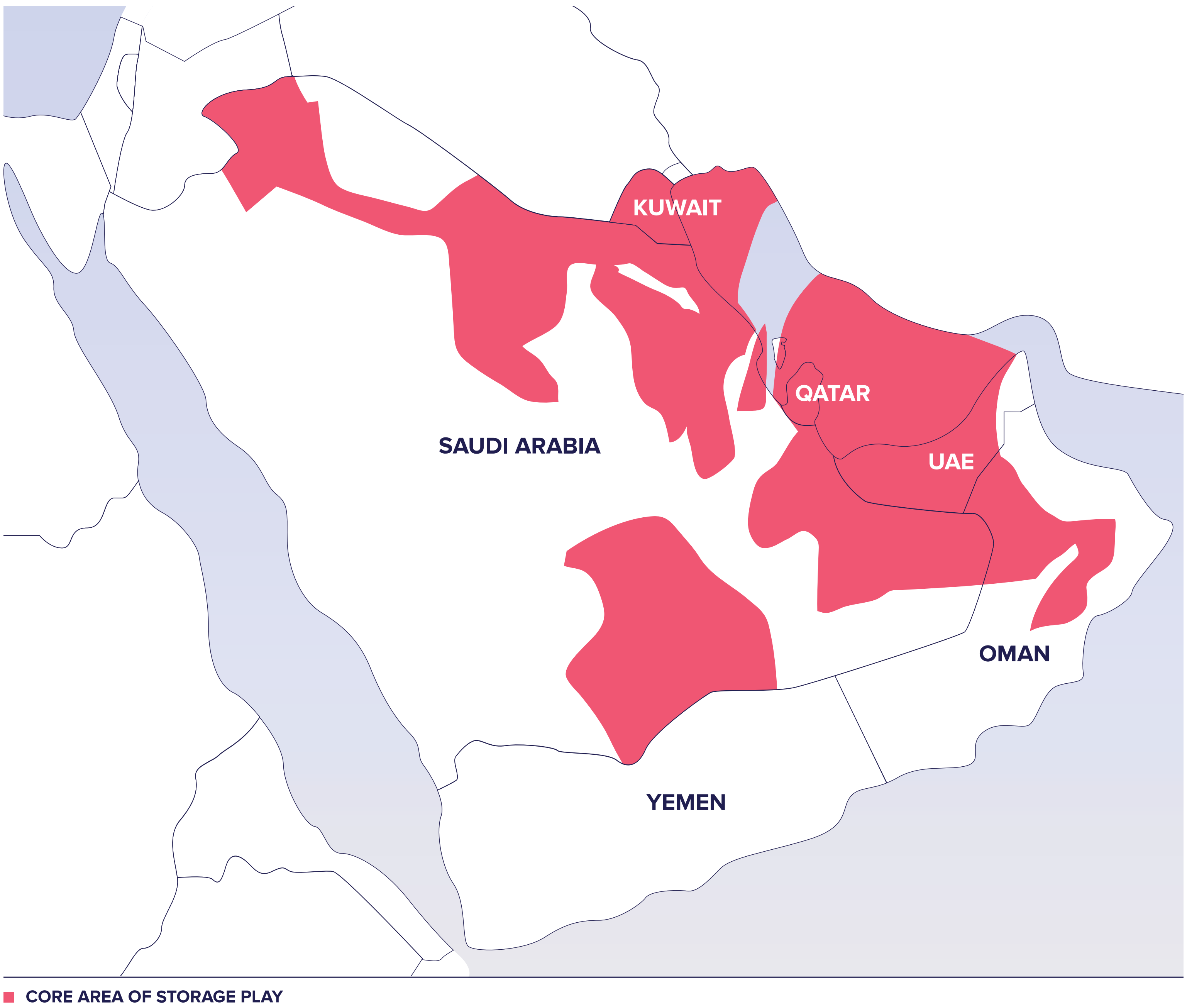
- Qatar Gas expects to expand its capture rate to 5 Mtpa by 2025 (9). This carbon capture new phase is expected to be accelerated after the announcement that the North Field expansion is the world's largest liquefied natural gas (LNG) project (10).
- ADNOC estimates that Phase II and Phase III will capture about 5 Mtpa of CO_2 before 2030. This is expected to be captured from two sources: 2.3 Mtpa of CO_2 from the Shah sour gas plant and another 1.9 Mtpa from the Habshan and Bab gas processing facility (11,12).

There are two regional CO_2 utilisation facilities:

- Saudi Basic Industries Corporation captures 0.5 Mtpa of CO_2 at its Jubail ethylene facility for use in methanol and urea production.
- Qatar Fuel Additive Company captures 0.2 Mtpa of CO_2 at its methanol refinery.

Aiming to develop a fully integrated CCUS supply chain, the MENA region shows a very high potential for CCUS hubs. A recent study conducted by AFRY and GaffneyCline on behalf of the Oil and Gas Climate Initiative (OGCI) evaluated the potential for carbon capture and CCUS hubs in the Gulf Cooperation Council (GCC) countries (Saudi Arabia, UAE, Qatar, Kuwait, Bahrain, and Oman) (13). With current carbon capture facilities, industrial facilities, available natural CO_2 sinks and future plans in the GCC countries, the GCC countries could be a world-class hub for CCS. In addition, CCUS has promising applications across multiple industrial activities in the GCC countries and will play a role in the decarbonisation of hard-to-abate industries.

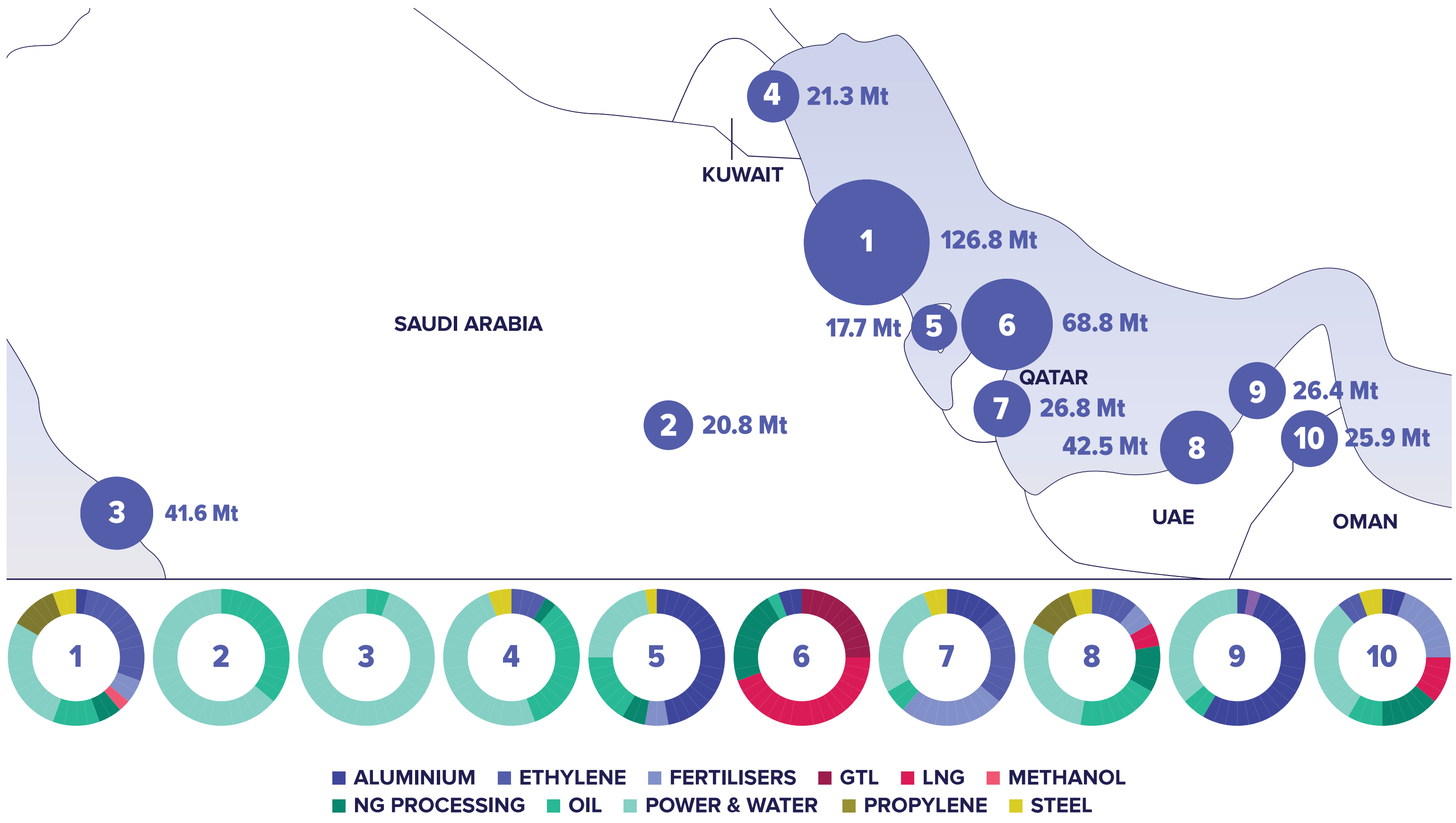
FIGURE 16: *Geological storage map in GCC region*



AFRY and GaffneyCline have revealed the significant subsurface potential for storage in the GCC countries, both in depleted gas reservoirs and saline aquifers, with the greatest opportunity found in the Rub'al Khali Basin and in the sequences beneath Kuwait. Based on this study, the current best-guess storage capacity for the GCC countries is 170 Gt of CO_2 – see the figure above, which shows potential locations for CO_2 geological storage in the Gulf Cooperation Council region.

Moreover, the AFRY and GaffneyCline study revealed that the Gulf Cooperation Council region has the potential to develop active CCUS hubs due to the availability of natural sinks and concentrated sources of CO_2 emissions. Clusters of high-purity, low-cost capture industries coupled with nearby geological storage make it possible to develop hubs that could benefit from economies of scale. This study has identified 10 promising hub locations with the most favourable being in Jubail (Saudi Arabia), northern Qatar, and Abu Dhabi (see figure below).

FIGURE 17: *Potential hubs across the GCC countries (source: Energy Review MENA) (10)*



In addition to the Gulf Cooperation Council, other countries in the MENA region and wider Africa could form a potential location for CCUS hubs. The region in the north of Egypt with its current natural gas facilities and gas reservoirs has great potential. The potential for CCS in Egypt, Nigeria, South Africa, and other countries in the region is being evaluated. The World Bank Group has been aiding its partner countries on carbon capture capacity-building and the evaluation of CO_2 geological storage potential. The most recent study on the potential for CCS in Nigeria was announced in 2022 (14).

POLICY

Most countries in the MENA region have introduced climate policies, but not CCS-specific policies. Ahead of COP26 in Glasgow in November 2021, Lebanon, Israel, the UAE, and Yemen pledged to be carbon neutral by 2050, Turkey by 2053, and Saudi Arabia and Bahrain by 2060. Jordan, Morocco, Oman, Palestine, Tunisia, and Qatar submitted more ambitious nationally determined contributions and increased their gas emissions reduction goals (1).

The trend of CCS growth in the region is driven by the commitments and vision of national governments, which makes it less dependent on policy incentives than other parts of the world. The governments in the region are focusing on the environmental impact and strategic growth of decarbonisation technologies. In addition, the deployment of CCS in the region could be driven by EOR value, low-carbon hydrogen production and the potential of the region as a hub for CCUS and carbon trading.

Saudi Arabia, the UAE and Egypt have announced the establishment of voluntary carbon market initiatives and fully regulated carbon trading exchange and trading schemes (15–17). The establishment of such platforms is expected to drive the carbon market in the region, which benefits all decarbonisation technologies, including CCS.

OUTLOOK

The UN climate change partners organised the first MENA region climate week in 2022, with the aim of enhancing regional collaboration (18). In addition, the region will also welcome COP27 and COP28, in Egypt and the UAE respectively in 2022 and 2023. This will bring outstanding opportunities to push forward negotiations on vulnerability points for the two countries. From a regional perspective, in October 2021 Saudi Arabia launched the first Middle East Green Initiative, which gathered leaders from the region and foreign partners to exchange opinions on regional climate action.

With the current international geopolitical situation, the growth in LNG exports from the different countries in the region presents an opportunity for low carbon fuels and CCS. Being one of the major LNG exporters in the region, Qatar has announced the extension of the North Field capacity to produce 126 Mtpa by 2027 (10). This extension will also be integrated with CCS to reduce emissions (19).

The Global CCS Institute has been actively monitoring the CCS development in the MENA region. To build on this momentum and future activities, the Institute has established its presence in the region with a regional office in Abu Dhabi. In addition, the Institute is working on increasing its MENA-based members.

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GLOBAL CCS INSTITUTE

ANALYSIS

CHAPTER 5

5.1

CARBON MARKETS

Carbon markets refer to the trade of carbon credits between parties and are either compliance or voluntary. By leveraging market forces, carbon markets enable least-cost pathways toward emissions reductions targets and incentivise investment in CCS infrastructure and networks. Carbon markets have grown considerably over recent years, and with such rapid growth, there is a current need for collective understanding of how CCS can work in current and future markets.

COMPLIANCE CARBON MARKETS

Compliance carbon markets (CCMs) are implemented and regulated by national or regional authorities. Compliance markets typically utilise cap-and-trade schemes, whereby the cap represents a limit of how many tonnes of CO_2 can be emitted by the industries covered in the scheme. This leads to a specific number of tradeable carbon allowances given to each company over a fixed period of time, giving them the legal right to emit an equivalent amount of CO_2. In principle, if a company reduces its emissions below the limit, unused allowances can be traded with other companies that require additional allowances.

The price of allowances is determined by the market, so emitters can choose the most cost-effective approach between purchasing allowances and investing in technologies to reduce their emissions. Over time, governments may reduce allowances given to emitters to meet more ambitious emissions targets. This increases the scarcity of allowances, thereby increasing their price. As the price of allowances increases, investing in technologies such as CCS becomes economically more viable for emitters.

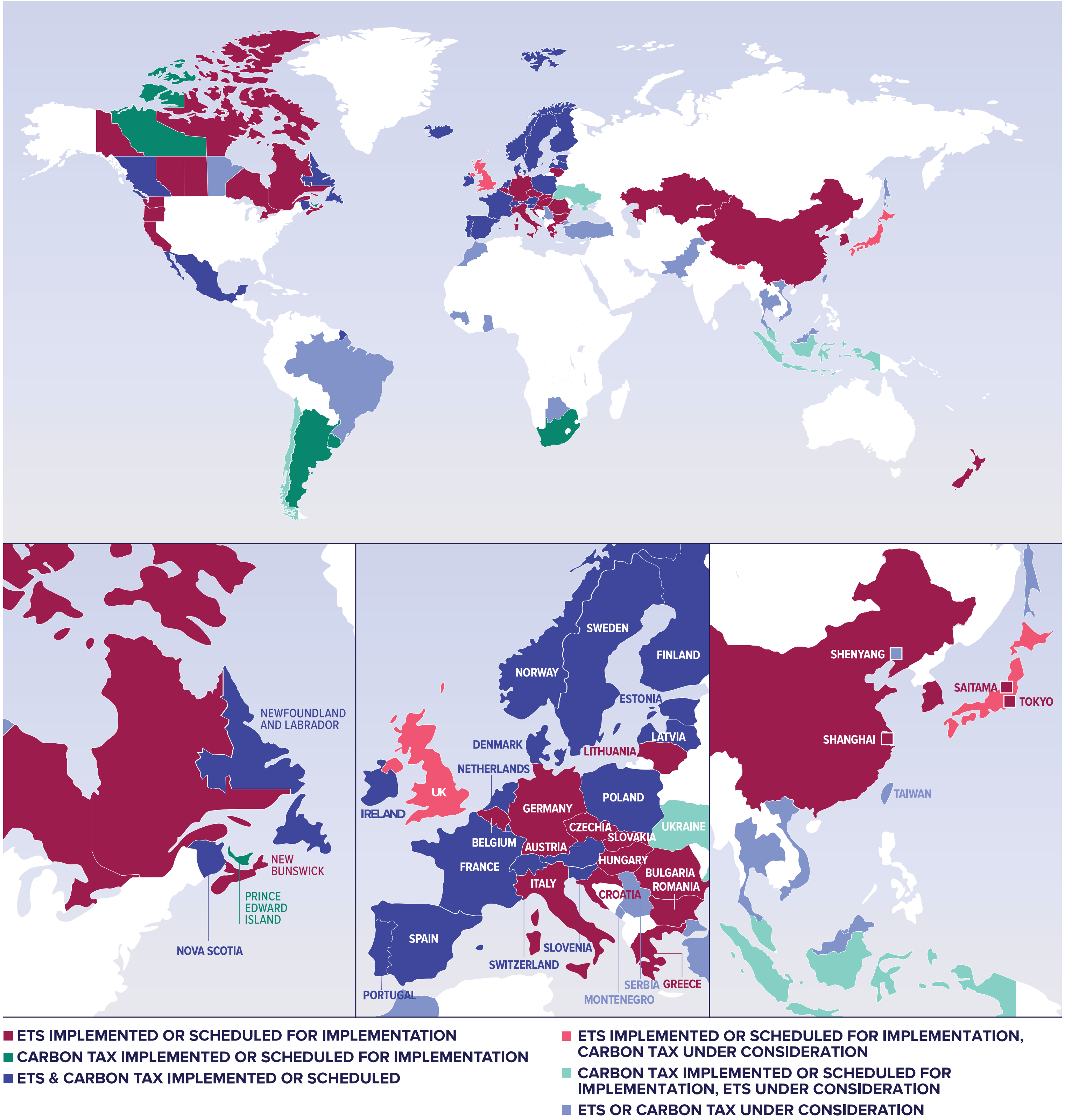
Compliance markets, known as emissions trading systems (ETS), are increasing in number and distribution. Based on data from the International Carbon Action Partnership, an estimated 25 national and sub-national ETSs are in force, nine are in development and 14 are under consideration (1).

Currently, there are two large jurisdictions for compliance markets that include CCS protocols – the EU ETS and the California Low-Carbon Fuel Standard (2,3). Cap-and-trade systems in Tokyo and Quebec do not have CCS protocols, but since they operate in countries with CCS activity, CCS could potentially be included in the future (4,5). This was seen in California, which instituted a CCS protocol under the Low-Carbon Fuel Standard years after it launched its ETS (3). Similarly, the EU ETS adopted a CCS directive some years after it was launched.

VOLUNTARY CARBON MARKETS

Voluntary carbon markets (VCM) are created by private organisations and are self-regulated. VCMs underwent record growth last year, and market could reach US$50–100 billion per year by 2030, driven by net-zero commitments from the private sector (6). VCMs enable investors, governments, non-government organisations and businesses to purchase carbon offsets, called verified emissions reductions (VERs), from project developers and other third parties. VERs are generated by projects that are assessed using greenhouse gas (GHG) reduction methodologies. Projects are then registered in a VCM registry, which tracks the generation of and trade in VERs. As organisations make increasingly ambitious climate pledges, many of them have few cost-effective options to reduce their emissions. Carbon offsets provide companies with a practical and scalable means through which they can achieve emissions reductions. In practice, a company's carbon offset strategy operates in tandem with efforts to reduce emissions directly.

__FIGURE 18:__ Worldwide Carbon Markets – Compliance and Voluntary (Source: World Bank 2022)



THE ROLE OF ARTICLE 6

CCMs and VCMs use different standards and systems, meaning that project developers must satisfy the requirements of multiple methodologies for different systems. This diminishes the potential impact of carbon markets, increasing the cost of decarbonising the world's economy. Article 6 of the Paris Agreement has the potential to overcome this challenge by increasing coordination between governments and the private sector to harmonise project methodologies. Specifically, Article 6 enables countries to trade with one another to achieve their nationally determined contributions (NDC). It has been estimated that US$250 billion per year in savings can be attained by 2030 as a result of Article 6, although this will be much determined by how well it functions (7). In July 2022, the supervisory body responsible for implementing the mechanism for trade under Article 6 was operationalised.

Precedents exist for some market linkages, such as between Switzerland's ETS and the EU ETS, and between Quebec's and California's systems. Other types of overlaps found in markets today see emission allowances traded alongside carbon offsets. For example, California's Cap-and-Trade Compliance Offsets Program allows entities covered by the cap to satisfy a percentage of their regulatory obligations through the trade of VERs under the Verra registry.[1]

The need to include CCS in Article 6 is underpinned by the fact that carbon dioxide removal (CDR) is vital to unlocking the 'net' in net-zero emissions and achieving the 1.5˚C goal of the Paris Agreement. The use of CCS networks can further streamline cost and resource efficiency, especially when planned on a regional or global level.

CCS plays a versatile role in supplying point-source capture and storage as well as CDR, while offering the capacity to store CO_2 over longer and more permanent timeframes than other mitigation/removal options. While the price of a CCS carbon credit will be determined by underlying market supply and demand interactions, credits generated by CCS projects could attain higher values because geological storage of CO_2 is much more secure than storage via nature based solutions (eg, storage in trees or soil). Prices of CCS-generated credits could also increase if market participants would be willing to pay a premium for innovative and novel solutions such as DACCS and BECCS, which currently have no methodologies in place. To further unlock and scale up CCS-related climate action in carbon markets, the CCS+[2] Initiative is working on delivering an integrated methodological framework for generating carbon credits for the full suite of CCS activities for the VCMs and Article 6 (8). The upcoming years will indeed be critical to establishing ways to direct investment and climate finance to CCS, with current thought leadership in academic and industry circles focusing on carbon sequestration/storage units (CSU) and carbon storage obligations (CSO)/carbon takeback obligations as a solution to enhancing the expected value resulting from permanent geological storage (9–11).

FOOTNOTES

[1] Verra is one of the leading VCM registries with almost 1,600 registered projects.

[2] [The CCS+ Initiative includes the plus sign to indicate the use of CCS at point-source, CCUS and CDR in carbon markets.

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5.2

CARBON REMOVALS

Carbon dioxide removal (CDR) technologies remove carbon dioxide from the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) finds that all scenarios that limit warming to no more than 1.5˚C deploy CDR technologies. Further, most models are unable to find pathways that limit warming to 1.5˚C without CDR technologies (1).

NECESSITY OF CARBON REMOVALS

Direct air carbon capture and storage (DACCS) removes CO_2 directly from the atmosphere, while bioenergy with carbon capture and storage (BECCS) captures CO_2 from bioenergy combustion. Because BECCS provides both CDR and usable energy, BECCS is typically a lower cost option than DACCS. BECCS, though, is limited by the sustainable biomass available for energy, approximately 131 EJ globally (2).

Recent economic modelling by the Global CCS Institute found that reaching net-zero (based on IPCC SSP1-1.9) is expected to require the maximum possible deployment of BECCS (3), which is determined by the availability of sustainable biomass. The deployment of DACCS however is determined by its future cost, which is uncertain. To understand the potential role of DACCS in achieving net-zero, the Institute examined a range of possible DACCS costs from US$137 per tCO_2 to US$412 per tCO_2 (compared to the IPCC DACCS cost range of US$100–300 per tCO_2). The Institute's model provided results that are broadly consistent with the IPCC's projections of DACCS & BECCS deployment.

FIGURE 19: *Cumulative CDR through 2100 ($GtCO_2$)*[1]

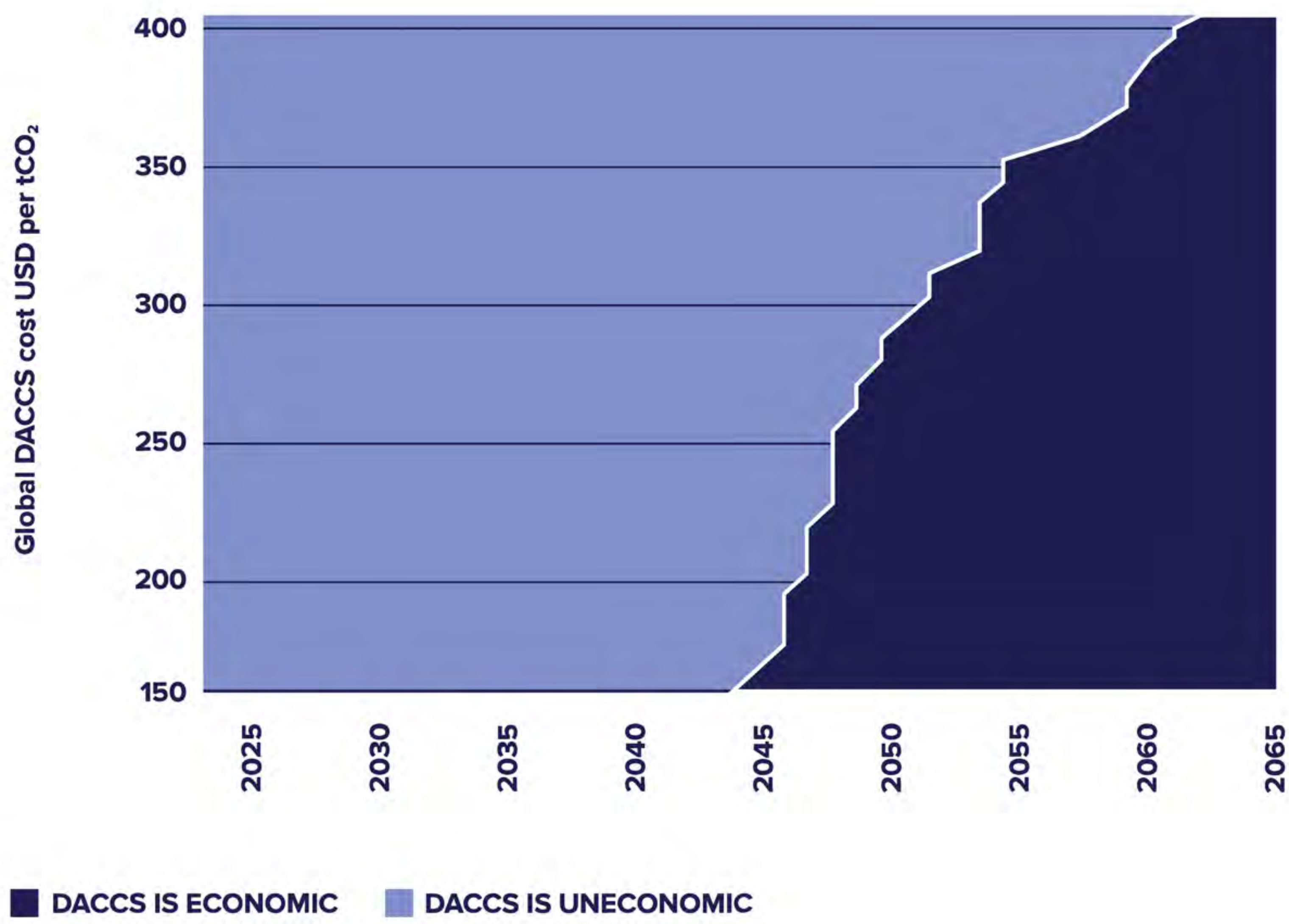
	BECCS	DACCS	Total CDR
IPCC	226-842	109-539	333-1,221
CAPTURE CAPACITY	491-510	1.2-786	511-1,277

Staying within the remaining carbon budget through this century will be more difficult and costly without CDR. The scale of the energy transition to net-zero is staggering. Advanced fuels and their infrastructure must be developed, the electricity sector must decarbonise, and industry and transport must be transformed. CDR can buy time so that the rate of transformation is more manageable for the hardest-to-abate, highest-cost applications (3). CDR can also act as insurance if unexpected constraints arise in other decarbonisation pathways (3).

ECONOMIC POTENTIAL OF DACCS

Another result from the Institute's modelling is that the earliest DACCS would be deployed on *an economic basis* without any dedicated DACCS incentives is 2043, with the lowest-cost DACCS assumption (US$137 per tCO_2), but not until 2062 with the highest-cost assumption (US$412 per tCO_2). Figure 21 shows the economic breakeven point by year and cost of DACCS.

FIGURE 20*: Breakeven costs for DACCS over time (assumes no DACCS-specific incentives)*



The economic deployment of DACCS beyond the breakeven point depends on how low the cost of DACCS is and how early that breakeven occurs. Very little DACCS is deployed if the cost is higher than US$350 per tCO_2. Significant levels of DACCS are economic between US$137 and US$223 per CO_2 (16 $GtCO_2$ and 8 $GtCO_2$, respectively, by 2065).

FIGURE 21: *Quantities of CO_2 stored from DACCS at different costs over time*

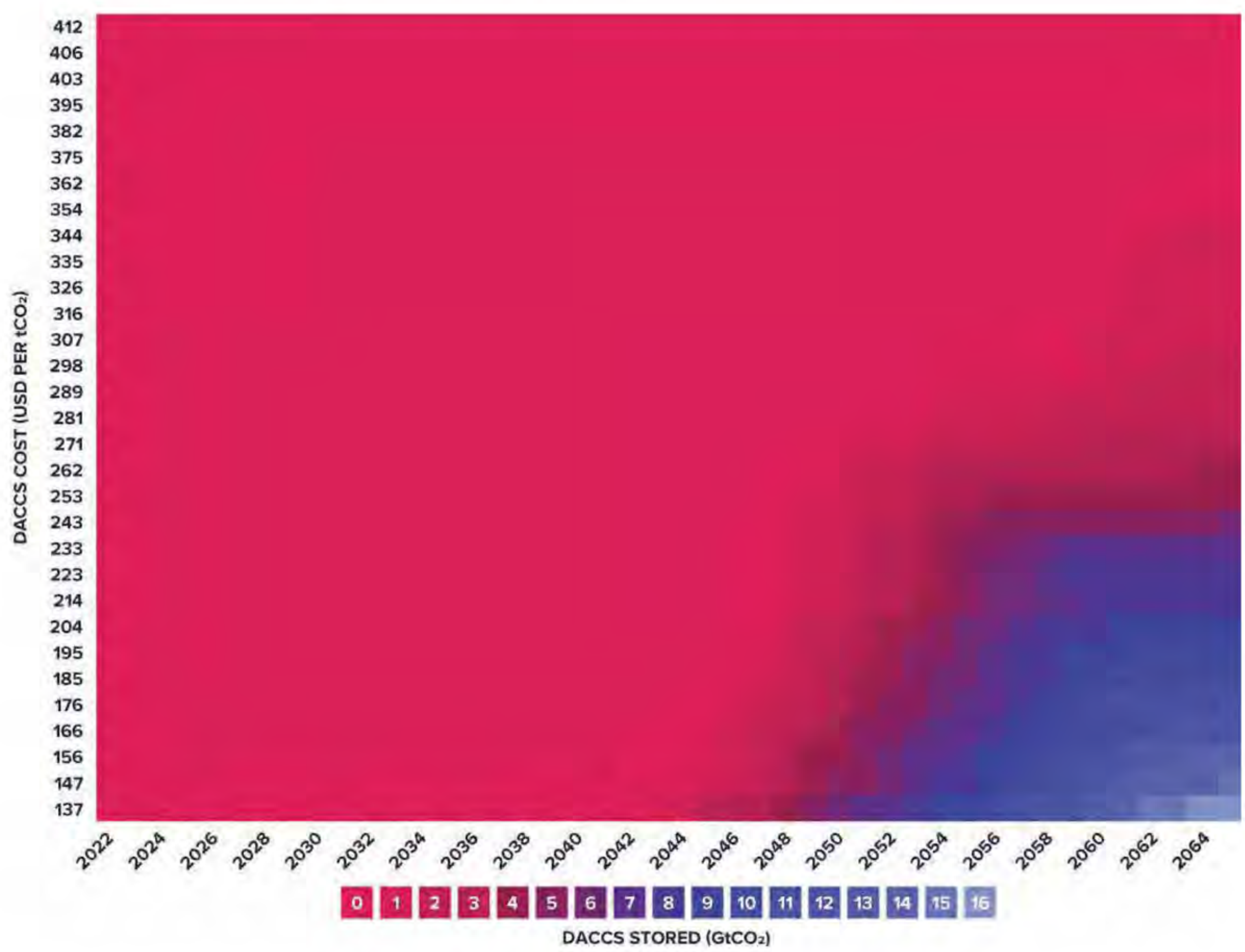
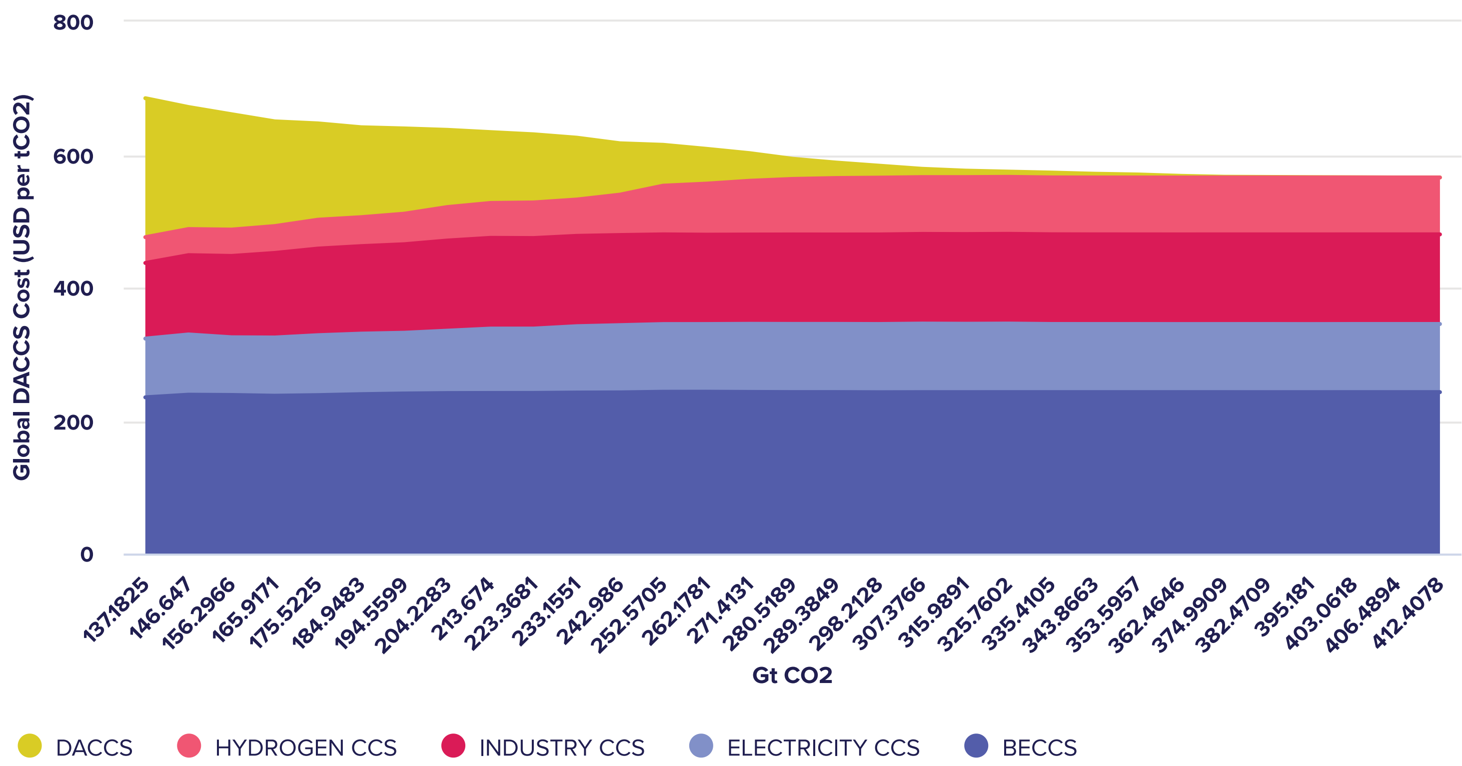


Figure 22 shows how different DACCS cost assumptions affect other types of CCS, including BECCS, electricity fossil CCS, industry CCS, and hydrogen CCS. BECCS remains constant regardless of the cost of DACCS, as do, for the most part, industry and electricity CCS. The lower the cost of DACCS, the more it is cost-effective in offsetting emissions that would otherwise be decarbonised through a hydrogen pathway, which in turn reduces the need for both green and blue hydrogen and the CCS associated with blue hydrogen.

FIGURE 22: *Cumulative CO_2 stored from 2022 to 2065 by CCS type as the cost of DACCS changes*



DRIVERS AND INCREASING SUPPORT

The primary driver for CDR is the pathway toward net-zero emissions by mid-century. All available BECCS is likely to be deployed because it offers CDR and energy. The lower the cost of DACCS, the more it will be deployed, the lower the price of CO_2 that will result, and the lower the cost of the transition to net-zero.

According to Institute's modelling, the potential cost savings are huge. If the future cost of DACCS can be reduced to US$ 200 per tonne of CO_2, the net present value of savings in the global energy system would be around US$1 trillion (3). If the future cost of DACCS can be reduced to US$137 per tonne of CO_2, the net present value of savings in the global energy system would be around US$3 trillion.

In an effort to drive DACCS technology toward commercialisation to reduce the overall costs of reaching net-zero, governments are implementing specific policies for DACCS. For example, the US Department of Energy announced in May that it would provide US$3.5 billion in funding to four direct air capture hubs over the next five years (4). DACCS also qualifies in the US for 45Q tax credits of US$180 per tCO_2 stored (5). Canada recently announced an investment tax credit of 60 per cent for direct air capture equipment till 2030 and 30 per cent till 2040 (6).

An individual country is unlikely to invest in DACCS at a level needed for globally optimal benefits. Therefore, cooperation among countries is critical to ensuring that DACCS can reach levels that benefit all. This cooperation would fall within Article 6 of the Paris Agreement and the UNFCCC process. One possible approach would be for a group of like-minded countries to form a club and pool money to invest in DACCS projects to drive commercialisation (7).

5.3

HYDROGEN

Hydrogen produced with very low life cycle greenhouse gas emissions (clean hydrogen) has broad application in supporting the achievement of net-zero emissions.

Clean hydrogen can be combined with carbon to create synthetic fuels to replace conventional fossil fuels. It can be used in fuel cells to generate electricity and may be used as a feedstock for many chemical processes. Projections of future clean hydrogen demand exceed 500 Mtpa by 2050 compared to total hydrogen production today of approximately 120 Mtpa, including clean hydrogen production of only around 1 Mtpa[1] (1).

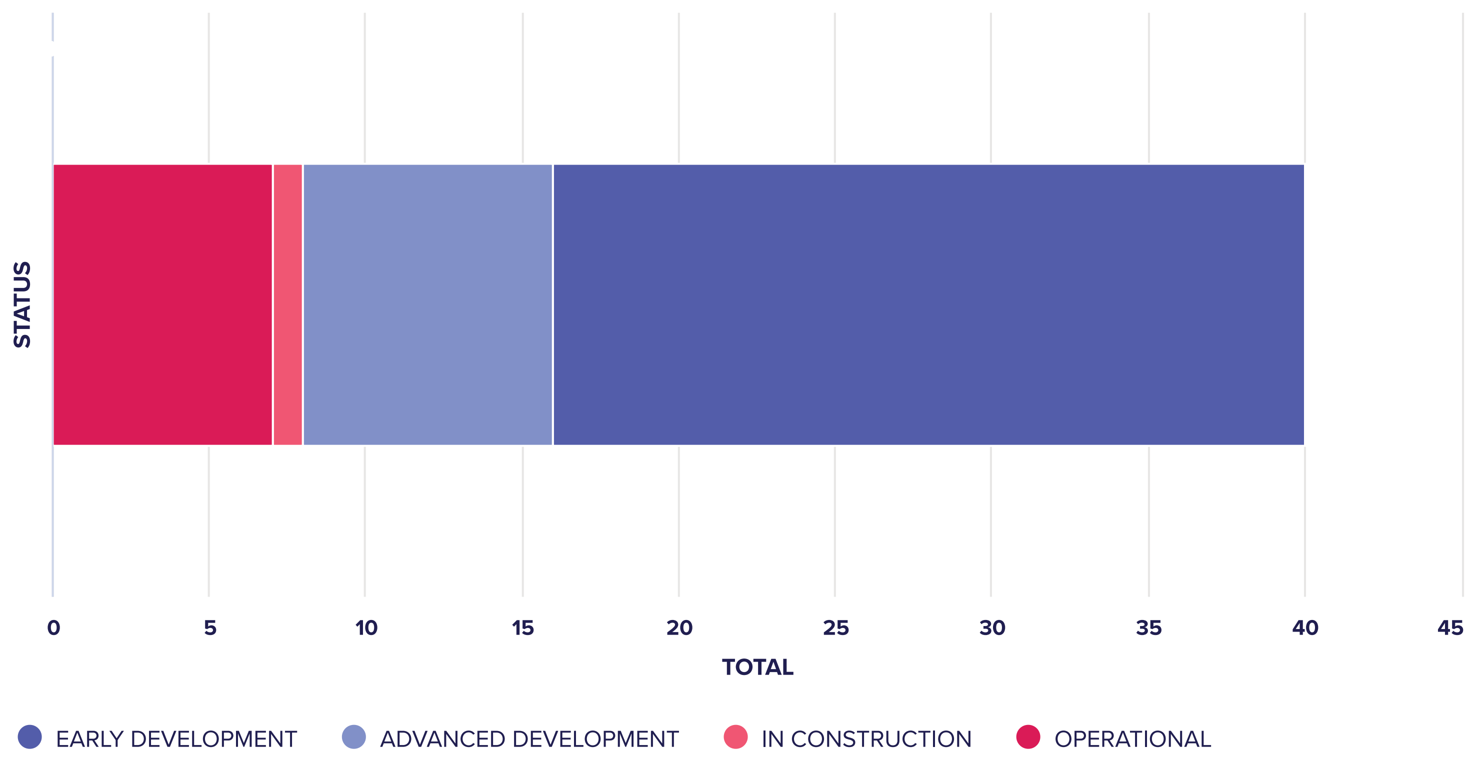
Potential suppliers of blue hydrogen, produced with fossil fuels and CCS, have responded by investing in new projects. As of September 2022, there were 28 blue hydrogen projects in varying stages of development and two in operation. The production capacity of each of these facilities ranges from tens of thousands to hundreds of thousands of tonnes of hydrogen per year.

A large investment in hydrogen transport infrastructure will be required to deliver hydrogen to demand centres. The expected international trade in clean hydrogen will require a fleet of purpose-built ships together with loading and offloading terminals at ports. The Hydrogen Energy Supply Chain (HESC) pilot project has demonstrated the transport of liquid hydrogen from Victoria in Australia to Kobe in Japan. Port infrastructure was constructed at the Port of Hastings in Victoria and in Kobe, and a purpose-built ship, the *Suiso Frontier*, successfully unloaded the liquid hydrogen on 25 February 2022 (2).

Hydrogen has an extremely low boiling temperature of -253°C, which adds to the cost of cooling and transporting hydrogen by ship. Consequently, other options, such as the transport of hydrogen as ammonia (NH_3), are also being pursued. There is already significant international shipping of ammonia across a network of 120 ports with appropriate facilities and using 120 ships that are capable of carrying semi-refrigerated ammonia as cargo (3).

Blue hydrogen project developers are predominantly from the petroleum and industrial chemical industries who currently produce hydrogen using conventional emissions-intense methods such as reformation of natural gas or gasification of coal without CCS. For these companies, moving from conventional hydrogen production to blue hydrogen production is evolutionary, not revolutionary, from a business perspective. Hydrogen production and the management of gases are their core competencies. Oil and gas producers also understand the behaviour of fluids (such as dense phase CO_2) in the subsurface, and operating injection and production wells, and implementing subsurface monitoring programs are routine operations for them. Further, these industries have a strong strategic driver to shift their businesses to support the achievement of net-zero emissions. Production of blue hydrogen allows them to apply their existing knowledge and expertise to a new business opportunity, and in some cases, to use infrastructure and resources (for example, pipelines and platforms) that would otherwise become redundant. These industries are very well positioned to win a large share of any future clean hydrogen market due to the cost competitiveness of blue hydrogen compared to green hydrogen; the scale of their operations; existing competencies and resources, including financial resources; and strong strategic motivation.

FIGURE 23: *Number of Blue Hydrogen Production Facilities by Development Status*



Over time, newer technologies, such as Shell's Gas Partial Oxidation process, will replace older technologies such as steam methane reformation. The current fleet of operating hydrogen production facilities with CCS – the oldest being 40 years old – are retrofits of CCS to existing hydrogen production facilities. They were not designed to achieve very high CO_2 capture rates because there was no requirement or financial incentive to do so. Consequently, they only capture around 60 per cent of their scope one emissions. The next generation of blue hydrogen facilities is being designed from the ground up to achieve very high capture rates. Ninety-five per cent capture is becoming the default capture rate, with some facilities expected to approach 100 per cent capture. Ultimately, the market will demand hydrogen with very low life cycle emission intensity. Blue (and green) hydrogen production facilities will need to demonstrate they meet this high standard to access this market, and new facilities are being designed on that basis.

While production of blue hydrogen can ramp up relatively quickly, this is contingent on there being sufficient demand to justify the investment. The cost of clean hydrogen is a significant factor in creating demand. Hydrogen must compete with conventional fossil energy, which is relatively low cost and enjoys all the benefits of incumbency (for example, distribution infrastructure, supply chains, and mature utilisation technologies). Creating demand for clean hydrogen requires policy that creates value from the emission abatement it provides, as well as significant investment in hydrogen production, storage and distribution infrastructure. Governments have recognised this; the IEA reports that 15 national governments plus the European Union have adopted national hydrogen strategies, almost all with targets and funding (4). Nine of those national strategies, and the European Union strategy, include blue hydrogen.

FOOTNOTES

[1] Includes hydrogen produced in synthesis gas

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5.4

FINANCE

The role of finance in supporting the more widespread deployment of CCS is critical. At the country level, several governments have again sought to prioritise the technology through the provision of a variety of targeted incentives and grants. In parallel, however, it is clear that far greater support from the private finance sector will be required to align investments with a net-zero pathway and provide more tangible assistance to enable widespread CCS deployment.

In line with the wider shift toward green lending and sustainable investing, increased focus has been placed on the role of green or sustainability-focused taxonomies. Taxonomies of this nature now provide guidance to investors as to which activities and investments may formally be classified as environmentally sustainable. In several jurisdictions, regulations and secondary guidance setting out the application and scope of these taxonomies is already in place, while work is underway in many other jurisdictions to develop further examples in the coming years. Efforts to harmonise approaches and adopt the use of common principles has been highlighted by many as an important approach toward a globally consistent approach.

Significantly, CCS has already been formally recognised as an economic activity within the EU's taxonomy, with the subsequent delegated Act setting out technical screening criteria. While this approach has afforded the technology a pathway within the EU model, it will be critical to ensure that other schemes in development around the world also reflect this view and approach.

The examination of environmental social and governance (ESG) factors is increasingly a feature of wider financing and investment decisions. Recent years have seen ESG factors rise from the periphery to become an important aspect of corporate decision making. Climate-related issues have become synonymous with the "E" factor, occupying a significant space within the ESG landscape, and have resulted in increasingly detailed consideration by corporations, investors and the wider public.

While financial and litigation risks continue to motivate companies to focus on climate considerations in their reporting, a focus on mandatory reporting obligations is now expected to drive further climate-related disclosures in the future. Public and private sector net-zero commitments are also a key driver for closer scrutiny of ESG disclosures by shareholders and financiers. Investors are now keen to ensure that companies are aligning their activities with their net-zero commitments and as a result, are looking for companies to provide clear and consistent disclosure statements. The emergence of several net-zero disclosure frameworks, standards and protocols are indicative of the weight that is now afforded to this information.

Where CCS fits within the ESG reporting space, if at all, has been the subject of previous analysis undertaken by the Global CCS Institute. Although clearly not excluded, the quality and utility of information generated through current reporting methodologies may not meet the needs of either project proponents or end-users of this information.

The Institute's recent analysis, however, has considered in greater detail how project proponents and investors may leverage the benefits of their CCS-related investments and project operations in the context of the wider reporting environment.[1] In accordance with the prevalent view that far greater consolidation and harmonisation of reporting schemes will be required, the Institute has proposed a methodology that aims to highlight how CCS-specific factors may be included within the parameters of existing, well-defined reporting pathways.

[1] *An ESG Reporting Methodology to Support CCS-related Investment*
https://www.globalccsinstitute.com/resources/publications-reports-research/an-esg-reporting-methodology-to-support-ccs-related-investment/

FOOTNOTES

[1] *An ESG Reporting Methodology to Support CCS-related Investment*
https://www.globalccsinstitute.com/resources/publications-reports-research/an-esg-reporting-methodology-to-support-ccs-related-investment/

5.5

INDUSTRY

CCS is an essential pathway for key industrial applications. Industries such as cement, iron and steel, and chemicals all have characteristics that make them challenging for decarbonisation (the so-called "hard-to-abate" industries).

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CO_2 is an unavoidable chemical by-product of the calcination reaction that is at the heart of cement manufacturing. On top of this, cement is produced at temperatures well above 600˚C; temperatures typically produced by the combustion of fossil fuels. As such, even if biofuels or other low-carbon sources of heat are used in cement kilns, this CO_2 will still need to be managed. This dual-sourcing, as well as the vast global demand for cement for construction, makes the cement industry highly CO_2 emissions-intensive, accounting for around eight per cent of global anthropogenic greenhouse gas emissions (1).

The world's first cement CCS project is under construction at the Norcem cement plant in Brevik, Norway. Part of the Langskip network, this project is intended to capture 400,000 tonnes per year of CO_2 with an amine-based absorption capture plant. It is expected to be operational in 2024 and will liquefy CO_2 for ship transport to the Naturgassparken CO_2 facility for ultimate storage under the North Sea. Larger scale cement CCS projects are in early development by LafargeHolcim (US) and Hanson Cement (UK).

Cement is proving to be an active sector for new CO_2 capture innovations. Technology company Calix is testing its novel calciner reactor in the LEILAC project in Belgium. This reactor is novel in that it keeps calcination CO_2 (high purity) and the heat sources separate, with indirect heating through a tubular reactor wall. Effectively a form of inherent capture (CO_2 is produced in a pure state), this approach offers a new pathway for the cement sector in the future, as well as the potential to exploit new heat sources such as renewable electricity, further decarbonising the process.

Many of the world's cement kilns produce CO_2 at much smaller scales than seen in natural gas processing plants or in thermal electricity generation. This scale impacts on CO_2 capture cost, as capture cost per tonne typically rises with reduced scale of the CO_2 source (2). As such, cement kilns can have higher capture costs than some other applications. This represents an opportunity for capture technology companies to bring their cost advantage to bear on this sector. Firms such as Carbon Clean and Svante are good examples of capture technology development that is ideally placed for medium-scale applications, such as in the sector.

The global iron and steel sector is also a major contributor to global CO_2 emissions. During iron production from iron ore, carbon-based reductants (such as coal) react with oxygen in the ore to form CO_2. There is one operational CCS plant in this sector, at the Emirates Steel facility in Abu Dhabi. This amine-based capture plant has a capacity of 800,000 tonnes per year of CO_2, significantly reducing the emissions of its host Direct Reduced Iron facility.

Alternative, non-carbon-based ironmaking pathways are also in development, based on hydrogen as a reductant. These may form a basis for new iron and steelmaking facilities into the future. If successful, they could become another use for decarbonised hydrogen – including hydrogen produced from natural gas with CCS.

The global chemicals sector is another significant emitter of CO_2 globally, especially ammonia and ammonia-derived fertilisers (such as ammonium nitrate). Ammonia is synthesised using a reaction of nitrogen and hydrogen. Almost all the hydrogen used in ammonia production today is produced from fossil fuels, primarily with steam-methane reforming. A shift to decarbonised hydrogen, including blue hydrogen in large utility-scale hydrogen plants, would enable deep decarbonisation of this essential sector.

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5.6

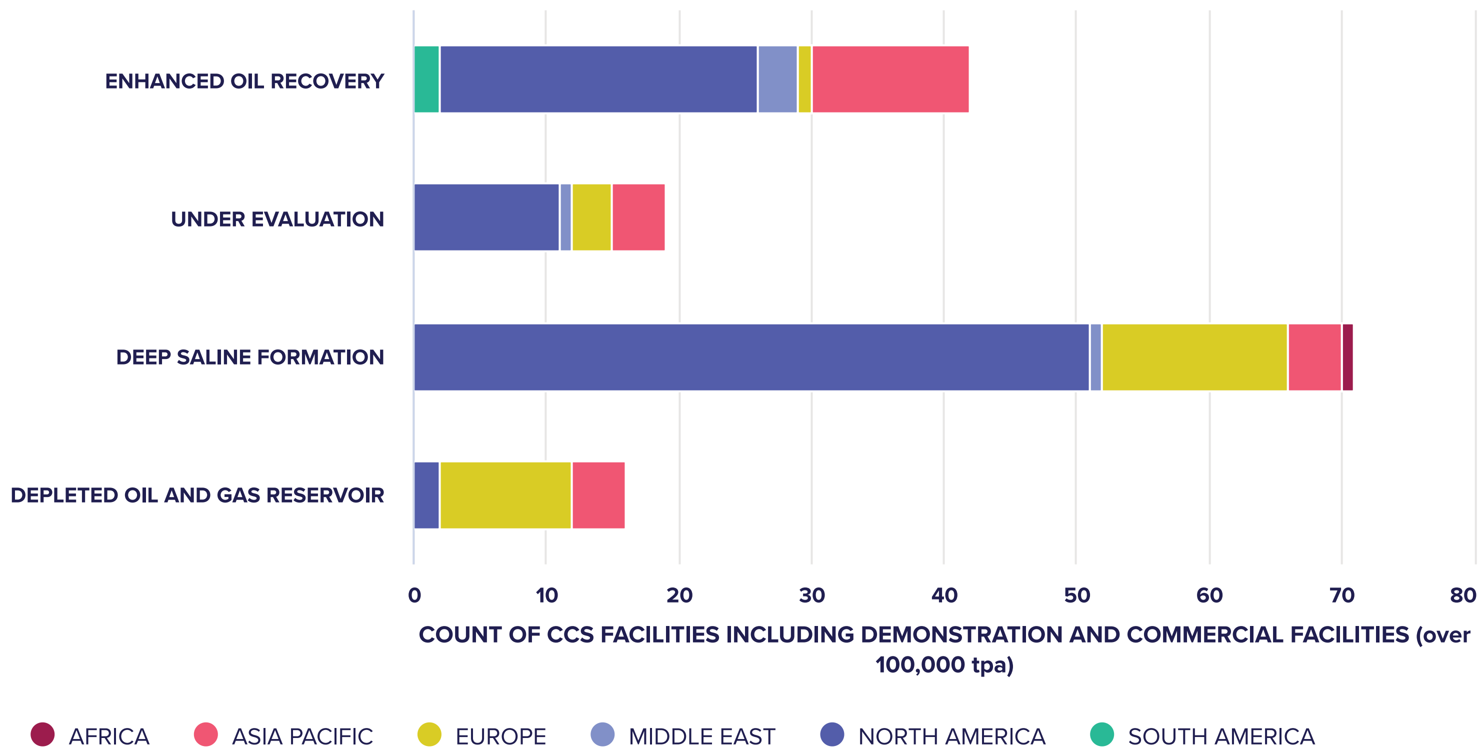
EVOLUTION OF STORAGE

The rate of carbon dioxide storage, currently around 40 million tonnes per year must grow to billions of tonnes per year to meet climate targets. Historically, most carbon dioxide has been used for enhanced oil recovery (EOR). Whilst effectively all carbon dioxide injected for EOR is permanently trapped in the pore space that previously held the oil, the majority of future storage will not be associated with EOR.

The historic dominance of CO_2 stored through EOR is understandable given the CCS industry was born out of EOR in the US. These facilities showed that million-tonne CO_2 injection rates at multimillion-tonne storage sites were possible. Importantly, monitoring confirms that all the CO_2 injected is ultimately stored. This monitoring has laid the foundation for CCS to become a critical climate change technology.

Today, deep saline formations are the most common type of CO_2 storage reservoir across all storage facilities (over 150) at all stages of development from operational through to early development phases, and including completed facilities (Figure 25). CCS deployment is expanding with a greater diversity of geographies and storage targets. CO_2 storage facilities targeting deep saline formations are most substantial in North America and the North Sea. Storage in depleted oil fields is also set to become more common, for example in the UK and in Australia and Southeast Asia.

FIGURE 24: *Count of completed, current and future CO_2 storage projects across storage types and geographies. Data derived from over 150 CCS facilities, including commercial and demonstration projects (over 100,000 tpa CO_2) across all stages of development.*

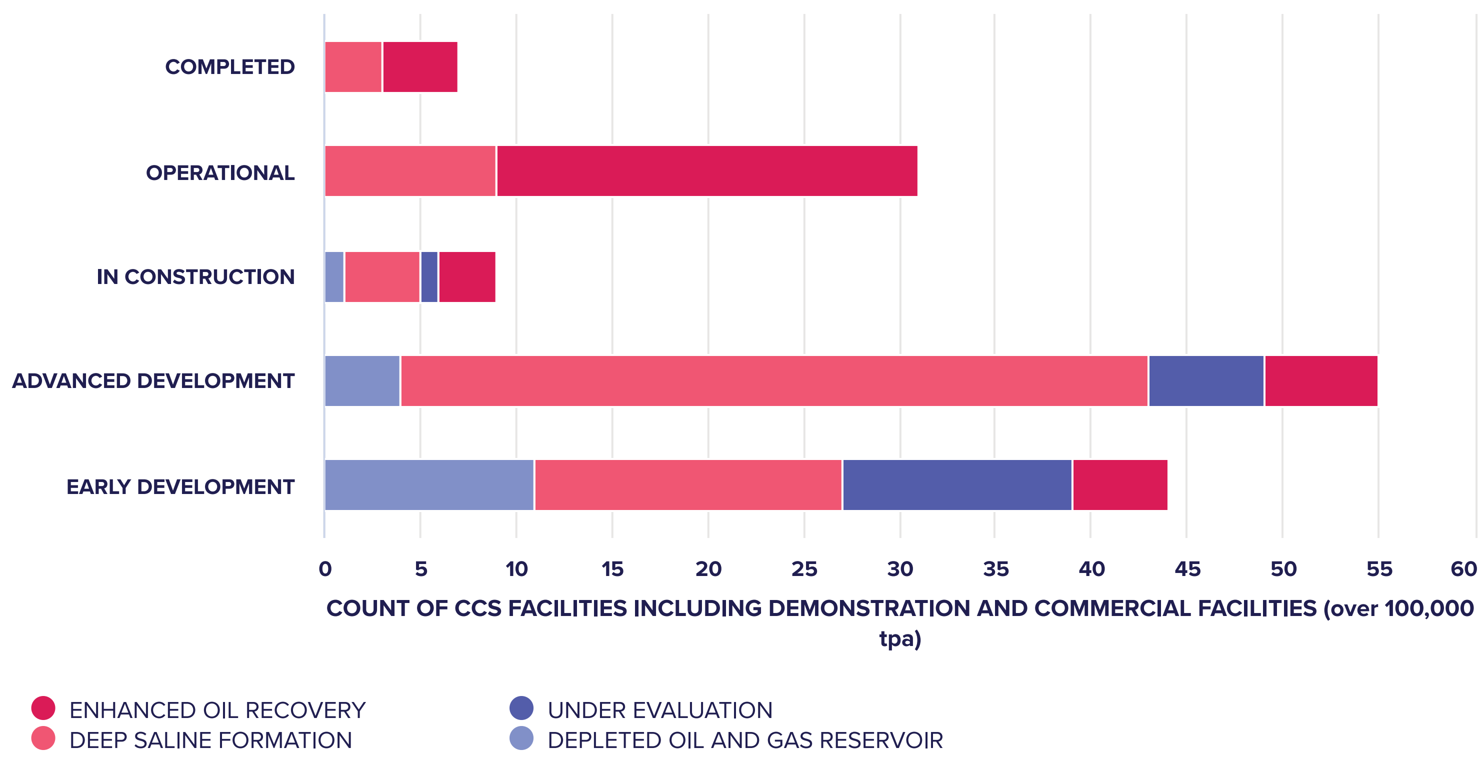


The trend of storing CO_2 via dedicated geological storage is evident in comparing the deployment pipeline of facilities coming online and those actively storing – deep saline formations dominate the portfolio of emerging facilities (Figure 25). A focus on deep saline formations rather than depleted fields is an interesting development. Historically, the expectation was that the low-cost, fast-to-develop depleted fields would be targeted first. But facilities are clearly targeting deep saline formations. This is evident in both North America and a lesser extent in Europe (Figure 24).

Two reasons emerge for this choice. First, CCS networks that dominate the development pipeline focus on deep saline formations; those networks have multimillion-tonne-per-annum injection rates. Second, the pipeline includes a substantial portion of facilities from the US and the North Sea (UK and Europe). Both these regions have access to volumetrically significant (over 1,000 Mt), high-quality deep saline formations as their nearest and therefore first option for storage.

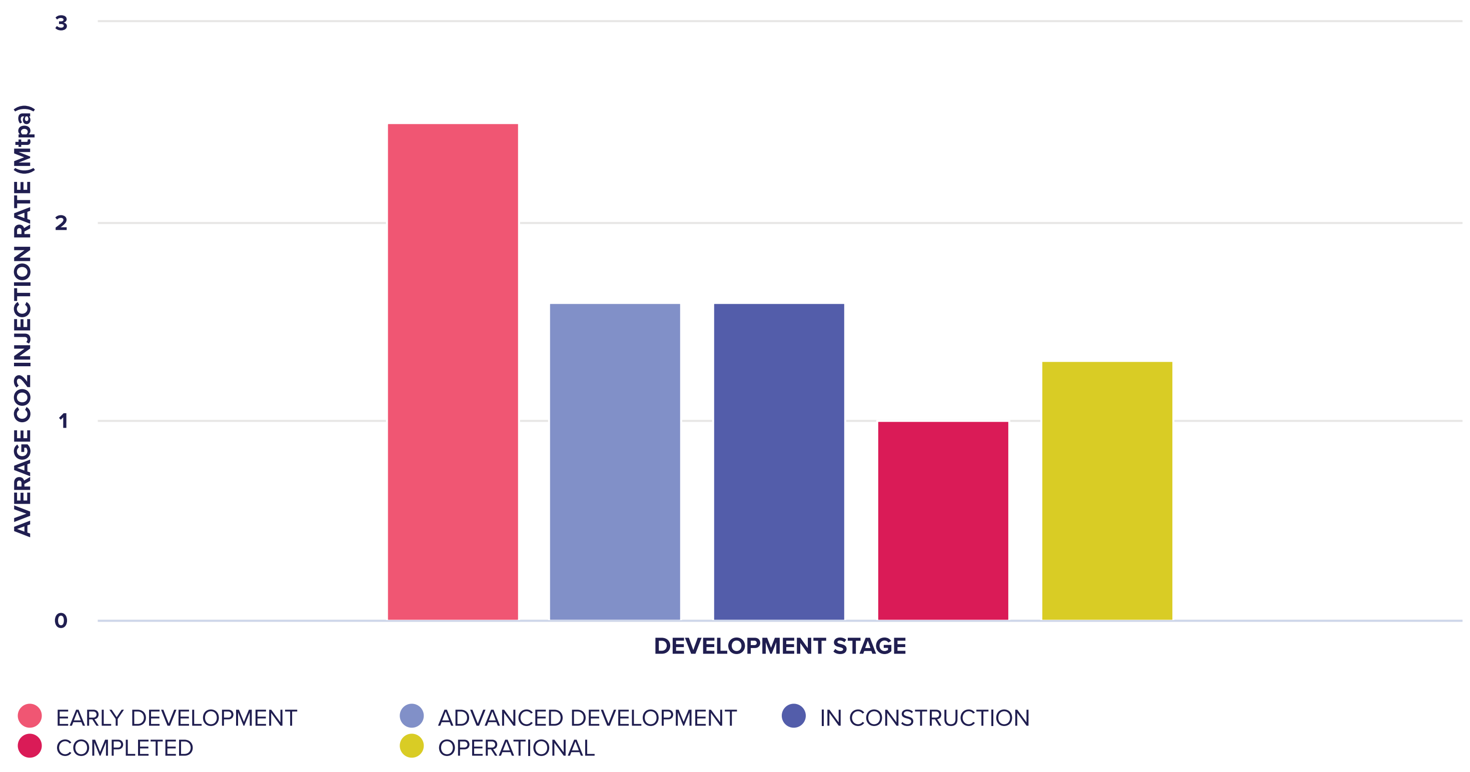
There is clear evidence in comparing operational facilities today with the pipeline in the future, that there is a greater diversity of storage targets. Depleted fields are significant to future project development, mainly in the UK North Sea. In addition, the EOR pipeline is still growing, particularly in the US and Middle East.

FIGURE 25: *Potential and current CO_2 stored across storage types and deployment status. Data derived from over 150 CCS facilities, including commercial and demonstration projects (over 100,000 tpa CO_2) across all stages of deployment*



Perhaps the most important trend in geological storage is that the average injection rate per project is increasing. Operational facilities, on average, inject just over 1 Mtpa CO_2. That average could more than double within a decade as new larger projects commence operation. Storage projects associated with CCS networks in development generally have injection rates of around 5 Mtpa. Further, storage operators are now announcing 10 Mtpa CO_2 rates or more (1). This growth in injection rate has emerged in the past two to three years.

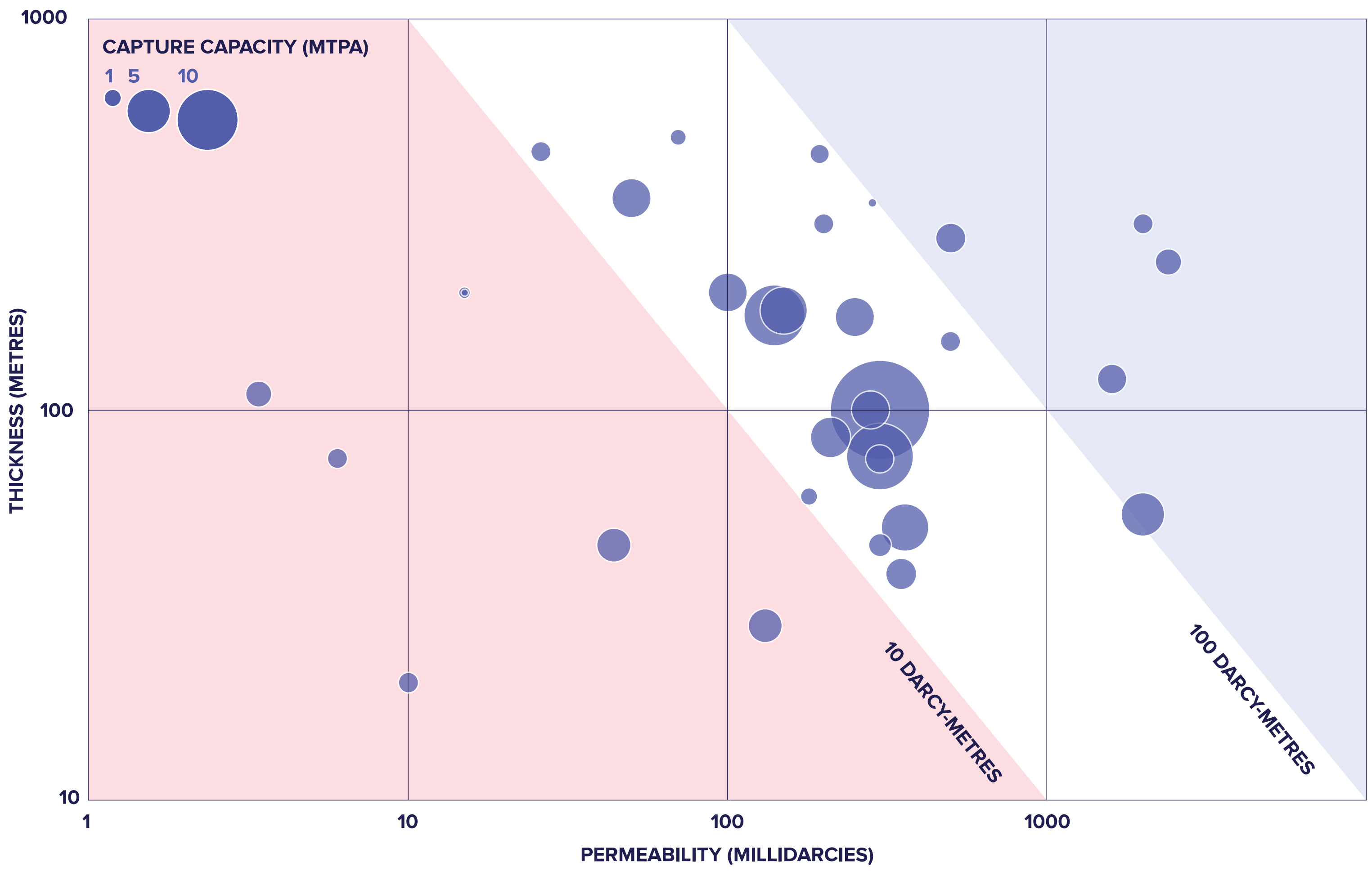
FIGURE 26: *The average injection rate (million tonnes per annum) of commercial CCS facilities in the deployment pipeline. Data derived from over 30 CCS facilities with dedicated geological storage, including commercial and demonstration projects (over 100,000 tpa CO_2), across all stages of deployment.*



The geological characteristics of dedicated storage resources (i.e. non EOR) vary widely. Facilities are targeting or actively injecting into thin reservoirs with low permeability, through to multi-Darcy (very high permeability – almost like sand on the beach) reservoirs hundreds of metres thick. The highest quality deep saline formation is not necessarily the best option, with operators needing to balance many factors. For example, injecting into a higher quality formation means the CO_2 spreads further, increasing the monitoring area required.

Whilst the range of reservoir permeabilities and thicknesses that have been utilised for CO_2 storage is quite broad, there appears to be a geological sweet spot at a permeability of around 300 millidarcies and a formation thickness of 100–200 metres. This combination may be described quantitatively by *injectivity potential* which is the mathematical product of reservoir permeability and thickness. Most projects inject between 1 and 10 Mtpa of CO_2 into storage reservoirs with injectivity potential of between 10 and 100 Darcy-metres according to Hoffman et al. (2015) (2).

FIGURE 27: *Injectivity of storage sites across the entire pipeline of facilities*
Adapted and modified from Hoffman, N., George Carman, Mohammad Bagheri, Todd Goebel, & The CarbonNet Project. (2015). Site characterisation for carbon storage in the near shore Gippsland Basin.



The diversity of storage types, geological conditions, and injection rates will likely increase with the ongoing development of storage resources across new geographies and geological basins. Much like sectors adopting CCS for decarbonisation, the geological sites for storage are diversifying as more resources are developed.

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5.7

INFRASTRUCTURE

As CCS networks have emerged as a key CCS deployment model, the development of shared transport and storage infrastructure has become a focus for project developers and policymakers.

Shared infrastructure includes all the capital equipment required to move CO_2 from capture plants to its ultimate permanent storage site: pipelines; compression systems; ships; port facilities, such as CO_2 liquefaction plants and temporary holding tanks; and ultimately storage installations where multiple CO_2 sources can be injected into storage in shared wells.

Infrastructure projects enable better economics for the transport and storage of CO_2. By taking advantage of economies of scale, shared pipelines enable long-distance transport at a much lower cost per tonne of CO_2 than would be possible with dedicated, smaller capacity pipelines. Infrastructure also enables more rapid deployment of CCS at scale, by aggregating the parts of the life cycle (pipelines and storage) with longer timelines.

Infrastructure projects are under development by existing players in the oil and gas sector who have long histories of building pipeline projects and drilling wells. These projects fit well with the experience and core competencies of these companies.

In the US, ExxonMobil is leading the Houston Ship Channel CCS infrastructure project. Incorporating 14 companies operating emissions-intensive businesses in the Houston region, this world-scale network project will involve the development of shared CO_2 pipelines in the Houston Ship Channel region. Companies such as Air Liquide, BASF and Shell have agreed to participate in the project (1). The use of shared infrastructure (pipelines and offshore storage wells in the Gulf of Mexico) will greatly improve the economics of CO_2 transport and storage in the region.

In the UK, the East Coast Cluster is working to aggregate CO_2 captured from a multitude of industrial and energy facilities. In addition to these onshore pipeline networks, supporting infrastructure in the form of offshore pipelines and offshore storage facilities is being developed under the Northern Endurance Partnership (2). This large-scale offshore storage project will become essential infrastructure for the entire Humber and Teesside industrial region, enabling up to 27 Mtpa of captured CO_2 to be stored far more cost effectively than multiple, smaller storage projects.

In Europe, Equinor and Fluxys have announced plans for a world-scale CO_2 subsea pipeline from Belgium to storage sites in the Norwegian North Sea (3). This 1,000 km long pipeline, with an anticipated capacity of 20–40 Mtpa, is intended to support the transport of captured CO_2 from Belgium and surrounding countries as an open-access transport system. This would form an essential backbone of CO_2 pipeline infrastructure across Northwestern Europe. In the Dutch North Sea, the Aramis project will provide open-access CO_2 transport and storage services through an offshore pipeline to depleted gas fields.

As well as pipelines, shipping is emerging as an essential transport vector for CO_2 – often when CO_2 sources and storage sites are too far apart for pipelines. Ship-based CO_2 transport relies on the refrigeration of CO_2 to liquefy it, making it denser and enabling ships to transport larger tonnages for a given volume. Early ship designs, such as those used in the Langskip network in Norway, are dedicated carriers shuttling CO_2 from particular individual CO_2 capture facilities in Oslo and Brevik. As such, their 7,500 m^3 CO_2 volume is determined by logistics, with shipping distance and annual CO_2 volume the key considerations (4). These early ships were adapted from existing LPG carrier designs. It is anticipated that future CO_2 ships will likely be developed with larger capacities to facilitate longer open water shipping routes, using clean sheet designs.

In Iceland, CO_2 storage company Carbfix is developing the Coda project (5). Leveraging the low-cost basalt storage available in Iceland, this CO_2 terminal will enable CO_2 to be shipped from across Northwestern and Western Europe. CO_2 port infrastructure like Coda is expected to become a common feature of coastal CCS networks more generally. Ship-based CO_2 movements increase the scale of CCS networks and will require CO_2 loading facilities (at source ports) and unloading facilities (at receiving ports). A key advantage of port facilities is that CO_2 transport routes can change over time (unlike pipelines), allowing ships to take CO_2 to the lowest-cost storage facilities in a region.

As well as industrial players, governments play a key role in the incentivisation and development of CCS infrastructure. For example, the CarbonNet pipeline and storage project in Victoria, Australia has been an ongoing effort to develop a new storage sector for energy and industrial businesses in the state. Similarly, the Alberta Carbon Trunk Line (ACTL) project in Alberta, Canada has benefited from public support to kickstart the CCS sector in the region, building a world-scale pipeline connecting CO_2 sources to storage resources 240 km away.

This support goes beyond technical work – it includes supportive regulations to enable a firm legal basis to undertake storage, guidance for pipeline route development, and government support for early-stage exploration to confirm storage resource quality. These are key roles for governments to help overcome some of the early barriers to infrastructure development.

The continued growth and scale-up of CCS to enable CCS to move to gigatonne scales globally, will depend on more pipelines, storage projects and shipping infrastructure over the coming decades.

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5.8

TIMELINES FOR CCS PROJECT DEVELOPMENT

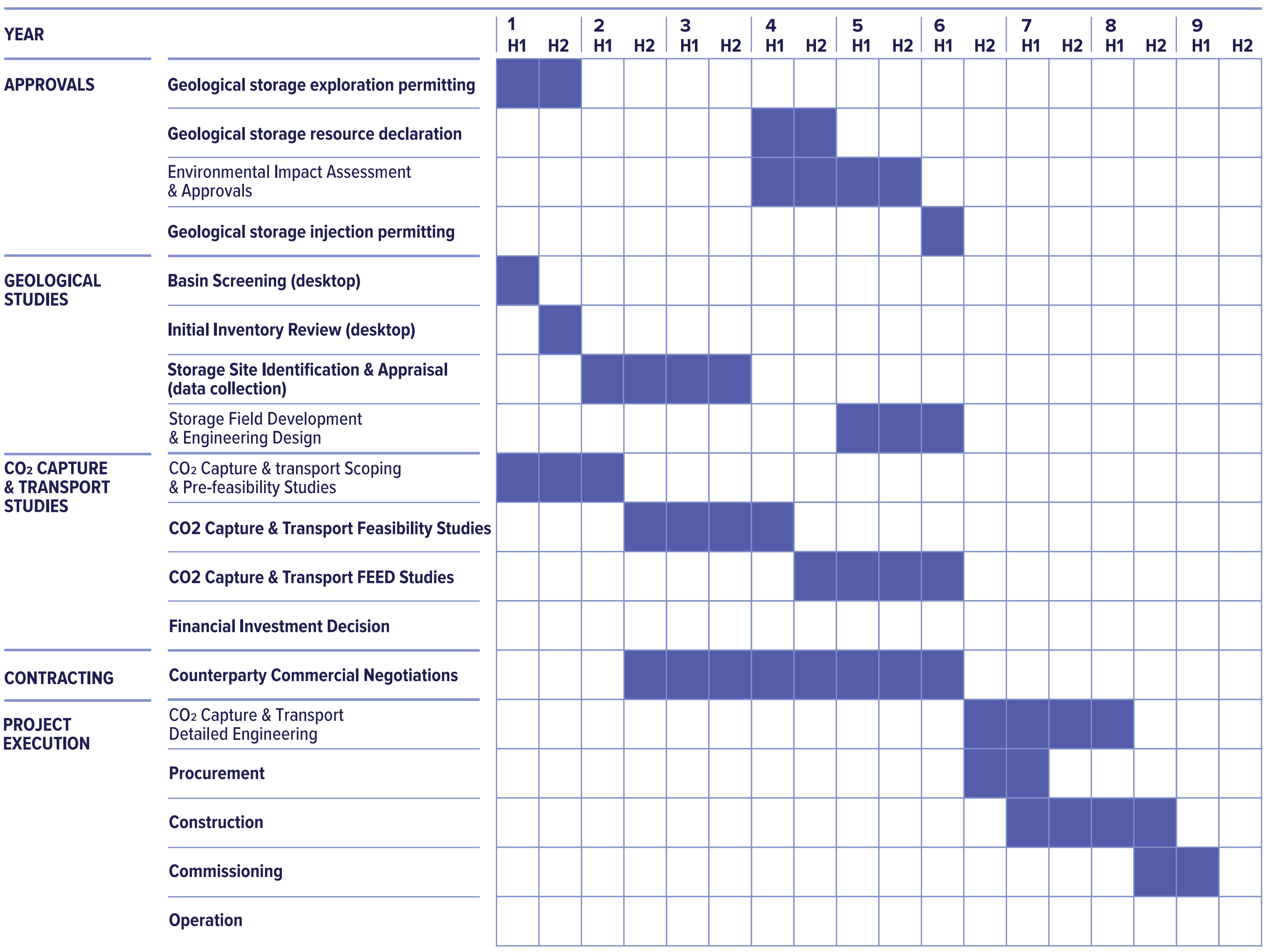
Building a new CCS facility or retrofitting CCS to an existing facility is a major industrial project requiring the full suite of studies, from concept through pre-feasibility and feasibility, before detailed engineering studies commence.

The complexities of identifying and negotiating commercial agreements with counterparties where required (for example, CO_2 offtake agreements) and completing environmental impact assessment processes, as well as obtaining the necessary tenements and approvals for geological storage of CO_2 from regulators, generally requires years to complete. This is assuming that appropriate legislation for the regulation of CCS has been promulgated; in most jurisdictions, this is still not the case. The development of a CCS project shares many similarities with mining and mineral processing and oil or gas production projects; a large complex CCS project may take a decade to progress from concept to operation.

The identification and appraisal of geological resources for the storage of CO_2 is a costly and time-consuming process. It requires a desktop review of existing geological models covering the area in question, "imaging" of the subsurface using seismic techniques and complex data processing, and finally, the drilling of a well to collect core samples for analysis and to undertake small scale injection testing. These activities typically take a few years to complete and are subject to the availability of geoscientists with appropriate experience and the critical equipment required to collect data and drill wells. Storage appraisal is on the critical path for CCS deployment.

Figure 28 is a highly simplified Gantt chart for the development of a complex CCS project, assuming appropriate CCS regulation is in place and there is no significant community opposition. It is possible to deliver a complex project in less time if relevant pre-existing studies are available (for example, storage site appraisal or capture engineering studies).

FIGURE 28: *Simplified Gantt chart for a complex CCS project*



At the other end of the spectrum, less complex CCS projects can be developed in less than five years. These projects will generally require CO_2 capture processes that are simple to integrate with the CO_2 source, are vertically integrated (no offtake agreements), utilise existing infrastructure and/or access rights, and access geological storage resources that are already well characterised and not facing any significant risk of community opposition. An excellent example of a less complex CCS project is Santos's Cooper Basin CCS Project in Australia, which is scheduled to commence operation in 2024. This project will capture CO_2 from gas processing facilities and, using an existing pipeline corridor, transport it 50 km to a depleted hydrocarbon reservoir for storage. Santos will own and operate every element of the project, which is in a remote part of Australia with extremely low population density.

While there are likely many opportunities around the world to develop less complex CCS projects such as the Cooper Basin CCS Project, these represent a minority of the total capacity required to meet climate targets. CCS projects in development today typically have disaggregated value chains and connect to a CO_2 transport and storage network because of the cost and the risk benefits that networks provide. The downside is increased complexity and longer development timelines.

In the last few years, as CCS networks have emerged, the scale and complexity of CCS projects has increased significantly. A large majority of these projects are leveraging some existing studies, most commonly related to geological storage resources. Those with access to pre-existing studies would be expected to advance to operation in less than nine years, but some may take longer. Large industrial projects take time to develop. If ambitious climate targets are to be met, the majority of projects that will deliver multi-mega-tonne-per-year-abatement in the 2030s need to commence development in the 2020s. In addition, less complex projects that can be delivered in five years or less should be pursued with urgency. Policymakers must take these timelines into account and develop policy that incentivises investment in more complex and less complex CCS projects to support net-zero strategies. Further, capacity-building across all relevant disciplines, especially geoscience, will be necessary in some developing countries, particularly those without a well developed petroleum production industry.

GLOBAL CCS INSTITUTE

APPENDICES

CHAPTER 6

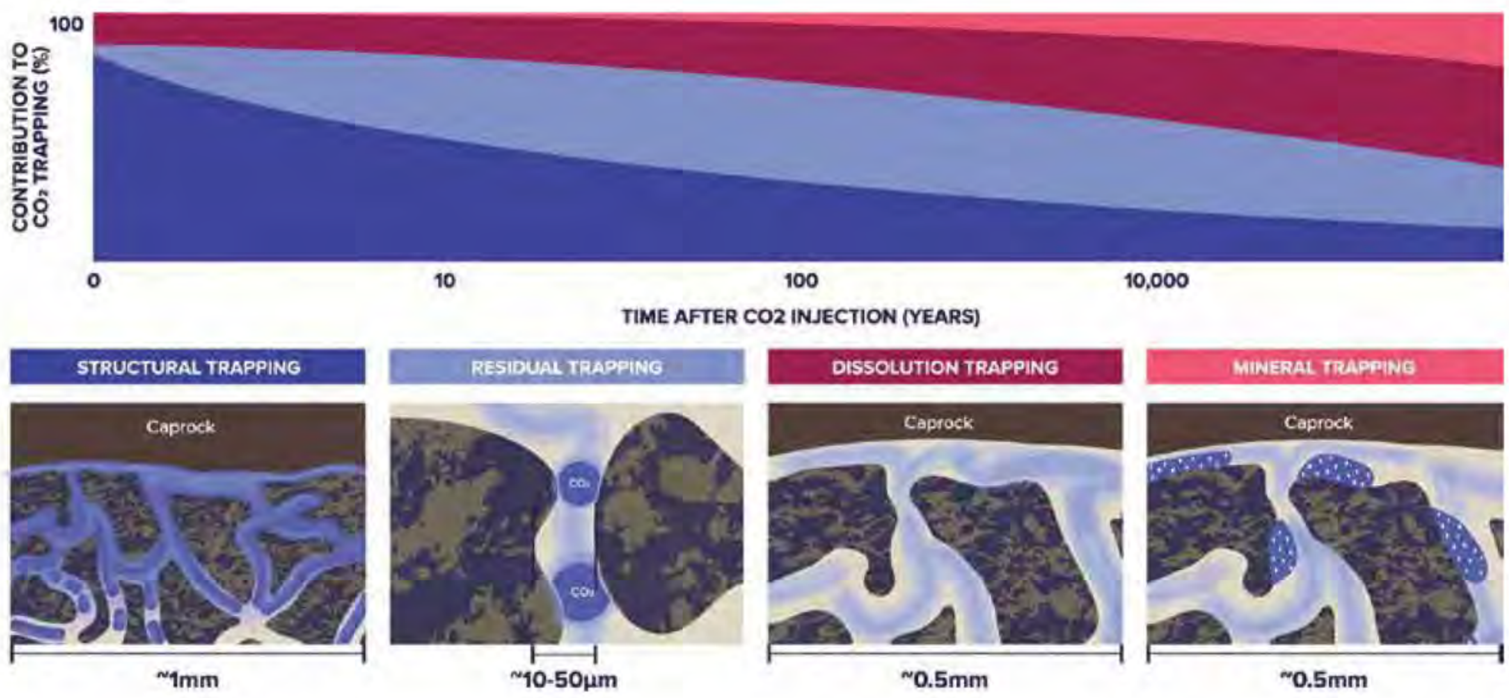
6.1

CO2 GEOLOGICAL STORAGE

SUMMARY OF STORAGE MECHANISMS AND SECURITY

Four mechanisms exist for trapping CO_2 in the subsurface. These mechanisms occur simultaneously upon injection but occur at different rates (Appendix figure 1). The relative contribution of each trapping mechanism – physical, residual, dissolution, mineralisation – changes with time and with a CO_2 plume's evolution. In the initial decades of a standard storage operation, physical trapping of free-phase CO_2 is the primary trapping mechanism. Trapping of CO_2 is strongly dependent on a site's geology and local formation conditions (in-situ fluids, pressure, temperature). A portion of the CO_2 plume may always remain in its free phase, but physical trapping is permanent when the geologic setting is stable and the CO_2 plume is behaving in the reservoir as predicted.

APPENDIX FIGURE 1: *(Lower panel) The four trapping mechanisms operating in the subsurface to permanently store CO_2. (Upper panel) Relative contribution of the four trapping mechanisms to permanent CO_2 storage through time. Each mechanism operates simultaneously upon CO_2 injection, but they occur at different rates.*

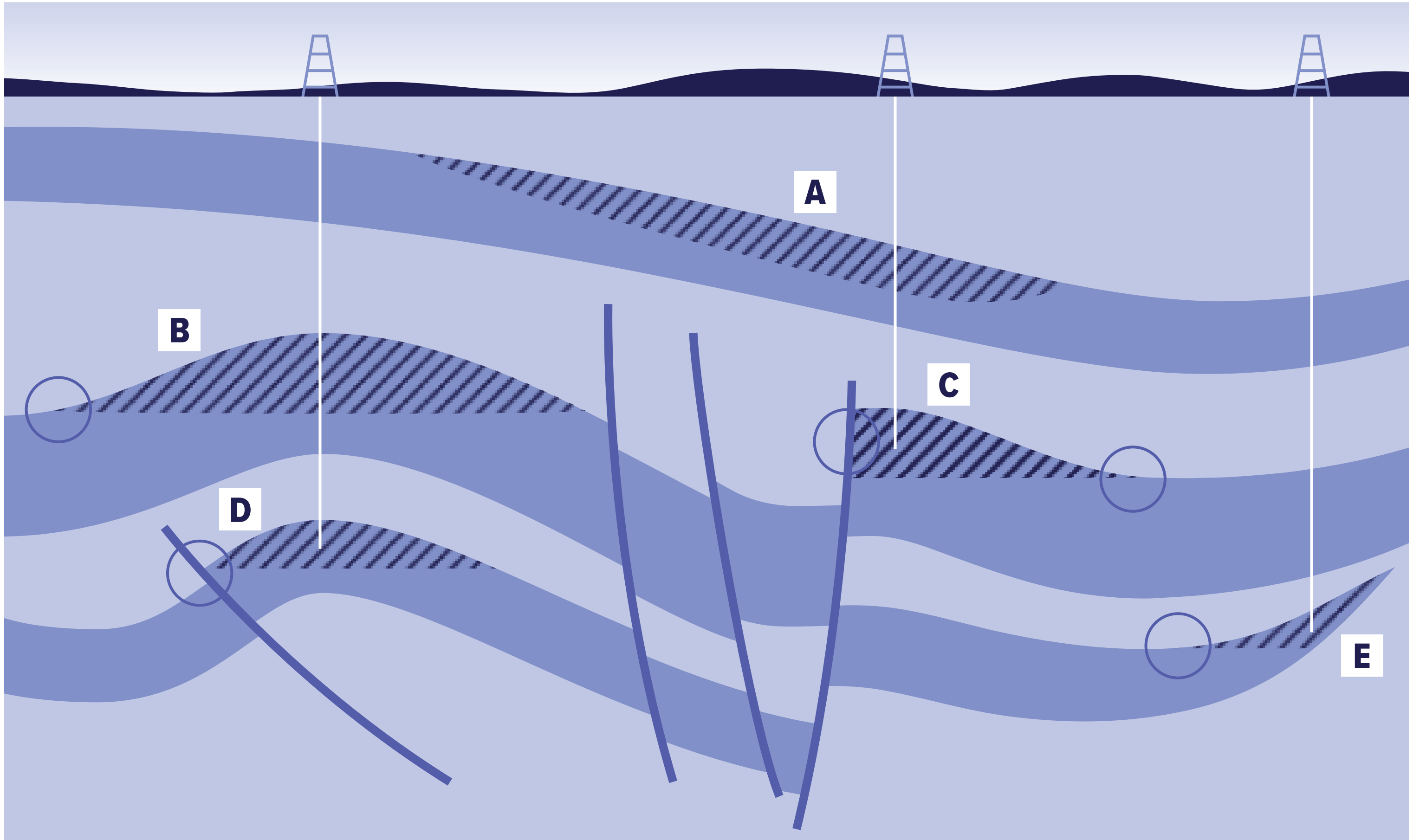


Source: IPCC (2005)

PHYSICAL TRAPPING

Physical trapping occurs when buoyant, free-phase CO_2 migrates into a body of rock that has been folded or faulted into a subsurface structure (or "trap"), which closes in three or four directions, and is contained below a low-permeability caprock (or "seal") (see Appendix figure 2). Physical trapping is the same mechanism that traps hydrocarbons in the subsurface. Appendix figure 2 illustrates types of physical traps, including independent folded rock bodies and fault-dependent folds (which rely on closure against a fault for CO_2 containment). In certain geological settings, physical trapping of CO_2 occurs when a reservoir thins laterally and ultimately pinches-out. This is called a stratigraphic trap and is shown at "E" in Appendix figure 2.

APPENDIX FIGURE 2: *Schematic illustration of physical traps in the subsurface. Circles show "spill points" or fault dependency of structural closures. (A) Residual trapping can be the dominant trapping mechanism in gently dipping (that is, relatively flat-lying) rock bodies that do not exhibit structural closure. (B) A fault-independent folded rock body (anticline) can trap buoyant CO_2 down to its "spill point", below which CO_2 will migrate out of the folded trap. (C) A fault-dependent (extensional fault) folded closure relies on the juxtaposition of sealing lithologies across the fault plane to prevent CO_2 migration out of the trap. (D) A fault-dependent (contractional fault) folded closure relies on the juxtaposition of sealing lithologies across the fault plane to prevent CO_2 migration out of the trap. (E) A stratigraphic trap relies on lateral changes in lithology (often lateral stratigraphic terminations or "pinch-outs") to prevent CO_2 migration out of the trap.*



RESIDUAL TRAPPING

As a CO_2 plume migrates through a reservoir, a portion of the plume will become trapped in the pore space and micro-scale reservoir heterogeneities by capillary forces (see Appendix figure 1). This process is called residual trapping and is controlled by the connectivity between pores, pore throat size, reservoir lithology, and pre-existing pore fluid chemistry. Pores in suitable reservoirs are typically <1 mm in size, well connected, and often make up 10–30 per cent of the bulk rock volume. Buoyancy forces of the CO_2 plume are generally strong enough to overcome capillary forces in rock pores; however, along the margins and tail of a migrating plume, capillary forces are strong enough to "snap-off" small amounts of CO_2 from the plume. These small amounts of CO_2 are held permanently in pores against the surface of mineral grains. As the CO_2 plume migrates away from the higher pressures at an injection well, residual trapping becomes increasingly important. Although residual trapping occurs at the micro-scale, the mass of CO_2 trapped by this mechanism becomes significant at the reservoir scale (tens of metres of thickness and over an area of hundreds of square kilometres). Residual trapping contributes significantly to permanent storage in the early decades of a storage project.

DISSOLUTION TRAPPING

Dissolution trapping is a simple mechanism that occurs when injected CO_2 comes into contact with a brine and the CO_2 is able to dissolve into the brine solution. CO_2 solubility is dependent on brine salinity and the temperature and pressure conditions of a reservoir. A CO_2-saturated brine solution is denser than unsaturated brine and will sink in a reservoir. Dissolution trapping is considered permanently trapped. Over time, the CO_2-saturated brine diffuses and disperses within the regional hydrogeological system of the basin. Dissolution trapping happens immediately on contact, but only becomes a significant contributor to storage at decadal to century timescales.

MINERAL TRAPPING

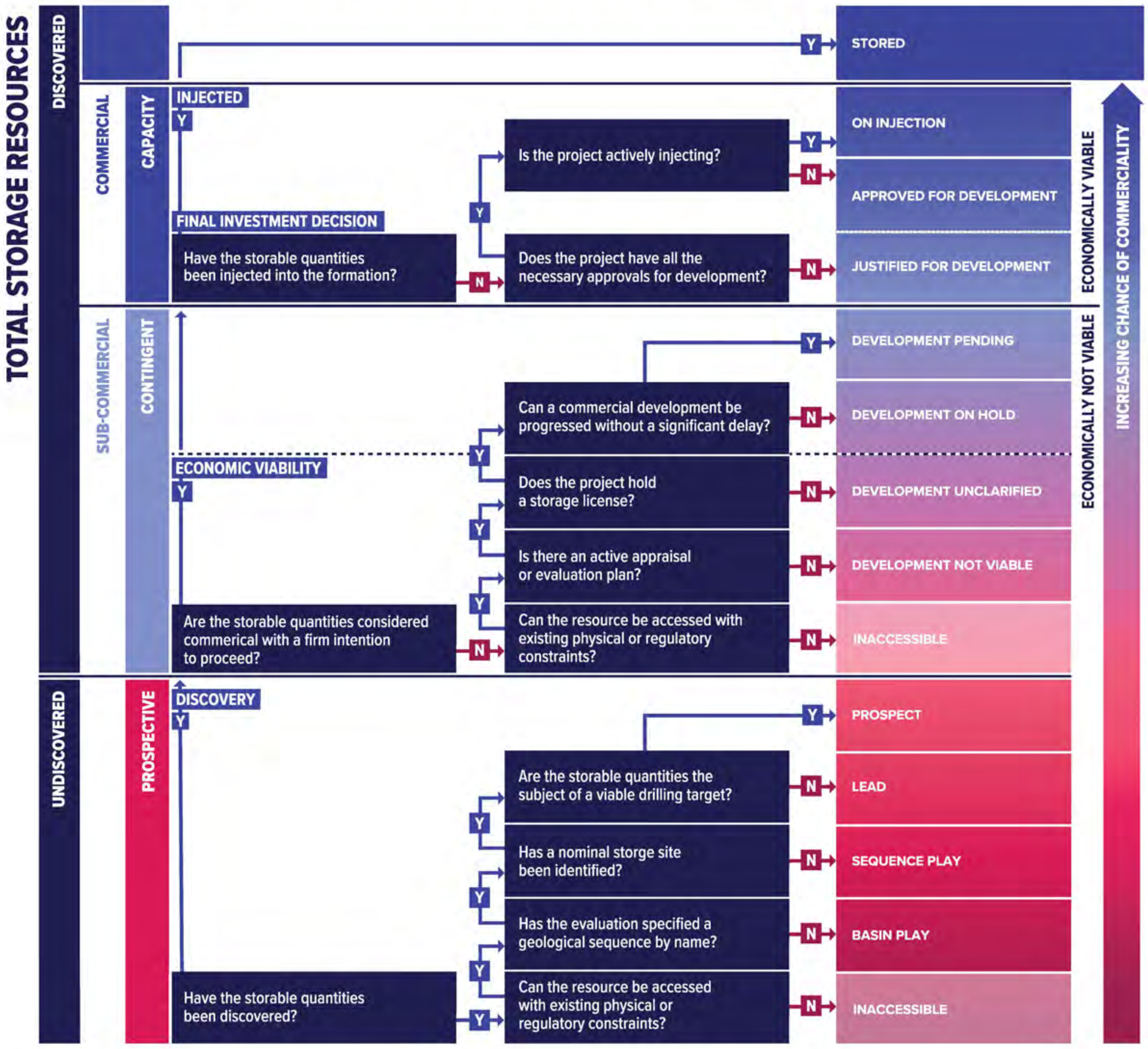
Mineral trapping occurs when injected CO_2 chemically reacts with the minerals in a reservoir rock to form solid stable product minerals – often carbonate minerals. Mineral trapping is a permanent form of storage. Reaction rates and the mineralogy of product minerals depend on reservoir pressure, temperature, and reservoir mineralogy. Reservoirs targeted for CO_2 storage often have favourable conditions for mineralisation. Mineral carbonation begins immediately upon injection, but is generally a minor component of a storage project until thousands of years have passed. At this timescale, in a conventional storage reservoir, the majority of CO_2 will have already been permanently stored by the three mechanisms discussed above. However, injection into some rock formations (such as basalts) that contain reactive iron and magnesium minerals can result in rapid mineralisation of the majority of the CO_2 in as quickly as two years (2).

CO2 STORAGE RESOURCE CATALOGUE

The CO_2 Storage Resource Catalogue is a comprehensive global database of storage resources classified according to their commercial readiness using the 2017 Society of Petroleum Engineers Storage Resources Management System (SRMS). The purpose of the catalogue is to accelerate the commercial-scale development of CCS projects, build confidence in storage resource estimates, provide a consistent global picture of storage potential, and to establish the SRMS as a robust and authoritative reporting mechanism for storage resources. The catalogue is a six-year project funded by the Oil and Gas Climate Initiative, with technical assessments undertaken by the Global CCS Institute and Storegga. It is expected that by 2025, the catalogue will have assessed all countries across the globe.

The SRMS classifications are shown in Appendix figure 3. The Global CCS Institute in partnership with Storegga developed a series of guiding questions to help users classify their storage resources correctly. There are four major resource classes in the SRMS – these are Stored, Capacity, Contingent, and Prospective resources. Each class implies a different level of commercial maturity, with Prospective resources being the least mature and Stored being the most mature. Together, these make up the total storage resource base.

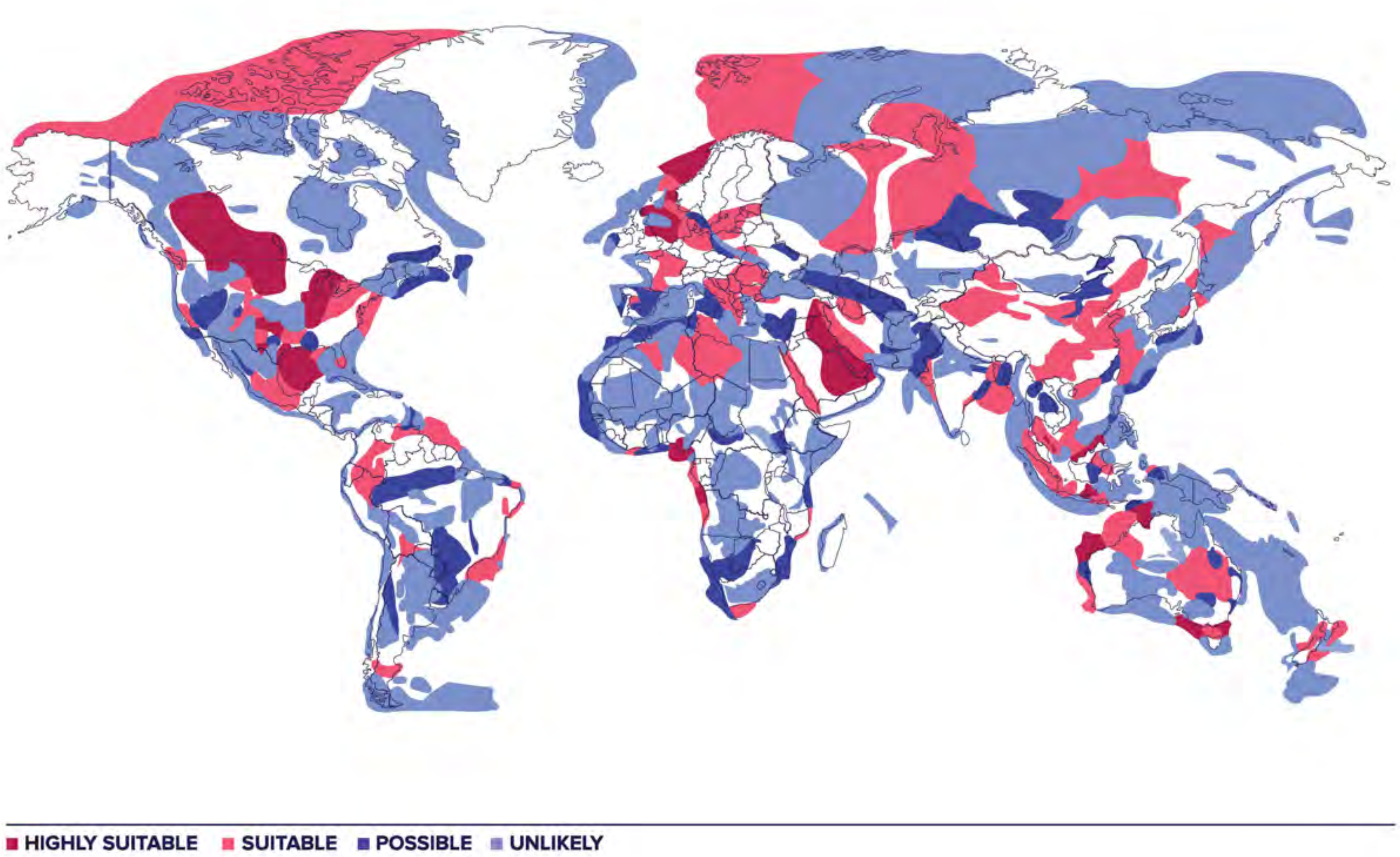
APPENDIX FIGURE 3: *The Storage Resource Management System classification system for CO_2 storage resources. Follow the question flow chart (blue boxes) to guide your resource classification.*



Source: OGCI et al. (2022)

The third annual assessment cycle ("Cycle 3" in OGCI et al. (2022)) was completed in March 2022 and added approximately 1,000 gigatonnes of CO_2 ($GtCO_2$) of storage resources to the global resource base, which stands at 13,954 $GtCO_2$.

APPENDIX FIGURE 4: Results from assessment cycle 3 of the CO_2 Storage Resource Catalogue



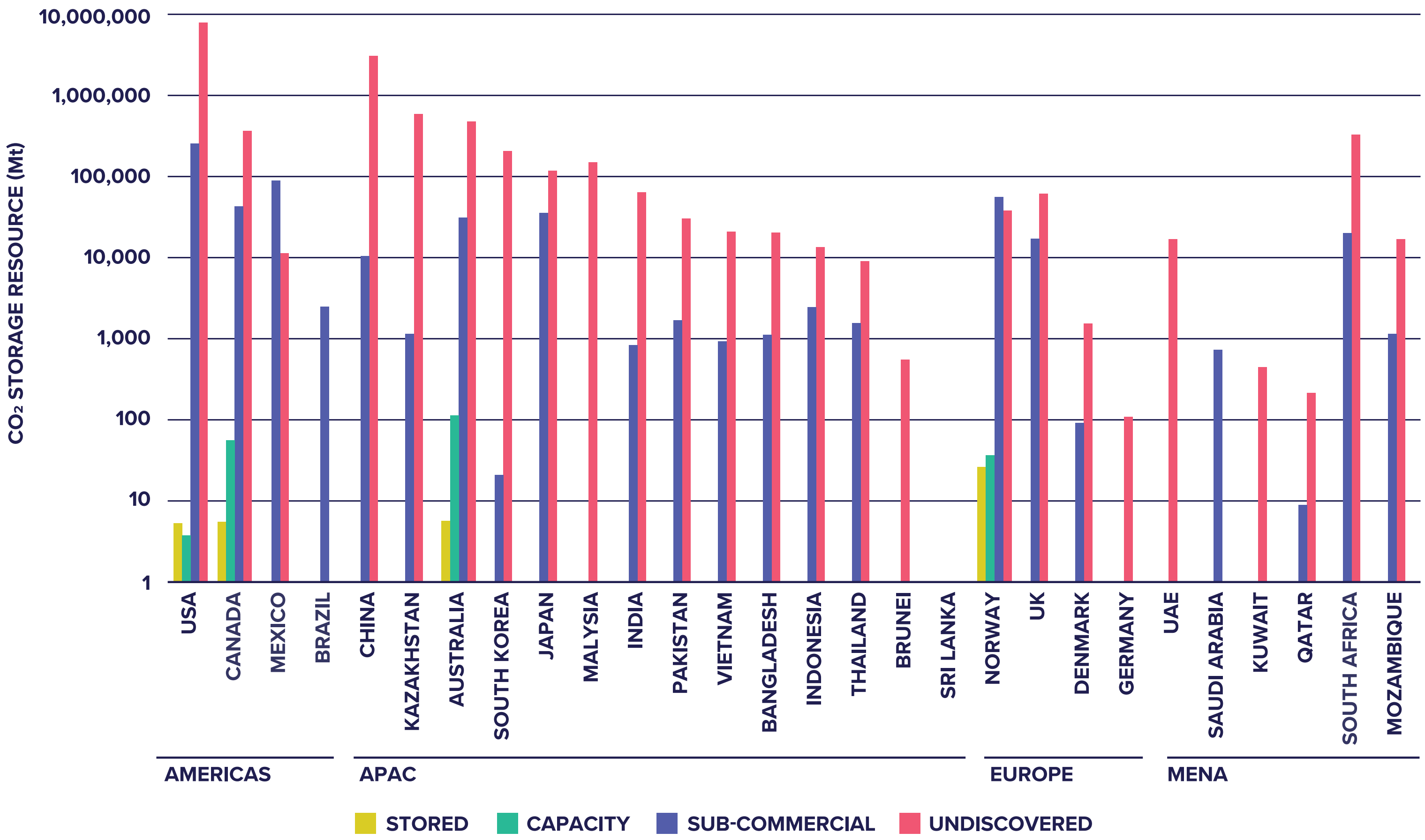
Source: OGCI et al. (2022)

Assessment cycle 3 increased the number of storage sites to 852 and the number of assessed countries to 30. Appendix figure 4 shows the total discovered and undiscovered storage resource. Just over 577 Gt of storage resources (or 4.1 per cent of the total global resource base) have been discovered – meaning they have been proven with subsurface data such as a well and seismic surveys. Unfortunately, only a very small fraction of the total global storage resource base can be considered commercial resources – just 253 $MtCO_2$ (or 0.002 per cent). Commercial resources must be ready for a storage operation to proceed and have:

- a legal and regulatory framework that enables CO_2 storage
- a thorough technical assessment and understanding of the storage complex
- a notional project development plan
- no significant barrier causing delay in development of the project.

The order of magnitude difference between sub-commercial resources and commercial resources suggests a significant opportunity exists to explore, develop, and appraise storage resources globally (Appendix figure 5). The CO_2 Storage Resource Catalogue can only use data in the public domain, so classifications in Appendix figure 5 likely underestimate resource commerciality because companies tend to keep their CCS project information private.

APPENDIX FIGURE 5: CO_2 storage resources (which are associated with storage projects) by country and SRMS maturity class



Source: OGCI et al. (2022)

In February 2022, Santos became the first company to officially claim ownership of (or "book") CO_2 storage resources using the SRMS system (4). It has booked 100 Mt of storage resources in the Cooper Basin of Australia ahead of its Moomba CCS Project, which has reached its final investment decision (FID). Santos booked nine Mt of 2P (proved plus probable) resource and 91 Mt of contingent (2C) resource.

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6.2
2022 FACILITIES LIST

FACILITY	COUNTRY	FACILITY STATUS	OPERATIONAL DATE	FACILITY INDUSTRY	CAPTURE CAPACITY Mtpa CO2	FACILITY STORAGE CODE
TERRELL NATURAL GAS PROCESSING PLANT (FORMERLY VAL VERDE NATURAL GAS PLANTS)	USA	Operational	1972	Natural Gas Processing	0.5	Enhanced Oil Recovery
ENID FERTILIZER	USA	Operational	1982	Fertiliser Production	0.2	Enhanced Oil Recovery
SHUTE CREEK GAS PROCESSING PLANT	USA	Operational	1986	Natural Gas Processing	7	Enhanced Oil Recovery
MOL SZANK FIELD CO2 EOR	Hungary	Operational	1992	Natural Gas Processing	0.16	Enhanced Oil Recovery
SLEIPNER CO2 STORAGE	Norway	Operational	1996	Natural Gas Processing	1	Dedicated Geological Storage
GREAT PLAINS SYNFUELS PLANT AND WEYBURN-MIDALE	USA	Operational	2000	Synthetic Natural Gas	3	Enhanced Oil Recovery
CORE ENERGY CO2-EOR	USA	Operational	2003	Natural Gas Processing	0.35	Enhanced Oil Recovery
SNOHVIT CO2 STORAGE	Norway	Operational	2008	Natural Gas Processing	0.7	Dedicated Geological Storage
ARKALON CO2 COMPRESSION FACILITY	USA	Operational	2009	Ethanol Production	0.29	Enhanced Oil Recovery
CENTURY PLANT	USA	Operational	2010	Natural Gas Processing	5	Enhanced Oil Recovery
PETROBRAS SANTOS BASIN PRE-SALT OIL FIELD CCS	Brazil	Operational	2011	Natural Gas Processing	7	Enhanced Oil Recovery
BONANZA BIOENERGY CCUS EOR	USA	Operational	2012	Ethanol Production	0.1	Enhanced Oil Recovery
AIR PRODUCTS STEAM METHANE REFORMER	USA	Operational	2013	Hydrogen Production	1	Enhanced Oil Recovery
COFFEYVILLE GASIFICATION PLANT	USA	Operational	2013	Fertiliser Production	0.9	Enhanced Oil Recovery
PCS NITROGEN	USA	Operational	2013	Fertiliser Production	0.3	Enhanced Oil Recovery
BOUNDARY DAM 3 CARBON CAPTURE AND STORAGE FACILITY	Canada	Operational	2014	Power Generation	1	Various

KARAMAY DUNHUA OIL TECHNOLOGY CCUS EOR	China	Operational	2015	Methanol Production	0.1	Enhanced Oil Recovery
QUEST	Canada	Operational	2015	Hydrogen Production	1.3	Dedicated Geological Storage
UTHMANIYAH CO2-EOR DEMONSTRATION	Saudi Arabia	Operational	2015	Natural Gas Processing	0.8	Enhanced Oil Recovery
ABU DHABI CCS (PHASE 1 BEING EMIRATES STEEL INDUSTRIES)	United Arab Emirates	Operational	2016	Iron and Steel Production	0.8	Enhanced Oil Recovery
ILLINOIS INDUSTRIAL CARBON CAPTURE AND STORAGE	USA	Operational	2017	Ethanol Production	1	Dedicated Geological Storage
CNPC JILIN OIL FIELD CO2 EOR	China	Operational	2018	Natural Gas Processing	0.6	Enhanced Oil Recovery
GORGON CARBON DIOXIDE INJECTION	Australia	Operational	2019	Natural Gas Processing	4	Dedicated Geological Storage
QATAR LNG CCS	Qatar	Operational	2019	Natural Gas Processing	2.2	Dedicated Geological Storage
ALBERTA CARBON TRUNK LINE (ACTL) WITH NORTH WEST REDWATER PARTNERSHIP'S STURGEON REFINERY CO2 STREAM	Canada	Operational	2020	Oil Refining	1.6	Enhanced Oil Recovery
ALBERTA CARBON TRUNK LINE (ACTL) WITH NUTRIEN CO2 STREAM	Canada	Operational	2020	Fertiliser Production	0.3	Enhanced Oil Recovery
ORCA	Iceland	Operational	2021	Direct Air Capture	0.004	Dedicated Geological Storage
GLACIER GAS PLANT MCCS	Canada	Operational	2022	Natural Gas Processing	0.2	Dedicated Geological Storage
SINOPEC QILU-SHENGLI CCUS	China	Operational	2022	Chemical Production	1	Enhanced Oil Recovery
RED TRAIL ENERGY CCS	USA	Operational	2022	Ethanol Production	0.18	Dedicated Geological Storage
CNOOC SOUTH CHINA SEA OFFSHORE CCS	China	In Construction	2023	Natural Gas Processing	0.3	Enhanced Oil Recovery
GUODIAN TAIZHOU POWER STATION CARBON CAPTURE	China	In Construction	2023	Power Generation	0.3	Enhanced Oil Recovery
SANTOS COOPER BASIN CCS PROJECT	Australia	In Construction	2023	Natural Gas Processing	1.7	Dedicated Geological Storage
MAMMOTH	Iceland	In Construction	2024	Direct Air Capture	0.03	Dedicated Geological Storage
NORCEM BREVIK - CEMENT PLANT	Norway	In Construction	2024	Cement Production	0.4	N/A
NORCEM BREVIK - SHIPPING ROUTE	Norway	In Construction	2024	Cement Production		N/A

NORTHERN LIGHTS - STORAGE	Norway	In Construction	2024	Various		Dedicated Geological Storage
OXY AND CARBON ENGINEERING DIRECT AIR CAPTURE AND EOR FACILITY	USA	In Construction	2024	Direct Air Capture	0.5	Dedicated Geological Storage
HAFSLUND OSLO CELSIO- KLEMETSRUD WASTE TO ENERGY PLANT	Norway	In Construction	2025	Waste Incineration	0.4	N/A
NORTH FIELD EAST PROJECT (NFE) CCS	Qatar	In Construction	2025	Natural Gas Processing	1	Under Evaluation
LOUISIANA CLEAN ENERGY COMPLEX	USA	In Construction	2026	Various	5	Dedicated Geological Storage
WABASH CO2 SEQUESTRATION	USA	Advanced Development	2022	Fertiliser Production	1.75	Dedicated Geological Storage
BRIDGEPORT ENERGY MOONIE CCUS PROJECT	Australia	Advanced Development	2023	Various	0.2	Enhanced Oil Recovery
HUANENG LONGDONG ENERGY BASE CARBON CAPTURE AND STORAGE	China	Advanced Development	2023	Power Generation	1.5	Dedicated Geological Storage
NORTHERN DELAWARE BASIN CCS	USA	Advanced Development	2023	Natural Gas Processing	0.03	Dedicated Geological Storage
ABERDEEN BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.14	Dedicated Geological Storage
AIR LIQUIDE REFINERY ROTTERDAM CCS	Netherlands	Advanced Development	2024	Hydrogen Production	0.8	Dedicated Geological Storage
AIR PRODUCTS NET-ZERO HYDROGEN ENERGY COMPLEX	Canada	Advanced Development	2024	Hydrogen Production	3	N/A
AIR PRODUCTS REFINERY ROTTERDAM CCS	Netherlands	Advanced Development	2024	Hydrogen Production		Dedicated Geological Storage
ATKINSON BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.16	Dedicated Geological Storage
CASSELTON BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.5	Dedicated Geological Storage
CENTRAL CITY BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.33	Dedicated Geological Storage
EXXONMOBIL BENELUX REFINERY CCS	Netherlands	Advanced Development	2024	Hydrogen Production		Dedicated Geological Storage
FAIRMONT BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.34	Dedicated Geological Storage

FEDERATED CO-OPERATIVES LIMITED (ETHANOL)	Canada	Advanced Development	2024	Ethanol Production	3	Enhanced Oil Recovery
GALVA BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.11	Dedicated Geological Storage
GOLDFIELD BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.22	Dedicated Geological Storage
GRAND JUNCTION BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.34	Dedicated Geological Storage
GRANITE FALLS BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.18	Dedicated Geological Storage
HERON LAKE BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.19	Dedicated Geological Storage
HURON BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.09	Dedicated Geological Storage
LAMBERTON BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.16	Dedicated Geological Storage
LAWLER BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.57	Dedicated Geological Storage
MARCUS BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.46	Dedicated Geological Storage
MASON CITY BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.34	Dedicated Geological Storage
MERRILL BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.16	Dedicated Geological Storage
MINA BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.4	Dedicated Geological Storage
NEVADA BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.26	Dedicated Geological Storage
NORFOLK BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.15	Dedicated Geological Storage
ONIDA BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.23	Dedicated Geological Storage
OTTER TAIL BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.17	Dedicated Geological Storage
PLAINVIEW BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.32	Dedicated Geological Storage

POLARIS CARBON STORAGE	Norway	Advanced Development	2024	Hydrogen Production		Dedicated Geological Storage
PORTHOS - COMPRESSOR STATION	Netherlands	Advanced Development	2024	Various		N/A
PORTHOS - OFFSHORE PIPELINE	Netherlands	Advanced Development	2024	Various		N/A
PORTHOS - ONSHORE PIPELINE	Netherlands	Advanced Development	2024	Various		N/A
PORTHOS - STORAGE	Netherlands	Advanced Development	2024	Various		Dedicated Geological Storage
REDFIELD BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.17	Dedicated Geological Storage
SAN JUAN GENERATING STATION CARBON CAPTURE	USA	Advanced Development	2024	Power Generation	6	Dedicated Geological Storage
SHELL REFINERY ROTTERDAM CCS	Netherlands	Advanced Development	2024	Hydrogen Production	1.4	Dedicated Geological Storage
SHENANDOAH BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.24	Dedicated Geological Storage
SIOUX CENTER BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.19	Dedicated Geological Storage
STEAMBOAT ROCK BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.23	Dedicated Geological Storage
SUMMIT PIPELINE	USA	Advanced Development	2024	Bioenergy		Dedicated Geological Storage
SUPERIOR BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.17	Dedicated Geological Storage
WATERTOWN BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.37	Dedicated Geological Storage
WENTWORTH BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.26	Dedicated Geological Storage
WOOD RIVER BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.35	Dedicated Geological Storage
YORK BIOREFINERY CARBON CAPTURE AND STORAGE	USA	Advanced Development	2024	Ethanol Production	0.14	Dedicated Geological Storage
PROJECT GREENSAND	Denmark	Advanced Development	2025	Various		Dedicated Geological Storage
ABU DHABI CCS PHASE 2: NATURAL GAS PROCESSING PLANT	United Arab Emirates	Advanced Development	2025	Natural Gas Processing	2.3	Enhanced Oil Recovery

COPENHILL (AMAGER BAKKE) WASTE TO ENERGY CCS	Denmark	Advanced Development	2025	Waste Incineration	0.5	Dedicated Geological Storage
COYOTE CLEAN POWER PROJECT	USA	Advanced Development	2025	Power Generation	0.86	Under Evaluation
EAST COAST CLUSTER	United Kingdom	Advanced Development	2025	Various	27	Dedicated Geological Storage
GHASHA CONCESSION FIELDS	United Arab Emirates	Advanced Development	2025	Natural Gas Processing	Under Evaluation	Dedicated Geological Storage
HAFSLUND OSLO CELSIO- TRUCK ROUTE	Norway	Advanced Development	2025	Waste Incineration		N/A
LAKE CHARLES METHANOL	USA	Advanced Development	2025	Chemical Production	4	Under Evaluation
ONE EARTH ENERGY FACILITY CARBON CAPTURE	USA	Advanced Development	2025	Ethanol Production	0.5	Dedicated Geological Storage
STOCKHOLM EXERGI BECCS	Sweden	Advanced Development	2025	Bioenergy	0.8	Dedicated Geological Storage
STOCKHOLM EXERGI BECCS - SHIPPING ROUTE	Sweden	Advanced Development	2025	Bioenergy		N/A
CODA SHIPPING	Iceland	Advanced Development	2026	Various		N/A
CODA TERMINAL ONSHORE INFRASTRUCTURE	Iceland	Advanced Development	2026	Various		N/A
CODA TERMINAL PIPELINE	Iceland	Advanced Development	2026	Various		N/A
CODA TERMINAL STORAGE	Iceland	Advanced Development	2026	Various		Dedicated Geological Storage
FEDERATED CO-OPERATIVES LIMITED (REFINERY)	Canada	Advanced Development	2026	Oil Refining	1	Dedicated Geological Storage
PTTEP ARTHIT CCS*	Thailand	Advanced Development	2026	Natural Gas Processing	1	Dedicated Geological Storage
BAYU-UNDAN CCS	Timor-Leste	Advanced Development	2027	Natural Gas Processing	10	Dedicated Geological Storage
HUMBER ZERO - VPI IMMINGHAM POWER PLANT CCS	United Kingdom	Advanced Development	2027	Power Generation	Under Evaluation	Dedicated Geological Storage
HUMBER ZERO - PHILLIPS 66 HUMBER REFINERY CCS	United Kingdom	Advanced Development	2028	Hydrogen Production	Under Evaluation	Dedicated Geological Storage
ANTWERP@C - BASF ANTWERP CCS	Belgium	Advanced Development	2030	Chemical Production	1.42	Dedicated Geological Storage
JAMES M. BARRY ELECTRIC GENERATING PLANT CCS PROJECT	USA	Advanced Development	2030	Power Generation	Under Evaluation	Under Evaluation
PROJECT TUNDRA	USA	Advanced Development	2025 - 2026	Power Generation	3.6	Dedicated Geological Storage

CAL CAPTURE	USA	Advanced Development	Mid 2020s	Power Generation	1.4	Enhanced Oil Recovery
GERALD GENTLEMAN STATION CARBON CAPTURE	USA	Advanced Development	Mid 2020s	Power Generation	4.3	Under Evaluation
PLANT DANIEL CARBON CAPTURE	USA	Advanced Development	Mid 2020s	Power Generation	1.8	Under Evaluation
PRAIRIE STATE GENERATING STATION CARBON CAPTURE	USA	Advanced Development	Mid 2020s	Power Generation	6	Dedicated Geological Storage
DEER PARK ENERGY CENTRE CCS PROJECT	USA	Advanced Development	N/A	Power Generation	5	Dedicated Geological Storage
FARLEY DAC PROJECT	USA	Advanced Development	Under Evaluation	Direct Air Capture	Under Evaluation	Under Evaluation
MUSTANG STATION OF GOLDEN SPREAD ELECTRIC COOPERATIVE CARBON CAPTURE	USA	Advanced Development	Under Evaluation	Power Generation	1.5	Under Evaluation
SOUTHEAST SASKATCHEWAN CCUS HUB - STORAGE	Canada	Advanced Development	Under Evaluation	Various		Dedicated Geological Storage
PETRONAS KASAWARI GAS FIELD DEVELOPMENT PROJECT	Malaysia	Early Development	2023	Natural Gas Processing	Under Evaluation	Under Evaluation
MIDWEST AGENERGY BLUE FLINT ETHANOL CCS	USA	Early Development	2022	Ethanol Production	0.18	Dedicated Geological Storage
PROJECT INTERSEQT - HEREFORD ETHANOL PLANT	USA	Early Development	2023	Ethanol Production	0.35	Dedicated Geological Storage
PROJECT INTERSEQT - PLAINVIEW ETHANOL PLANT	USA	Early Development	2023	Ethanol Production	0.35	Dedicated Geological Storage
AEMETIS	USA	Early Development	2024	Ethanol Production and Fertiliser Production	2	Dedicated Geological Storage
CALEDONIA CLEAN ENERGY	United Kingdom	Early Development	2024	Power Generation	3	Dedicated Geological Storage
HYDROGEN 2 MAGNUM (H2M)	Netherlands	Early Development	2024	Power Generation	2	Dedicated Geological Storage
NORTHERN LIGHTS - PIPELINE	Norway	Early Development	2024	Various		N/A
PROJECT POUAKAI HYDROGEN PRODUCTION WITH CCS	New Zealand	Early Development	2024	Various	1	Under Evaluation
YARA SLUISKIL	Netherlands	Early Development	2025	Fertiliser Production	0.8	Dedicated Geological Storage
ACORN HYDROGEN	United Kingdom	Early Development	2025	Hydrogen Production	Under Evaluation	Dedicated Geological Storage
BAYOU BEND CCS	USA	Early Development	2025	Various		Under Evaluation

CARBON TERRAVAULT I PROJECT	USA	Early Development	2025	Under Evaluation	1	Dedicated Geological Storage
CLEAN ENERGY SYSTEMS CARBON NEGATIVE ENERGY PLANT - CENTRAL VALLEY	USA	Early Development	2025	Power Generation and Hydrogen Production	0.32	Dedicated Geological Storage
DRY FORK INTEGRATED COMMERCIAL CARBON CAPTURE AND STORAGE (CCS)	USA	Early Development	2025	Power Generation	3	Dedicated Geological Storage
FORTUM OSLO VARME - SHIPPING ROUTE	Norway	Early Development	2025	Waste Incineration		N/A
ILLINOIS ALLAM-FETVEDT CYCLE POWER PLANT	USA	Early Development	2025	Power Generation	1	N/A
MENDOTA BECCS	USA	Early Development	2025	Bioenergy	0.3	Dedicated Geological Storage
NET ZERO TEESSIDE - CCGT FACILITY	United Kingdom	Early Development	2025	Power Generation	Under Evaluation	Dedicated Geological Storage
NEXTDECADE RIO GRANDE LNG CCS	USA	Early Development	2025	Natural Gas Processing	5.5	Under Evaluation
PREEM REFINERY CCS	Sweden	Early Development	2025	Hydrogen Production	0.5	Dedicated Geological Storage
SOUTH EAST AUSTRALIA CARBON CAPTURE HUB	Australia	Early Development	2025	Natural Gas Processing	2	Dedicated Geological Storage
STANLOW REFINERY LOW CARBON HYDROGEN PLANT	United Kingdom	Early Development	2025	Oil Refining	0.6	N/A
THE ILLINOIS CLEAN FUELS PROJECT	USA	Early Development	2025	Chemical Production	8.13	Dedicated Geological Storage
VELOCYS' BAYOU FUELS NEGATIVE EMISSION PROJECT	USA	Early Development	2025	Chemical Production	0.5	Dedicated Geological Storage
ACORN DIRECT AIR CAPTURE FACILITY	United Kingdom	Early Development	2026	Direct Air Capture	1	Dedicated Geological Storage
ADRIATIC BLUE - ENI HYDROGEN CCS	Italy	Early Development	2026	Hydrogen Production	Under Evaluation	Dedicated Geological Storage
ADRIATIC BLUE - ENI POWER CCS	Italy	Early Development	2026	Power Generation	Under Evaluation	Dedicated Geological Storage
CINFRACAP - PIPELINE	Sweden	Early Development	2026	Various		N/A
CINFRACAP - SHIPPING ROUTE	Sweden	Early Development	2026	Various		N/A
DELTA CORRIDOR PIPELINE NETWORK	Netherlands	Early Development	2026	Various		N/A
HYNET NORTH WEST - HANSON CEMENT CCS	United Kingdom	Early Development	2026	Cement Production	0.8	Dedicated Geological Storage

NORTHERN GAS NETWORK H21 NORTH OF ENGLAND	United Kingdom	Early Development	2026	Hydrogen Production		Dedicated Geological Storage
REPSOL SAKAKEMANG CARBON CAPTURE AND INJECTION	Indonesia	Early Development	2026	Natural Gas Processing	2	Dedicated Geological Storage
INPEX CCS PROJECT DARWIN	Australia	Early Development	2026	Natural Gas Processing	7	Dedicated Geological Storage
DRAX BECCS PROJECT	United Kingdom	Early Development	2027	Power Generation	8	Dedicated Geological Storage
G2 NET-ZERO LNG	USA	Early Development	2027	Natural Gas Processing	4	Under Evaluation
H2NORTHEAST	United Kingdom	Early Development	2027	Hydrogen Production		
KILLINGHOLME POWER STATION	United Kingdom	Early Development	2027	Hydrogen Production	Under Evaluation	N/A
NET ZERO TEESSIDE – BP H2TEESSIDE	United Kingdom	Early Development	2027	Hydrogen Production	Under Evaluation	Dedicated Geological Storage
NET ZERO TEESSIDE - SUEZ WASTE TO ENERGY CCS	United Kingdom	Early Development	2027	Waste Incineration	Under Evaluation	Dedicated Geological Storage
ZERO CARBON HUMBER - KEADY 3 CCS POWER STATION	United Kingdom	Early Development	2027	Power Generation	Under Evaluation	Dedicated Geological Storage
DIAMOND VAULT CCS	USA	Early Development	2028	Power Generation	Under Evaluation	Dedicated Geological Storage
ERVIA CORK CCS	Ireland	Early Development	2028	Power Generation and Refining		Dedicated Geological Storage
K6	France	Early Development	2028	Cement Production	0.8	Under Evaluation
SUKOWATI CCUS	Indonesia	Early Development	2028	Oil Refining	1.4	Enhanced Oil Recovery
ANTWERP@C – BOREALIS ANTWERP CCS	Belgium	Early Development	2030	Chemical Production	Under Evaluation	Dedicated Geological Storage
ANTWERP@C - EXXONMOBIL ANTWERP REFINERY CCS	Belgium	Early Development	2030	Chemical Production	Under Evaluation	Dedicated Geological Storage
ANTWERP@C – INEOS ANTWERP CCS	Belgium	Early Development	2030	Chemical Production	Under Evaluation	Dedicated Geological Storage
DAVE JOHNSTON PLANT CARBON CAPTURE	USA	Early Development	2020s	Power Generation	Under Evaluation	Enhanced Oil Recovery
SINOPEC SHENGLI POWER PLANT CCS	China	Early Development	2020s	Power Generation	1	Enhanced Oil Recovery
KOREA-CCS 1 & 2	South Korea	Early Development	2020's	Power Generation	1	Dedicated Geological Storage
HYDROGEN TO HUMBER SALTEND	United Kingdom	Early Development	2026-2027	Hydrogen Production	Under Evaluation	Dedicated Geological Storage

ACORN	United Kingdom	Early Development	Mid 2020s	Various	5	Dedicated Geological Storage
BARENTS BLUE	Norway	Early Development	Mid 2020s	Fertiliser Production	2	Dedicated Geological Storage
CAROLINE CARBON CAPTURE POWER COMPLEX	Canada	Early Development	Mid 2020s	Power Generation	3	Dedicated Geological Storage
HYNET NORTH WEST	United Kingdom	Early Development	Mid 2020s	Hydrogen Production		Dedicated Geological Storage
LAFARGEHOLCIM CEMENT CARBON CAPTURE	USA	Early Development	Mid 2020s	Cement Production	2	Under Evaluation
NAUTICOL ENERGY BLUE METHANOL	Canada	Early Development	Mid 2020s	Methanol Production	1	Enhanced Oil Recovery
NET ZERO TEESSIDE - NET POWER PLANT	United Kingdom	Early Development	Mid 2020s	Power Generation	Under Evaluation	Under Evaluation
PAU CENTRAL SULAWESI CLEAN FUEL AMMONIA PRODUCTION WITH CCUS	Indonesia	Early Development	Mid 2020s	Fertiliser Production	2	Under Evaluation
POLARIS CCS PROJECT	Canada	Early Development	Mid 2020s	Hydrogen Production	0.75	Dedicated Geological Storage
SASKATCHEWAN NET POWER PLANT	Canada	Early Development	Mid 2020s	Power Generation	0.95	Under Evaluation
SHARC PROJECT	Finland	Early Development	Mid 2020s	Hydrogen Production	0.4	N/A
BORG CO2	Norway	Early Development	Under Evaluation	Various	0.63	N/A
BURRUP CCS HUB	Australia	Early Development	Under Evaluation	Under Evaluation	5	Under Evaluation
CYCLUS POWER GENERATION	USA	Early Development	Under Evaluation	Bioenergy	2	Under Evaluation
MEDWAY HUB PIPELINE	United Kingdom	Early Development	Under Evaluation	Power Generation and Hydrogen Production		N/A
MEDWAY POWER STATIONS	United Kingdom	Early Development	Under Evaluation	Power Generation	7.6	Dedicated Geological Storage
HYNET HYDROGEN PRODUCTION PROJECT (HPP)	United Kingdom	Early Development	Under Evaluation	Hydrogen Production		
ISLE OF GRAIN LNG TERMINAL	United Kingdom	Early Development	Under Evaluation	Power Generation		
MEDWAY HUB - ESMOND AND FORBES CARBON STORAGE	United Kingdom	Early Development	Under Evaluation	Power Generation		Dedicated Geological Storage
MEDWAY HUB SHIPPING	United Kingdom	Early Development	Under Evaluation	Power Generation		
SEMPRA ENERGY HACKBERRY CCS PROJECT	USA	Early Development	Under Evaluation	Natural Gas Processing	Under Evaluation	Under Evaluation

WHITETAIL CLEAN ENERGY	United Kingdom	Early Development	Under Evaluation	Power Generation	Under Evaluation	
LOST CABIN GAS PLANT	USA	Operation Suspended	2013	Natural Gas Processing	0.9	Enhanced Oil Recovery
PETRA NOVA CARBON CAPTURE	USA	Operation Suspended	2017	Power Generation	1.4	Enhanced Oil Recovery

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THANK YOU

END OF REPORT