CIRCULAR CARBON ECONOMY

Carbon Management Technologies Initiative

Strategies to Scale Carbon Capture, Utilization and Storage

Dialogue Insight Report

September 2021

INTERNATIONAL ENERGY FORUM

www.ief.org/circular-carbon-economy

Contents

Preface 3

Mandates, Aims, and Acknowledgements 3

1. Introduction 4

1.1 It’s Time to Green Light CCUS 4
1.2 Ten Key Points 8

2. Six Key Drivers 9

2.1 Policy: The Advent of Climate Policies and Net-Zero Strategies 9
2.2 Investment: Financial Incentives in an Evolving Policy Landscape 10
2.3 Technology: Funding Research Development and Deployment (RD&D) 11
2.4 Sustainable Growth: Natural Gas and Hydrogen 12
2.5 Data and Digitalisation: The Fourth Industrial Revolution 14
2.6 Social License: Energy Security and Public Acceptance 14

3 Developments 15

3.1 Policy and Market Developments in World Regions 15
3.2 Accelerating Deployment in Industry Clusters and Major Ports 29

4 Findings 31

4.1 Preliminary Recommendations 31
4.2 Conclusion 33

5. Reference List 38

Preface

Mandates, Aims, and Acknowledgements

This report launches IEF work on Carbon Management Technologies in respect of Carbon Capture, Utilization, and Storage in accordance with the guidance obtained from IEF and G20 Energy and Climate Ministers reflected in the IEF Program of Work 2020-2021, and benefits from a voluntary contribution from the Department of Energy of the United States.

Published under the authority of the IEF, this report takes account of the work of other key international government and non-governmental organizations such as the Clean Energy Ministerial, the European Commission, the Global Carbon Capture and Storage Institute, the International Energy Agency, the International Panel on Climate Change, the International Renewable Agency, the King Abdullah Petroleum Studies Center, Mission Innovation, the Clean Air Task Force, and a wide range of industry perspectives and academic insights.

The report informs the IEF High-Level Roundtable on Carbon Management Technologies hosted virtually in collaboration with the Clean Energy Ministerial and the King Abdullah Petroleum Studies and Research Center on 27 September 2021 to discuss long-term strategies and mechanisms to scale carbon capture, utilization, and storage.

Report findings and dialogue outcomes shall facilitate negotiations at the UNFCCC Climate Conference (COP26) hosted by the United Kingdom in 2021 and advance the producer consumer dialogue at the 17th International Energy Forum Ministerial Meeting that Saudi Arabia will host in 2022.

Lee Beck, CCUS Policy Innovation Director, Clean Air Task Force; Tim Bertels, Senior Partner DAREL Group, and Advisor to Clean Air Task Force; Mohamad Hejazi, Research Fellow at the King Abdullah Petroleum Studies and Research Center; and Juho Lipponen, Coordinator of the Clean Energy Ministerial CCUS Initiative have reviewed the report and provided valuable insights and comments.

1. Introduction

1.1 It's Time to Green Light CCUS

The growth of renewables and electrification is crucial to achieving both climate and sustainability goals, but greater effort is required to bring other available solutions to market and explore new opportunities. The share of hydrocarbons in total primary energy demand is expected to range between 72 percent and 74 percent in 2040 according to main scenarios. This could fall to around 55 percent to meet both universal energy access and climate goals according to the IEA's and OPEC's alternative scenarios. The world economy will continue to rely on hydrocarbons under any scenario as the annual comparative analysis of outlooks shows.[1] This means that clean energy technology deployment must reach scale at warp speed to achieve shared goals over the next decades. If evolving market trends are to match the growing level of ambition to achieve climate goals without losing sight of energy market stability and affordability, carbon management technology deployment by the hydrocarbon sector and energy intensive industries should benefit from far greater support.

Carbon management solutions such as CCUS, whether by design or market failure, still constitute the weakest link in new energy and climate policies. Comprehensive and robust carbon management strategies must deliver a growing share of emission reductions and will depend on successful solutions as scenarios show. Greater engagement between government, industry, the public and local communities will help to broaden support and accelerate CCUS deployment to ensure swift, affordable, and inclusive transitions towards climate neutrality by mid-century.

Carbon management can take two forms. The first includes nature-based solutions such as afforestation. The second includes engineered solutions that focus on clean energy technologies that capture, and permanently store, and/or use carbon dioxide (CO_2) emissions to optimize biological and industry processes. Engineered solutions aim to control anthropogenic releases of CO_2 emissions through technologies such as **Carbon, Capture, Use and Storage or CCUS**. The process involves capturing CO_2 emissions from hydrocarbon production, coal, and natural gas power plants, and from heavy industry such as steel and cement manufacturing. Most CCUS facilities globally are tied to natural gas processing and made economically viable through enhanced oil recovery (EOR). Carbon capture processes can also be combined with Direct Air Capture (DACCS) and Bio Energy (BECCS) to provide a more comprehensive solution in achieving net-zero ambitions.

CCUS deployment can be accelerated in industry clusters by pooling CO_2 streams for energy generation, waste management and product manufacturing. Notwithstanding market hurdles and public acceptance issues, key international organizations cite the importance of CCUS as a critical solution to emissions reduction and achieving net-zero climate strategies.[2] Furthermore, CCUS is not an isolated function that captures, stores, and reuses carbon in a single value chain or biological cycle. Instead it offers holistic solutions necessary for climate neutrality.

1. IEF-Resources for the Future, Outlooks Comparison Report, 2021
2. IPCC, Special Report on Global Warming of 1.5 degrees Celsius, 2018, IEA, CCUS in Clean Energy Transitions, 2020, IRENA, Reaching Zero with Renewables, 2020

Table 1 – CCUS Facilities Around the World

	Operating	In Development	Total
North America	16	19	35
China	3	3	6
Europe	2	11	13
Gulf Coorperation Council	3	1	4
*Rest of World	3	3	5
Total	26	37	63

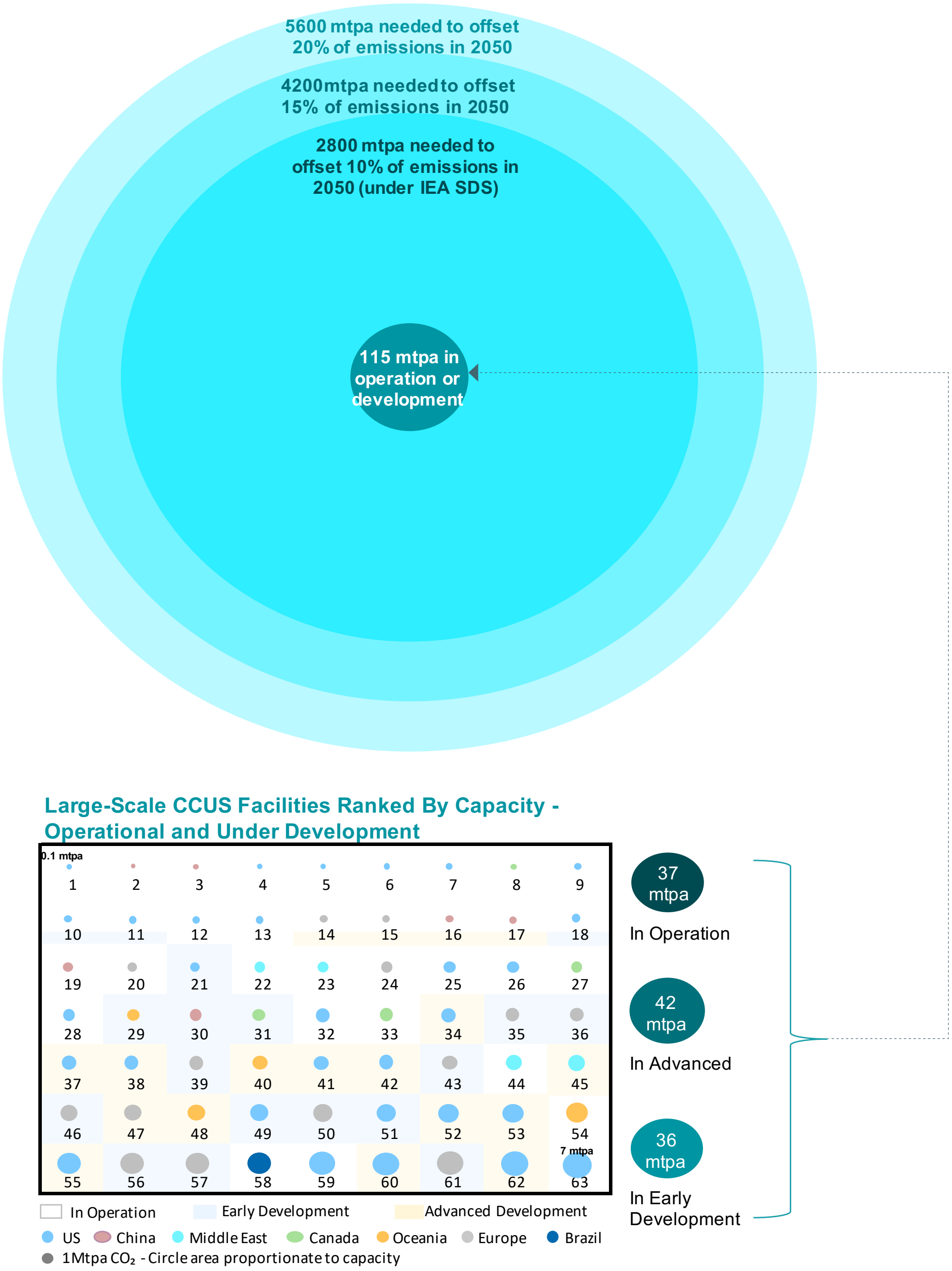
*Includes facilities in Australia, Brazil, New Zealand, and South Korea
Source: Global CCS Institute (GCCSI)

Today, about 40 million metric tons (Mt) of CCUS capacity is in operation though different classification criteria and market transparency issues mean that assessments can differ. To meet the Paris Agreement and UN Sustainable Development Goals, however, CCUS deployment must reach at least 5.6 Gigatons (Gt) of CO_2 by 2050. Without CCUS, the cost of energy sector transitions could increase by more than 70 percent as was highlighted at the US Summit on Climate Change on 22-23 April 2021. Despite the need for CCUS, several obstacles persist towards reaching economies of scale. These include large upfront costs and energy penalties, poor market signals, regulatory hurdles, and a lack of public acceptance due to safety and other concerns. These challenges can be resolved through creative incentivization programs, placing a price on carbon or benchmarking performance through standards, ramping up research and deployment (RD&D), wider public engagement, and enforcing regulations that address CCUS liability issues – solutions that need to be fast-tracked to expedite CCUS investment.

This report presents a concise overview of CCUS as it pertains to six key domains: **Climate Policies, Investments, Technologies, Sustainable Growth, Digitalization, and Social Acceptance** – key drivers that will play a significant role for CCUS in the future. This is followed by a summary of recent CCUS policy and market developments, potential of CCUS hubs around the world, and a set of policy recommendations and conclusions. A concise CCUS strength, weaknesses, opportunities, and threats analysis is included in the appendix, alongside scenario details, and a reference list of key publications.

Figure 1 – CCUS Project Ranked by Capacity, Stages of Development, and Emission Reduction Goals

The potential of captured and stored CO_2 depends on the capacity of a particular CCUS facility. Of the 63 facilities worldwide, the capacity ranges from small to very large (0.1 Mtpa to 7 Mtpa). Much greater CCUS and related infrastructure capacity will be required to offset growing emissions by 2050.

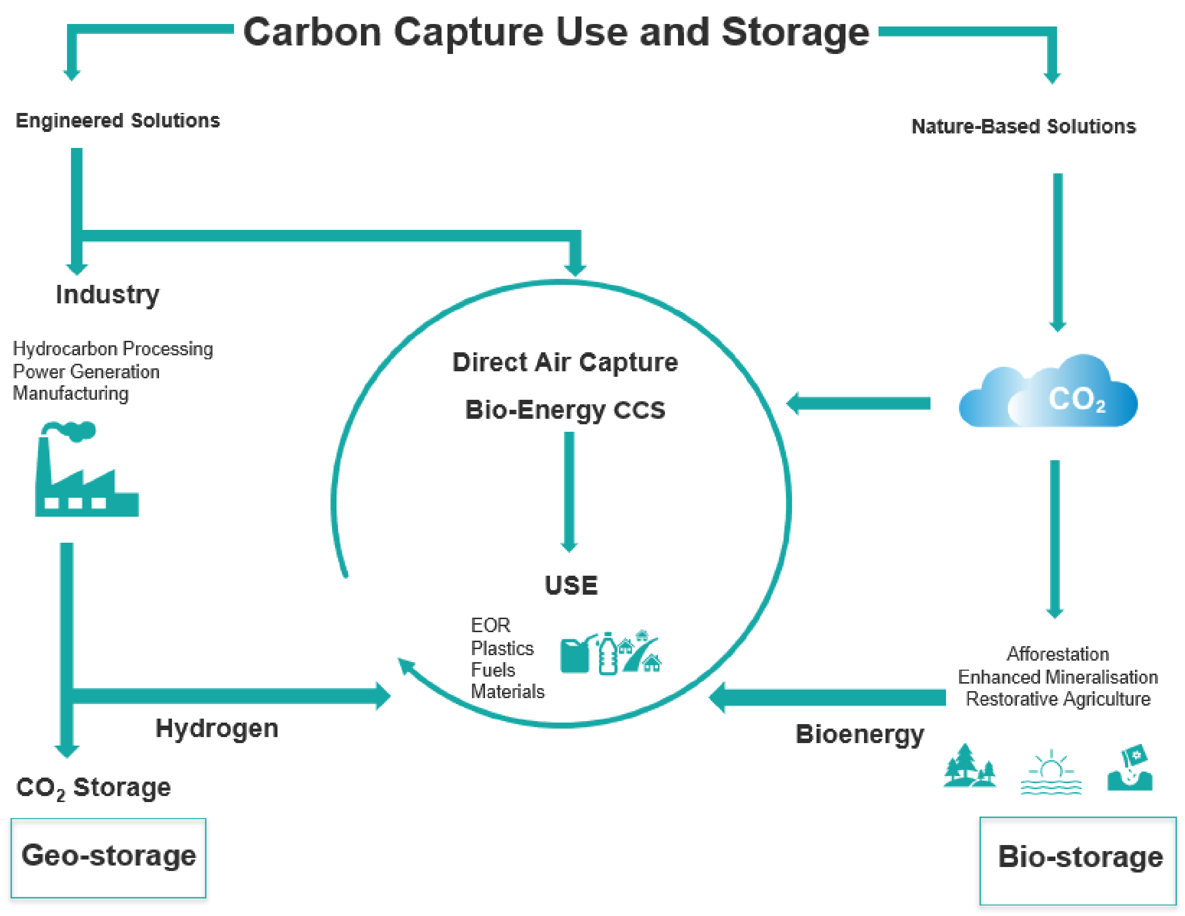


1 Bonanza
2 Karamay Dunhua
3 Sinopec Zhongyuan
4 Red Trail Energy
5 Enid
6 Arkalon
7 PCS Nitrogen
8 ACTL Nutrien
9 Intersegt – Hereford
10 Central Valley
11 Intersegt – Plainview
12 Core Energy
13 Terrell
14 Fortum Oslo Varme
15 Brevik Norcem
16 Sinopec Qilu
17 Yangchang
18 Velocys' Bayou
19 CNPC Jilin
20 Snohvit
21 LafargeHolcim
22 Uthmaniyah
23 Abu Dhabi Phase 1
24 Sleipner
25 Coffeyville
26 Air Products
27 Boundary Dam
28 Illinois Industrial
29 Project Pouakai
30 Sinopec Shengli
31 Quest
32 Great Plains
33 ACTL Sturgeon
34 Cal Capture
35 H2H Saltend
36 H21
37 The Zeros Project
38 Mustang Station
39 HyBet North West
40 Santos Cooper Basin
41 Wabash
42 Plant Daniel
43 Hydrogen 2 Magnum
44 Qatar LNG
45 Abu Dhabi Phase 2
46 Ervia Cork
47 Porthos
48 Carbonnet
49 Illinois Clean Fuels
50 Caledonia
51 Dry Fork
52 Project Tundra
53 Gerald Gentlement
54 Gorgon
55 Lake Charles
56 Drax BECCS
57 Acorn
58 Petrobras Santos Basin
59 Century Plant
60 San Juan
61 Teesside
62 Prairie State
63 Shute Creek

Source: IEF, GCCSI

Figure 2 – CCUS Engineered and Nature-Based Solutions

Engineered CCUS solutions help integrate energy systems and value chains in industrial clusters. Nature-based CCUS solutions are also gaining prominence and the interface between the two is likely to broaden over time.



Source: IEF

1.2 10 Key Points

The 10 key policy insights summarize the findings of this report. They point to the timeliness, versatility, and relevance of CCUS technologies to resolve pressing climate and energy policy challenges, and the levers governments and industry stakeholders can use to seize the opportunities they have in store.

1. **CCUS forges the link between energy security, affordable energy access, and climate change mitigation.**

2. **Accelerated timelines to achieve climate goals mean it is time to green light CCUS technologies** just like the oil price shock of the 1970s motivated energy efficiency policies that are mainstream today.

3. **CCUS enhances resource efficiency and climate neutrality** through CO_2 capture processes, productive use, and permanent storage, as well as part of integrated value chains.

4. **CCUS must be deployed on a much broader scale through** collective government and industry efforts **to align climate goals with current pathways.** The quest for a hydrogen economy depends on economy wide CCUS uptake.

5. **The versatility that CCUS offers across industries** makes it a practical technology for emissions reduction in hard-to-abate sectors. CCUS enables sector coupling and circular models that create both productivity and sustainability gains.

6. **Comprehensive CCUS strategies should cover a wide range of levers and transport modes between industry clusters and storage sites.** Offering investors suitable incentives and more predictability across value chains will spur development without stranding jobs or assets.

7. **Market incentives such as carbon price signals are strengthening** the investment case for CCUS across the power sector and industry value chains. However, they remain too volatile and regional to be sufficient to offer a stand-alone solution.

8. **Greater international engagement is required** to overcome obstacles that keep CCUS from reaching the required scale. These range from large upfront costs, energy losses, poor market signals, regulatory hurdles, to public acceptance issues and safety concerns.

9. **Making CCUS eligible for financing under Environmental, Social, and Governance Standards**, and part of contributions to climate mitigation, economic recovery and growth plans will boost market confidence and help achieve public service obligations.

10. **A new focus on high impact areas, trade-offs, and technology transfer between world regions** to access storage options and markets for new uses will create new jobs, CO_2 demand flows, and much needed technology breakthroughs.

2. Six Key Drivers

2.1 Policy: The Advent of Climate Policies and Net-Zero Strategies

In 2005, G8 leaders vowed to accelerate the deployment and commercialization of Carbon Capture and Storage Technology at the 2005 Gleneagles Plan of Action on Climate Change, Clean Energy, and Sustainable Development. Since then, progress has been slow due to the headwinds of the global financial crisis, a volatile market environment with weak investment incentives, and growing public acceptance and risk perceptions issues. This has disproportionately pushed policymakers towards renewables and energy efficiency solutions rather than enabling CCUS – an available carbon management technology that some interest groups believe will extend the world's reliance on fossil fuels rather than abate CO_2 emissions.

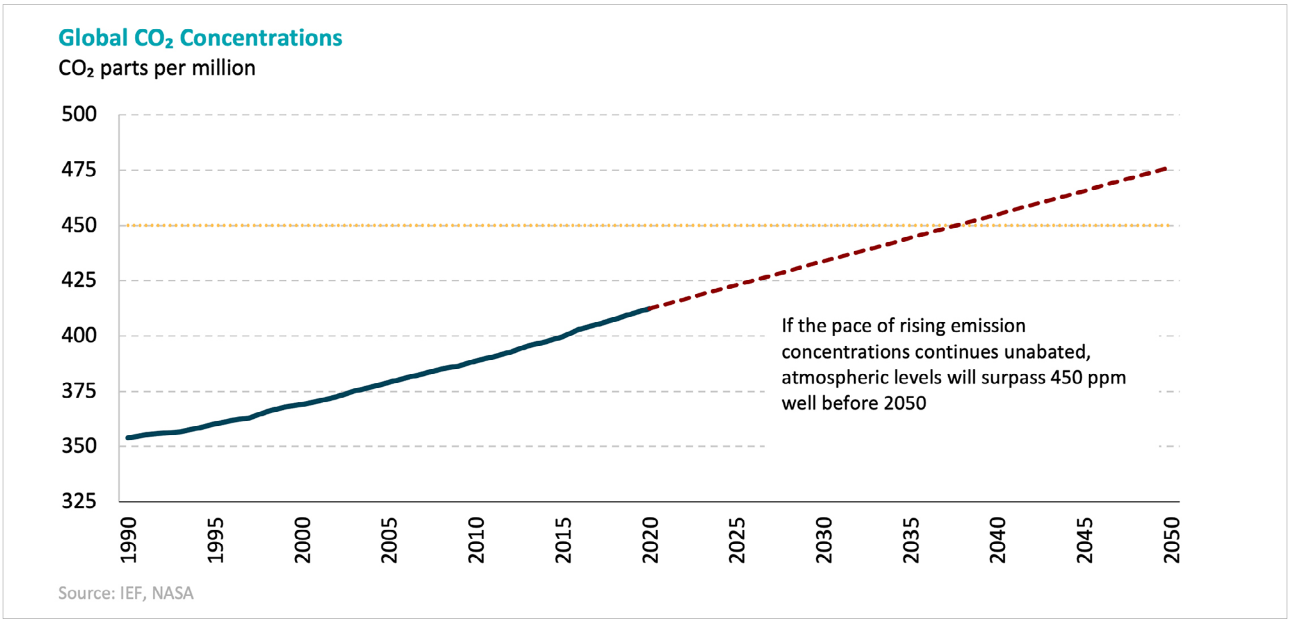
Recent G20 energy and climate ministers' meetings have again referenced CCUS in their communiqués. During the G20 Presidency of Germany in 2016, ministers encouraged countries that opt to use CCUS to continue to undertake RD&D and to collaborate on large-scale demonstration projects. Policy support has moved from restrictive and secondary references to CCUS, towards leading and more open formulations in which ministers acknowledge the role of CCUS more straight forwardly. This includes the endorsement of the Circular Carbon Economy Platform by energy ministers meeting virtually under the G20 Presidency of Saudi Arabia on 28 September 2020, and the recognition of the need for investment and financing for advanced and clean technologies, including CCUS or Carbon Recycling to abate emissions, considering that fossil fuels still play a significant role in the energy mix, as G20 energy and climate ministers agreed on 23 July 2021 in Naples, Italy.

Despite the progress made to date, CCUS technologies are still on a "too little too late" trajectory. However, strengthened climate policies to reach net-zero targets by mid-century and the quest for a hydrogen and a more circular economy could unlock CCUS Research, Development and Deployment (RD&D), facilitate technology transfer, trade, and investment for large-scale integrated projects. This will help lead the way towards rapid, affordable, and deep decarbonization on open and well-regulated global energy markets.

To curb emissions as part of the post-pandemic recovery, several countries have provided visions of net-zero strategies and circular models aimed at keeping the global temperature rise below 2 degrees if not 1.5 degrees Celsius above pre-industrial levels. Several European countries have already put net-zero strategies into law while more countries are in the planning stages. Climate policies include the increased use of renewable energy, improved energy efficiency in buildings and industry, greater use of electric vehicles, carbon pricing for climate mitigation, and most notably, an increased role for clean energy technologies.

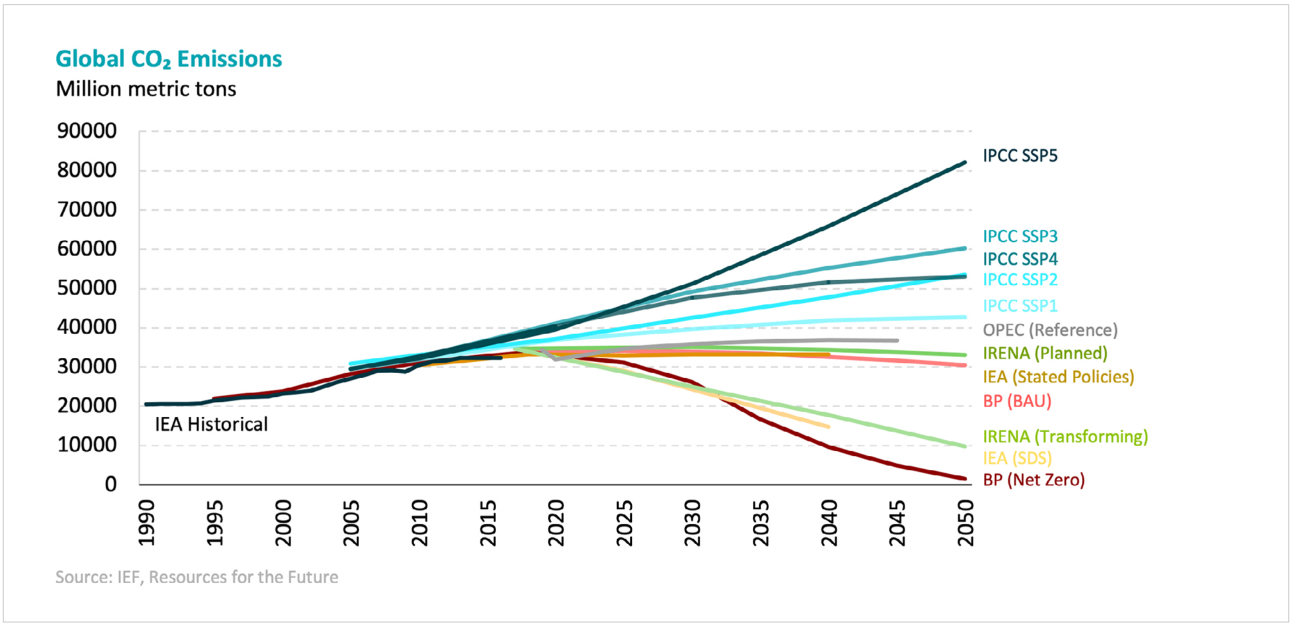
CO_2 levels in the atmosphere have risen steadily over the past decades. Extrapolating current trends from the satellite observations by NASA, **Figure 3** shows that they will reach critical levels (450 ppm) well before 2050 without concerted action on clean technology deployment.

Figure 3 – Increasing CO_2 Concentration Over Time



Beyond increasing CO_2 concentrations, several scenarios to 2050, issued by key international organizations and industry, show different carbon emissions scenarios depending on different assumptions and data sets. **Figure 4** shows net-zero scenarios with the greatest emissions declines by 2050 while current policy and less aggressive scenarios see emissions increase or plateau mid-century.

Figure 4 – Carbon Emissions Based on Key Scenarios to 2050



Note: See Appendix 2 for the assumptions that govern the diverse CO_2 emission scenarios of Figure 4 in relation to CCUS technology pathways.

2.2 Investment: Financial Incentives in an Evolving Policy Landscape

Market and policy signals are inextricably linked and vital to stimulate investment in CCUS. Although CCUS technology has been operational since the 1970s, mostly for enhanced oil recovery (EOR), investment has not lived up to expectations. While CCUS is hailed internationally as a carbon reduction technology, it has consistently accounted for less than 0.5 percent in clean energy investment according to the IEA. Investment dropped due to the global financial crisis and a reluctance by the private sector to make greater energy investments in a volatile market and uncertain policy environment. Although CCUS investment has accelerated since 2017 largely due to greater climate awareness and more supportive government policies, market incentives for investment in CCUS remain too weak to successfully unlock its true potential. High upfront costs, energy penalties, and risk perceptions of CCUS projects can be better managed by introducing enabling policies that enhance plant efficiency, address market failures, allocate risks efficiently, and achieve economies of scale. This can be done through sector coupling and pooling, for instance, by pursuing poly-generation, shared transport, waste management, and manufacturing options in large industrial clusters.

- **CCUS investment incentives are dependent on policy and new business models.** Government stimulus funding as part of post-COVID-19 recovery along with greater political will pertaining to sustainable development and climate policies should facilitate a more conducive investment climate. Since the global financial crisis, CCUS deployment has tripled due to expanding industry applications, declining costs, and new business models. New policy incentives in the form of tax credits and government funding in relation to clean energy technologies should become more accessible to CCUS project sponsors than in the past.

- **Government funding towards CCUS clusters and hubs help CCUS projects reach industrial scale.** Forming capture and storage hubs around industry clusters consisting of large industrial emitters will limit costs, increase efficiencies, reduce risks, and create new investment opportunities. As a policy catalyst, governments can make the initial investment towards transport and storage infrastructure for an initial anchor customer and then expand the network to service growing demand. Governments can also commit to managing risks in certain CCUS market segments such as CO_2 storage, which can be difficult to finance and insure by private stakeholders alone.

- **Environmental, Social, and Governance (ESG) standards for CCUS can enable investment.** There is a movement of capital away from higher to lower emission asset classes, as demonstrated by the rise of ESG investment funds and green bonds. As a carbon reduction technology, CCUS investments should be able to attract grants, loans, debt equity, and other types of financial support and be explicitly acknowledged as an ESG compliant technology.

- **The cost of capture is competitive with other mitigation technologies.** Depending on the market segment, CCUS can be deployed today from as low as USD 15-30/MtCO_2 for high concentration carbon streams in sectors such as natural gas production and petrochemicals and about USD 60-120/MtCO_2 for the coal-fired power sector where most advanced CCUS development and capacity additions are taking place. As is true for most projects today, EOR can offset storage costs during the initial phases of CCUS development.

2.3 Technology: Funding Research Development and Deployment (RD&D)

CCUS comprises a suite of technologies that includes the separation of CO_2 from gas streams, compression and transportation, and storage in a suitable geological site (i.e. deep saline aquifers, depleted oil, and gas reservoirs), or in industrial material and components, and nature-based solutions. While CCUS technologies help enable a carbon-neutral process, CO_2 removal (CDR) technologies such as bioenergy with CCUS (BECCS) and direct air capture (DACCS) provide carbon-negative options that can complement carbon-neutral CCUS approaches. CCUS technologies are also applicable to existing processes such as EOR, coal gasification, and hydrogen production. However, more RD&D is needed in hard-to-abate areas to enhance the role of CCUS in industry and reusing CO_2 to create products.

- **More R&D funding is required for CCUS in decarbonizing hard-to-abate sectors and other applications.** The cement, iron and steel, and chemical sectors are responsible for about 70 percent of industry emissions according to GCSSI, but CCUS technologies have not reached maturity in the sectors where they are most needed. For example, the most advanced technology for CO_2 capture in the cement industry is only at the demonstration stage. Similarly, technologies that use CO_2 to produce synthetic fuels also remain at an early stage of development and require greater research and development efforts and investment to reduce costs and reach scale.

- **CCUS used in combination with pre-combustion processes such as coal gasification provides a cleaner option in coal consuming countries.** Incorporating CCUS into the coal gasification process can eliminate CO_2 produced as a by-product of syngas. The carbon-free syngas can then help enable large-scale carbon-neutral petrochemical process to produce methanol, ammonia/fertilizer, olefins, steel, and power while the CO_2 can be used towards enhancing oil production and/or towards creating other products.

- **BECCS, DACCS, and carbon mineralization technologies can provide greater CO_2 reduction potential than carbon-neutral technologies alone.** As bioenergy is a carbon-neutral fuel, CCUS used in combination with bioenergy CCS (BECCS), or direct air capture (DACCS) results in net-negative carbon emissions. Enhanced mineralization is a similar concept by which carbon absorption is accelerated by certain minerals either in soil or the ocean. These technologies remove existing carbon from the atmosphere producing a net-negative effect. Negative emissions technologies are critical in offsetting emissions from long-distance transport and heavy industry that are more difficult to abate. Supplementing CDR technologies with nature-based solutions such as afforestation, reforestation, and restoring coastal wetlands and mangroves is also crucial.

- **Measurement, monitoring, and verification technologies are important to track CO_2 streams and ensure CO_2 is permanently stored.** Once carbon is stored underground, it must be monitored over time to ensure it does not escape into the atmosphere. These monitoring technologies provide extensive knowledge of the movement of gas and fluids in the subsurface and highlight any risks that might be associated with migration and leakage. Having these technological safeguards provides both investors, regulators, and local communities with the required confidence to proceed with approval of CCUS projects.

2.4 Sustainable Growth: Natural Gas and Hydrogen

As the post-COVID-19 recovery takes shape, greater energy demand will need to be balanced with sustainable practices. While renewables remain an important pathway towards sustainability, cleaner fossil fuels such as natural gas and emerging carriers and fuels such as hydrogen will also need to play a vital role. Incorporating CCUS will further enhance the sustainable potential of both.

More than 90 percent of hydrogen is produced via steam methane reforming through natural gas that produces CO_2 and hydrogen. Incorporating CCUS allows for hydrogen production without CO_2 emissions thereby accelerating the hydrogen economy. This CCUS enabled carbon-free hydrogen can be used as a transport fuel in fuel-cell vehicles, stored as a gas or liquid and converted to electricity, or used to make ammonia and methanol that have various industry applications. Without CCUS, hydrogen production will remain a carbon-intensive process until hydrogen production through water electrolysis, powered by renewables, reaches market parity and can be deployed at scale.

1. IRENA, Green Hydrogen Cost Reduction Scaling up Electrolysers to Meet the 1.5°C Climate Goal, 2020
2. Cho, R. Why we need green hydrogen Columbia Climate School State of the Planet,7 January 2021

Although there is renewed momentum behind renewable hydrogen production, several challenges exist:

- **Costs considerations for electricity and electrolysers.** Despite their market availability and maturity, electrolysers are still considered expensive from both CAPEX and OPEX perspectives, compared to fossil fuel-based hydrogen production, according to IRENA. The price of electricity at any given time is also an important consideration and a key determinant whether hydrogen produced from fossil fuel sources or renewables is more economically viable.

- **Infrastructure constraints due to increased electrification.** Limits on existing infrastructure such as power grids, storage, and transportation will be reached in the near term without new investment. Renewable hydrogen production may require about 300 percent more electricity transmission capacity than today, according to Columbia University's Center on Global Energy Policy. Before the grid capacity necessary to accommodate power enabled hydrogen production and increasing demand from electric vehicles, investment in existing and new infrastructure for CCUS enabled hydrogen production will be necessary to meet shared goals in time.

- **Insufficient renewable power in the electricity grid.** In most countries, it will take more time to increase the share of renewables in the electricity grid that would be optimal for hydrogen production. This will require parallel investments in grid infrastructure that foster smarter, more flexible, and efficient grids.

- **Water resource considerations for renewable hydrogen.** Every kilogram of hydrogen involves around 9 kg of water, both in the electrolysis process and in the fuel cell. The availability of water could become a critical factor for green hydrogen production. As a result, areas with water shortages will require improved water management and treatment processes.

Production of hydrogen with CCUS offers a more viable and complementary approach towards decarbonization as barriers to hydrogen production from renewable power are removed over time through policy, regulatory, and technological innovations.

Natural gas consumption, meanwhile, will comprise 23-25 percent of the energy mix by 2040 according to IEA and OPEC scenarios. LNG demand is set to double by 2040 with coal-to-gas switching in the power sector being a key development. Given this growth, CCUS technology can complement the existing benefits of natural gas while meeting climate goals.

- **Natural gas in combination with CCUS offers the greatest emissions reduction potential.** According to the International Gas Union, natural gas and CCUS used in tandem can reduce global emissions by 4 Gt of CO_2, or up to 11 percent by 2040 – the largest emissions reduction potential compared to any other natural gas technology.

- **CCUS allows for low-carbon natural gas processing and production of zero-carbon LNG.** With increasing scrutiny on life-cycle emissions and net-zero strategies, natural gas producers are tracking emissions from the wellhead to the import terminal, while others are delivering carbon-neutral cargoes offset with emissions certificates as requested by importers. CCUS allows both exporting or importing countries to reduce CO_2 emissions associated with LNG.

- **CCUS balances growing natural gas demand for economic growth with emissions reduction goals to mitigate climate change.** As natural gas-fired power generation continues to grow, CCUS serves as a balancing mechanism to enable sustainable economic growth and reduce CO_2 emissions associated with LNG.

2.5 Data and Digitalization: The Fourth Industrial Revolution

The Fourth Industrial Revolution, an era where digital innovation and artificial intelligence drives economic progress, has impacted many industries including the energy sector. Digitalization, big data, automation, and the Internet of Things enable a shift of traditional energy business models towards a new architecture of interconnected energy systems. For CCUS to operate effectively, digitalization can play an important role in measurement, monitoring and verification by making robust and readily comparable data available in a timely manner.

- **CCUS investment is dependent on carbon market data.** Close to real-time, sophisticated data on global carbon market movements will be required to help companies make better decisions. This will impact investment in clean energy technologies such as CCUS.

- **CCUS requires large-scale CO_2 monitoring data to inform markets and ensure safety.** Monitoring CO_2 flows in geological storage sites or nature-based solutions, use in materials and products, and related trade flows, requires a renewed collective effort to strengthen energy data transparency in carbon markets.

2.6 Social License: Energy Security and Public Acceptance

Concerns about environmental integrity, public safety, and health have slow-tracked investment in CCUS. These include risks posed by a sudden or gradual leakage of CO_2 from CCUS subsurface storage. However, the benefit CCUS technology offers to reduce anthropogenic CO_2 emissions, strengthen energy security, and increase resource efficiency through productive uses e.g. Enhanced Oil Recovery (EOR), Enhanced Gas Recovery (EGR), and other options, far outweigh the risk of CO_2 leakages, which can be prevented through regulations on toxic and hazardous substances.

Various safeguards can be employed to manage risks. Geological surveys, environmental impact assessment studies to select appropriate storage sites, evolving industrial competence and regulatory standards for the treatment of dangerous gases, dynamic risk management and data monitoring procedures, and insurance frameworks, all work together to reduce risks.

Perceptions that CCUS may extend reliance on fossil fuels wrongly equate CO_2 and other emission reduction goals with a reduction in demand for fossil fuels. Industry legacies and current pathway dependencies mean that ramping up renewables and other non-fossil fuel technologies alone will not reduce emissions in line with IPCC models. CCUS, therefore, is not a “nice to have” or de-facto subsidy to the fossil fuel industry but an essential technology solution that is urgently required to achieve energy and climate policy goals over the next decade and beyond.

Timely communication and ongoing engagement with concerned communities and the public at large on the opportunities that CCUS technologies can offer, including on the balance of risk and rewards, is essential to strengthening public acceptance and investor confidence.

3. Developments

3.1 Policy and Market Developments in World Regions

Despite the challenges facing CCUS investment and the policy mechanisms required for greater uptake, CCUS is nonetheless making meaningful inroads in many parts of the world. This includes key developments in the US, Canada, Australia, China, Middle East, and the European Union. Various safeguards can be employed to manage risks. Geological surveys, environmental impact assessment studies to select appropriate storage sites, evolving industrial competence and regulatory standards for the treatment of dangerous gases, dynamic risk management and data monitoring procedures, and insurance frameworks, all work together to reduce risks.

United States

US tax credits allow companies to overcome two of the main obstacles to investment in CCUS technologies: defraying high upfront costs and monetizing CO_2 use and storage.

Section 45Q of the US Internal Revenue Code of 1986 first introduced a credit for the sequestration of carbon dioxide (CO_2) on 3 October 2008. The tax credit provided an incentive of $20 per metric ton for CO_2 storage and $10 per metric ton for CO_2 in productive uses. However, the tax incentive was limited to a total of 75 million tons of qualified CO_2 captured across all projects that each were required to capture at least 500,000 metric tons of CO_2 to qualify. The low credit value and the lack of market transparency in respect to available credits remaining at any one moment delayed CCUS investment.

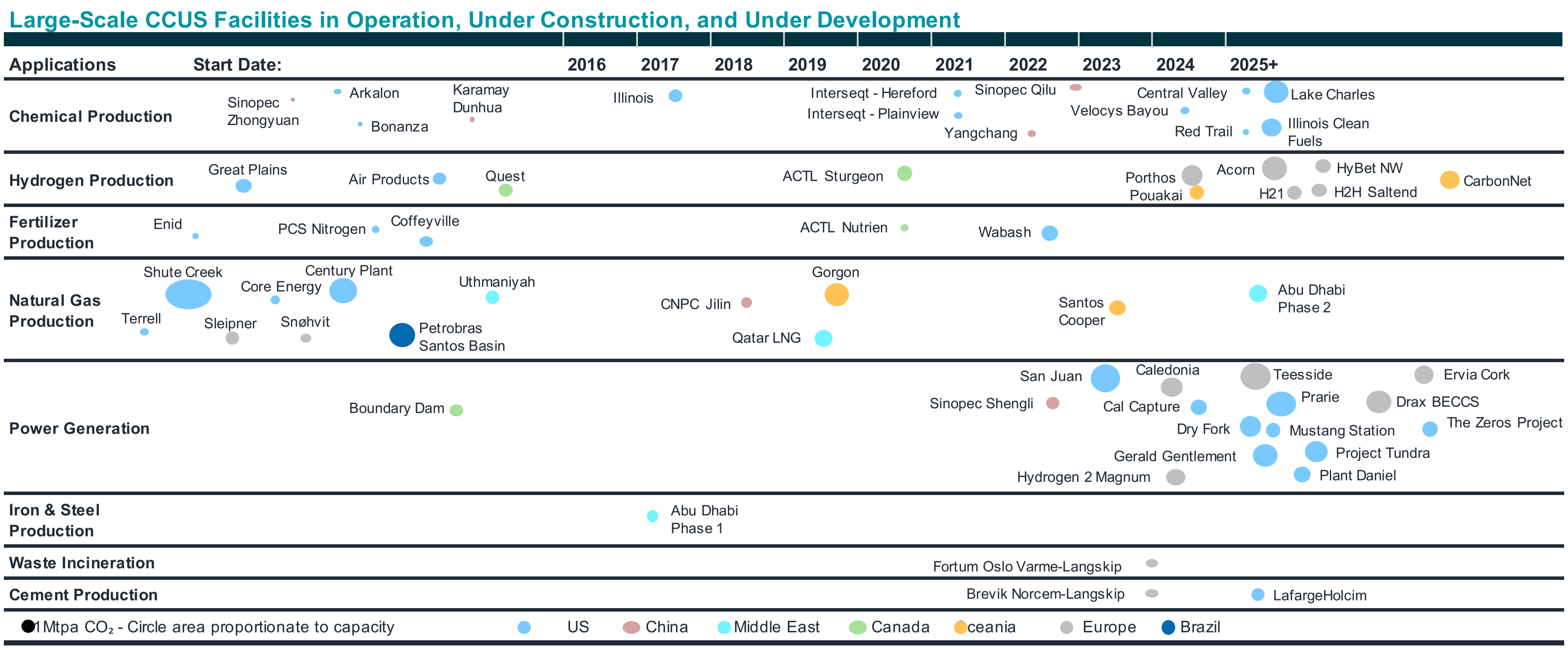
The Bipartisan Budget Act in February 2018, helped to further unlock CCUS investment by expanding the tax credit's applicability beyond CO_2 alone to "qualified carbon oxide", eliminating limits to credits available in the market, lowering the minimum threshold of carbon captured for certain investors, while increasing the credit up to $50 per metric ton for geologic storage and up to $35 per metric ton for EOR by 2026. The $35 tax credit was also made available for non-EOR CO_2 utilization and direct air capture projects. It also provided construction of a "qualified facility that includes carbon capture equipment" must begin before 1 January 2024 to enhance predictability for investors. Once facilities start, companies have 12 years to claim their funds.

Qualified facilities are further defined where:

- Facilities emit less than 500,000 metric tons of qualified carbon oxide into the atmosphere and capture not less than 25,000 tons of qualified carbon oxide per year.
- Power generation emits more than 500,000 metric tons of qualified carbon oxide and at least 500,000 tons is captured per year.
- Direct air capture facilities that capture at least 100,000 tons per year.

Carbon oxide is qualified when it is measured at the point of capture at an industrial source or from the ambient air at a direct air capture facility and verified where it is disposed of, injected, or utilised.

Figure 5 – Global CCUS Project List



Source: IEF, Global CCS Institute

Table 2 – Supercharging CCUS investment with the 45Q Tax Credit

	Threshold by Facility Type ($ktCO_2/y$)			Current ($/t)	Proposed Tax Credits ($/t)	
	Power Plant	Industrial Facility	Direct Capture	Budget Act	Catch Act	Amendments Act
Disposal	500	100	100	50	85[a]	120[b]
Injection	500	100	100	35	60	75
Use	25	25	25	35	60	75

IEF Sources: U.S Department of Energy, US House of Congress, Clean Air Task Force

Notes: [a] Without eligibility thresholds applicable to all CCUS technologies except Direct Air Capture.

[b] Applicable to CO_2 storage in saline geological formations from Direct Air Capture projects.

Early in 2020 and 2021 the U.S. Treasury and Internal Revenue Service (IRS) published additional guidance to make the mechanisms that apply the 45Q tax credits to the CCUS market more transparent. These long-awaited clarifications that broadly follow the model used to integrate wind and solar in power markets, have further boosted market stability and investor confidence in CCUS deployment. In addition, the so called “Extenders Bill” that was signed into law late December 2020 lengthened application of the tax credit by two years, shifting the “commence construction” requirement from 1 January 2024 to 1 January 2026 for CCUS projects to be eligible. The final regulations also provide a six-year timeframe to place qualified facilities or CCUS projects in service after construction has begun; two years longer than for wind and solar.

For disposal / injection of carbon oxide, further central requirements that must be met include compliance with the Federal Environmental Protection Agency (EPA) and rules for six classes of underground injection wells and the EPA Greenhouse Gas Reduction Program, as well as the International Standardization Organization standards. This includes monitoring, reporting, and verification of CO_2 stored under EPA Greenhouse Gas Reduction Program. In relation to EOR, a Class II Underground Injection Control permit is required under the Safe Drinking Water Act. There are currently 180,000 Class II wells associated with oil and gas production processes in operation in the U.S. However, permanent storage is less well established. This requires a Class IV permit that, with only two wells approved by the EPA to date, applies new and more stringent criteria increasing disclosure requirements, regulatory burdens, and lengthening lead times.

For use to be eligible for the 45Q tax credit it must either:

- Chemically convert carbon oxide into a compound in which it is securely stored;
- Fixate carbon oxide through photosynthesis or chemosynthesis;
- Use carbon oxide for other purposes for which a commercial market exists

The latter requirement is broadly defined without limitations to a particular product type or market and can include already existing as well as future carbon oxide demand. The amount of carbon oxide used is calculated through a life cycle assessment that should demonstrate a net reduction. Moreover, to be eligible to receive the tax credit the owner of the carbon capture facility does not need to own the emitting facility and can conclude a contract with other parties that inject or utilize the captured carbon. Operational flexibility is further increased by allowance made for the transfer in full or in part of the tax credit claim by the owner to counterparties that dispose, inject, or use the carbon oxide, provided credits are allocated in proportion to the amount of carbon sequestered by each counterparty, and these are not subcontractors.

On 25 March 2021, the US Senate introduced the Carbon Capture, Utilization, and Storage Tax Credit Amendments Act of 2021. The legislation proposes the following amendments to the existing act to stimulate CCUS deployment:

- **Further extends the "commence construction" requirement by five years.** The credits would be available to projects that begin by the end of 2030.

- **Allows for direct payment of carbon capture credits.** Allows project developers who otherwise lack sufficient taxable income to fully utilize the credits. The legislation clarifies that municipal power providers and electric cooperatives are eligible.

- **Substantially increases support for direct air capture (DACCS) of CO_2 from the atmosphere.** The bill would increase the 45Q credit value for direct air capture projects from $50 to $120 per metric ton for CO_2 captured and stored in saline geologic formations and from $35 to $75 per ton for CO_2 stored geologically in oil and gas fields. Increasing the credit for DACCS could substantially grow the deployment of the technology and create tens of thousands of high paying jobs.

- **Allows the 45Q credit to offset tax obligations due to the Base Erosion Avoidance Tax (BEAT).** The bill will grant the same tax treatment to CCUS and DACCS projects as is currently offered to wind and solar projects.

- **Revises 48A credit to make it work for CCUS retrofits.** The bill includes modifications to the 48A tax credit aligned with the recent Carbon Capture Modernization Act. This section of the bill updates the thermal efficiency and capture efficiency requirements for advanced coal CCUS projects to make it technically feasible to access these credits.

CCUS legislation has become a priority for lawmakers in the U.S. Other bills include the Carbon Capture Modernization Act which was reintroduced on 10 March 2021 to modernize the 48A tax credit's requirements to make it easier for businesses to receive the tax credit based on the capabilities of existing technology. Another bill was introduced on 17 March called The Storing CO_2 and Lowering Emissions (SCALE) Act which supports development of transport infrastructure that is not part of the 45Q but key to scaling up CCUS projects beyond individual projects and enables commercialization of geologic storage sites by building on DOE's CarbonSAFE Program. The Coordinated Action to Capture Harmful Emissions (CATCH) Act, introduced on 25 May 2021, proposes a more modest boost to 45Q tax incentives while removing all CO_2 capture threshold requirements for power, industry, utilization, and direct air capture projects on the grounds that these are arbitrary, serve no policy purpose, limit technology and innovation and CO_2 emission reduction potential. This will create new project opportunities especially with respect to productive uses of captured CO_2 and spur on carbon market development.

On 14 July 2021 the Senate Energy and Natural Resources Committee passed the Energy Infrastructure Act. Allocating $73 billion to power related infrastructure and authorizing almost $100 billion in energy programs. The Act is the committee's contribution to the infrastructure deal. The SCALE Act is part of the bill and allows captured CO_2 from emitters or by direct air capture facilities to connect to storage options irrespective of location, thus stimulating broader economy wide CCUS deployment. The SCALE Act consists of four key components:

- **The CO_2 Infrastructure Finance and Innovation Act program (CIFIA)** that makes $600 million available to the U.S. Department of Energy (DOE) in the fiscal years of 2022 and 2023 and $300 million in the 2024-2026 fiscal years to provide low-interest loans, loan guarantees and grants to CO_2; transportation projects that meet eligibility requirements.
- **Expansion of the DOE CarbonSAFE program** set up to focus on the development of geologic storage sites for captured and processed CO_2.
- **Funding support to EPA to CO_2 storage well permitting** by allocating $5 million in the 2022-2026 years each to facilitate permitting of Class VI wells.
- **Grants to foster demand for products made from captured CO_2,** including establishing standards and certifications to facilitate product commercialization.

The introduction and subsequent reforms of 45Q, including the final regulations the U.S. Treasury and IRS issued on 6 January 2021, increase operational flexibility, returns, and predictability for CCUS investors. They have significantly lowered and may well eliminate eligibility thresholds while enhancing market transparency and stability. This will broaden CCUS investment by small and medium sized enterprises and limit the exposure of CCUS project sponsors to the volatility of emerging carbon markets and trading schemes.

Leveraging these measures at federal level with state level initiatives such as the Low Carbon Fuel Standards of the State of California while fostering public private partnerships to advance innovation and RD&D will reduce market and regulatory hurdles and increase technology readiness levels. This will enable the creation of an economy wide CCUS market in the U.S. that can serve as a model for other world regions.

Canada

Canada is looking to build on its expertise in CCUS. Federal and provincial governments are collaborating to implement regulatory frameworks to establish Canada as a world leader in emissions reductions. The government's commitment is underscored by the proposed Net-Zero Emissions Accountability Act, introduced in Parliament on November 19, 2020, which will formalize Canada's target to achieve net-zero emissions by 2050.

Canada has four operational CCUS facilities, second only to the US. While the overwhelming majority of CCUS facilities globally are tied to natural gas processing, all four Canadian CCUS facilities are used for different applications which showcases the versatility of CCUS across sectors. The province of Alberta, where most of the CCUS capacity is based, is working with the federal government to explore further CCUS opportunities through the Alberta-Canada CCUS Steering Committee, announced in March 2021.

On 12 May 2021, the province also announced that it will be issuing carbon sequestration rights through a competitive process, advancing the development of strategically located carbon storage hubs where a single operator will provide carbon sequestration services to several industrial facilities. The intent is to enhance Alberta's carbon management system by providing confidence to industry investors and citizens that CCUS will be deployed in a responsible and strategic manner.

Furthermore, the most recent federal budget tabled on 19 April 2021, could provide incentives and grant funding for CCUS technology through:

- **Tax Incentives for CCUS –** The budget proposes tax credits for CCUS investment with the goal of reducing emissions by at least 15 Mtpa of CO_2 annually. The tax credit incentive is expected to take effect in 2022 and will include blue hydrogen production projects and exclude enhanced oil recovery projects.

- **Advancing CCUS Technologies –** The budget proposes to provide CAD $319 million over seven years, starting in 2021-22, with $1.5 million in remaining amortization, to Natural Resources Canada to support research, development, and demonstrations that would improve the commercial viability of CCUS.

- **First Federal Green Bond –** The “green bond” provides CAD $5 billion from 2021 to 2022 to facilitate investment in “green” infrastructure, clean technology innovations, nature conservation, and other efforts to address climate change. Additional details will be provided by the government in the coming months.

- **Supporting Innovation and Industrial Transformation –** The green project funding initiative commits CAD $5 billion over seven years to the Net Zero Accelerator. This is in addition to the CAD $3 billion over five years committed on December 11, 2020. The CAD $8 billion over seven years will support projects that help reduce Canada’s greenhouse gas emissions by expediting decarbonization projects, scaling-up clean technology, and accelerating Canada’s industrial transformation. Starting in 2021-2022, up to CAD $1 billion will also be earmarked, over five years, to help draw in private sector investment for such projects.

Australia

As one of the world’s leading LNG exporters, Australia is looking to CCUS technologies to mitigate CO_2 emissions from its LNG operations. On 2 March 2021, the government launched a USD $39 million fund to support the growth of CCUS projects – part of a wider USD $1.5 billion package for energy technologies announced in the federal budget last year.

There is also progress on the ground. The Gorgon Carbon Dioxide Injection Project, currently Australia’s only operational project, is one of the largest in the world with a capacity at 3.4-4 Mtpa. Prior to gas processing and liquefaction, the reservoir CO_2 is separated from the natural gas stream. While normal industry practice would vent the CO_2 into the atmosphere, the Gorgon project injects it underground. The CO_2 is captured and piped to one of three drill centers and injected into the Dupuy Formation more than 2 km beneath Barrow Island. Two additional projects including the Santos Cooper Basin and Bridgeport Energy Moonie are currently in advanced development with a combined capacity of close to 2 Mtpa.

CCUS is set to gain further traction through Australia’s Technology Investment Roadmap and the King’s Review Expert Panel which were both made public last year. Both reports include recommendations pertaining to low emission technologies including CCUS. The Roadmap outlines goals that include CCUS hub transport and storage for under $20 per ton of CO_2 – a potential decarbonization pathway for hard-to-abate industries such as natural gas processing and cement. On 19 May 2021, the federal government also accepted all recommendations of the King’s Review Expert Panel as they pertain to CCUS which examined additional sources of low-cost abatement.

Middle East

As a major energy producer, the Middle East is home to about 40 percent of global liquids production and 20 percent of natural gas output. Shared transport and storage infrastructure with key players in the Gulf region and between port cities can accelerate CO_2 sequestration and encourage investment and research, development, and deployment (RD&D) in CCUS and other clean energy technologies. Saudi Arabia, the United Arab Emirates (UAE), and Qatar are the prime CCUS movers in this region.

In Saudi Arabia, Aramco's Uthmaniyah CCUS demonstration project uses carbon dioxide for EOR. The project captures close to 1 Mtpa of CO_2 from the Hawiyah natural gas plant and transports it through 85 km pipeline for storage in the Uthmaniyah field. CCUS is also instrumental in enabling the circular carbon economy, a framework in which emissions of carbon and other GHG are addressed through the 4 Rs: Reduce; Reuse; Recycle; Remove – a key priority for Saudi Arabia and endorsed by the G20 in 2020. CCUS also helps to preserve employment in key energy sectors and unlocks significant future opportunities, including the export of clean hydrogen and low-carbon chemical production.

The UAE's ADNOC Al-Reyadah Carbon Capture facility – the first commercial-scale CCUS project in the MENA region and the only one in the world dedicated to steel production – provides the UAE with an existing blueprint and a working platform for future projects. This includes the Abu Dhabi CCS Phase 2 natural gas project that will capture 1.9 to 2.3 Mtpa of CO_2 from its gas processing plant for EOR that is set to become operational in 2025.

Qatar, the world's largest LNG exporter, has also made strides towards CCUS that will complement the first phase of its planned North Field East Project (NFE) announced in February 2021. The expansion will increase Qatar's LNG production from 77 Mtpa to 110 Mtpa. The project will feature CCUS technology that will reduce carbon emissions from natural gas liquefaction and storage by about 25 percent below comparable operations around the world. These developments will build on Qatar's existing Ras Laffan CCUS facility – the largest CO_2 recovery and sequestration facility in the MENA region with a capacity of 2.1 Mtpa.

China

China's pledge to achieve net-zero greenhouse gas emissions by 2060 will require the implementation of all technologies including CCUS. This is emphasized in China's 14th Five-Year plan adopted in March of 2021 (14FYP). Following active research on CCUS in the 13th five-year period, the 14FYP announces projects that will build on the three operational CCUS facilities that exist in China today that capture close to 1 $MtCO_2$. China's nascent Emissions Trading System is not only evidence of how the world's largest energy consumer is working to address climate change, but it also complements government-led clean technology deployment with market incentives for investment in CCUS.

With the support of the Oil and Gas Climate Initiative (OGCI) CCUS KickStarter initiative, China is developing a CCUS Hub in Northwest China. In 2018, China National Petroleum Corporation (CNPC) and OGCI Climate Investments (Climate Investments) announced their partnership and in 2019, CNPC and the OGCI set up Climate Investment China. The Northwest Hub is currently in demonstration phase and aims to capture and store over 3 $MtCO_2$ from hydrogen production.

The inland Xinjiang Province, where the project is based, presents key characteristics for CO_2 storage. Major power and industrial emissions sources and large-scale oil fields that can be leveraged for EOR provide many opportunities for CCUS.

Seven of the world's 10 largest ports are in China. The industrial clusters they provide also create ample opportunities for the development of CCUS hub and spoke systems. Shared transport infrastructure and international shipping routes provide access to storage in coastal areas that can help optimize product trade flows ranging from hydrogen to CO_2.

In addition to hub development, China also has existing CCUS facilities in operation and others in construction and early development. As demand for plastics and other chemicals soars in China, most CCUS facilities are tied to the petrochemical sector.

European Union

EU Carbon Capture and Storage Directive

The EU Carbon Capture and Storage Directive adopted by the European Parliament and the Council on 23 April 2009 (EU CCS Directive) identifies CO_2 capture and geological storage as a bridging technology that will contribute to mitigating climate change. Beyond the bridging qualification, the EU CCS Directive stipulates that CCS technology should not encourage an increase in the share of fossil fuel power generation or reduce efforts to support energy efficiency gains and advance renewable and other clean energy technologies. The EU CCS Directive does not cover the productive use of CO_2 in Carbon Capture and Use (CCU) applications, such as enhanced oil recovery, concrete manufacturing, or chemical processes for synthetic fuels and materials. Productive use of CO_2 in CCU applications helps make CCS more economically viable.

The EU CCS Directive assumes that with the right support, avoided CO_2 emissions could amount to 15 percent of total EU reductions required by 2030. The broader spectrum that CCUS offers could help increase avoided emissions further. The new EU target to reduce net greenhouse gas emissions from 40 percent to at least 55 percent by 2030, compared to 1990 levels, implies that the EU's reliance on new clean energy solutions will grow and that CCUS technologies must play a much larger role to meet goals. To enable industries to step up investment and accelerate deployment to meet the net zero goals of the 2019 European Green Deal, which the European Climate Law adopted on 21 April 2021 now enshrines, CCUS must benefit from more robust policy and financial support.

EU Climate Energy and Environmental State Aid Guidelines

The EU provides state aid to companies under certain circumstances compatible with the functioning of the single market and justified on the grounds of the EU's economic policies. A company receiving state aid in the form of subsidies, tax reductions, or any other measures with similar effect gains an advantage over its competitors – an exemption that needs to be managed. Hence, competition law is one of the strongest instruments of the European Commission that can enforce legally binding decisions regarding state aid without the involvement of EU member states. This creates regulatory uncertainty for member state governments, undertakings, and financers seeking to facilitate investment decisions and uptake of technologies such as CCUS in pursuit of national energy and climate policies in which the EU shares competence.

To enhance predictability and regulatory certainty, the EU publishes sector specific guidelines which detail the terms and conditions under which state aid could be permitted. EU state aid guidelines for environmental protection and energy applied on 1 July 2014 were applicable to 31 December 2020 and covered CCS explicitly but not CCU. Though guidelines remain fit for purpose and support the EU's competition, environmental and climate goals, the increased level of ambition to reduce emissions from 1990 levels require revision of state aid rules to enable the EU to reach a cost-effective transition to climate neutral growth by 2050.

The new Climate Energy and State Aid guidelines which should take effect by the end of 2021 take a more holistic and technology neutral approach. This provides an important opportunity to governments and industry to move from facilitating point-to-point CCS projects towards enabling investment in wider ranging CCUS technologies and projects, including transport infrastructure and broaden CCUS deployment at scale across EU industry clusters and storage basins. Measures currently under review include broadening the scope of the guidelines to include circularity including CCU technologies, increasing aid amounts up to 100 percent of the funding gap, and introducing new aid instruments such as carbon contracts for difference. In the case of new energy investments that require natural gas, beneficiaries will have to consider binding commitments to implement decarbonization technologies such as CCUS to be in line with EU2030 climate and 2050 climate neutrality targets. As a result, only technologies that deliver emissions reductions, such as CCUS, would benefit from state aid to facilitate gas sector investment.

EU Emission Trading System and Contracts for Difference

The EU Emissions Trading System (EU ETS) provides a market signal that stimulates clean technology deployment, including by rewarding emissions avoided through CCS. Recent reforms of the EU ETS and growing demand for emission allowances have led to a gradual rise in the EU carbon price that has narrowed the disparity between CCS project costs and market returns on investment. Contracts for Difference (CFD) between CCS deployment cost and prevailing market prices for alternative options fill the gap. Together with CO_2 taxation that provides a price floor, the ETS and CFDs reduce the risk of exposure of first movers to the high volatility that characterizes nascent and emerging markets including for CO_2.

When the EU ETS is combined with CFDs, as in the Dutch Stimulation of Sustainable Energy (SDE+) subsidy mechanism that enables the rollout of renewable energy generation technologies, it has accelerated market entry for solar and wind technologies. The SDE+ was therefore extended to other CO_2 abatement techniques such as CCS in the SDE++, unlocking significant government support for CCS projects.

CCU technologies cover a much wider spectrum of technology applications across economic sectors and are currently not explicitly covered by the EU ETS, CFDs, or direct market supports though they may benefit from these indirectly. The CO_2 that CCU applications include could be included in these and or other similar schemes. However, measurement, monitoring, and verification to take stock of emissions avoided through CCU involves more complex and dynamic analysis. These would have to cover different life cycles: for instance, in short-term applications that use CO_2 in the production of synthetic fuels, in agriculture and forestry over the medium-term, and in the long term using CO_2 in concrete.

TEN-E Regulation

The trans-European energy infrastructure (TEN-E Regulation) adopted on 17 April 2013 includes CO_2 projects in the guidelines it provides for the selection of projects of common European interest to upgrade Europe’s ageing networks and meet its core energy policy objectives. Eight cross border CO_2 transport projects have been submitted between 27 November 2018 and 8 March 2021. These are currently under consideration to be included in the fifth Union list of Projects of Common Interest that will be adopted in October 2021. Project sponsors can benefit from accelerated permitting and other supports, including access to funding from the Connecting Europe Facility, when the regulations’ specific criteria for CO_2 transport projects are fully met by significantly contributing to:

- Avoidance of CO_2 emissions while maintaining security of energy supply;
- Increasing the resilience and security of CO_2 transport;

- The efficient use of resources, by enabling the connection of multiple CO_2 sources and storage sites via common infrastructure and minimizing environmental burden and risks.

The energy infrastructure categories that the regulation specifies for CO_2 refer to mid-stream CO_2 transport facilities and related equipment used for permanent geological storage only. The TEN-E Regulation does not cover cross border CO_2 transport facilities used for CCU applications.

EU Taxonomy

The EU defines 'environmentally sustainable' in a green classification system to establish greater clarity and predictability for investors and attract more finance towards activities that address climate change in accordance with the EU's ambitions, laid down in the European Green Deal. Adopted on 18 June 2020 and taking effect on 1 January 2023, the EU Regulation on the establishment of a framework to facilitate sustainable investment (EU Taxonomy) lists six key objectives:

1. Climate change mitigation
2. Climate change adaptation
3. The sustainable use and protection of water and marine resources
4. The transition to a circular economy
5. Pollution prevention and control
6. The protection and restoration of biodiversity and ecosystems

For an economic activity to qualify as environmentally sustainable, it must make a substantial contribution to at least one of these objectives, not harm the other objectives, and meet minimum social safeguards. Technical screening criteria will establish the list of environmentally sustainable activities for each objective in yet to be adopted delegated acts that will evolve over time.

The EU Taxonomy describes an economic activity that qualifies as contributing substantially to climate change mitigation through avoidance or reduction of GHG emissions or increase in GHG removals, including through process and product innovations. Article 10 Paragraph 1 (e) anchors CCUS as an activity that increases the use of environmentally safe CCU and CCS technologies that deliver a net reduction in GHG.

The EU taxonomy does not impose a mandatory list of economic activities or performance standards for investment and financial services. Nor is the green classification it provides exhaustive. Different technologies across various economic activities can make substantial contributions to each objective. Though a voluntary transparency tool, the EU taxonomy does impose mandatory disclosure obligations on certain companies and investors to benchmark compliance with its goals. The regulatory guidance the EU Taxonomy provides to investors will influence their decisions in respect of clean energy technology deployment. The densely worded provisions of the EU Taxonomy reflect different views and priorities. The many interpretations that are possible can amplify regulatory uncertainty. There is a risk that companies and investors may fail to pursue innovation opportunities while financial markets may choose to over-comply with the EU Taxonomies guidance. Without greater clarity, this may limit financing of economic activities that do not tick all the boxes of the EU Taxonomy. This may affect CCUS despite its explicit inclusion, for instance, when perceived to hamper the development and deployment of low-carbon alternatives or lock in carbon intensive assets.

EU Hydrogen and Energy System Integration Strategy

The EU Hydrogen Strategy and EU Energy System Integration Strategy for a Climate Neutral Europe adopted on 8 July 2020 both refer to CCUS. The hydrogen strategy notes that although renewable hydrogen production is the priority and costs are falling, low carbon hydrogen produced from fossil fuels or biomethane with CCS will be necessary in the short to medium term to 2030 at least. EU carbon prices have more than doubled from pre-COVID-19 levels reaching $58, per ton CO_2 in August 2021. This is the lower level of the estimated price range that the hydrogen strategy cites to make fossil-based hydrogen with CCS competitive. The hydrogen strategy acknowledges that development will be gradual and require CCUS infrastructure to facilitate low carbon hydrogen production noting that such projects have yet to be launched in the EU. Carbon Contracts for Difference (CCfDs) are proposed to compensate investors for price differentials between CO_2 strike and actual prices that are likely to remain volatile in an emerging market. From 2030 onwards renewable hydrogen technologies will be deployed at scale using a quarter of the EU's renewable electricity production. This would enable production of synthetic fuels from hydrogen and captured CO_2 for the aviation, shipping, industry, and the commercial buildings sector as well. It remains unclear how renewable hydrogen deployment will interface with low carbon hydrogen derived from fossil fuels with CCUS. Project start up dates and project lifecycles suggest they will compete in the EU internal energy market. Without further clarification this may create an additional hurdle for investment in CCS projects related to hydrogen production and CCUS in general.

The EU Energy System Integration Strategy adopted in parallel as a complement to the EU Hydrogen Strategy aims to shape a new integrated EU energy system by coordinating planning and operation of the energy system 'as a whole', across energy sources, infrastructures, and demand centers. The strategy proposes a move away from rigid energy demand and supply silos towards a more circular energy system. The strategy will further support the EU's economic recovery in the aftermath of the COVID-19 crisis that has highlighted the need for better energy system integration to unlock investment in key clean technologies and value chains that can increase the EU's economic resilience.

The strategy devotes special attention to CCUS that together with alternative process technologies "is likely to play a role" in a climate-neutral energy system. It acknowledges that in addition to permanent geological storage that CCS provides, CCU can provide synthetic gases, fuels, and feedstocks in combination with renewable hydrogen. These can lead to different carbon abatement solutions depending on the source of CO_2 that can originate from fossil, biogenic and direct air capture solutions. The EU Energy System Integration Strategy notes that the EU Innovation Fund could be leveraged from 2021 to support these conversion processes through demonstration and upscaling of the full production process in parallel with ramping up renewable energy to provide alternative low carbon fuels in hard to abate sectors such as aviation.

In addition to the existing greenhouse gas emission monitoring and reporting system the strategy argues for a robust CO_2 removal certification mechanism that will ensure the traceability of the CO_2 along its emission, capture, use and potential reemission value chain segments. The development of such a certification system was announced in the EU Circular Economy Action Plan for a Cleaner and More Competitive Europe of 11 March 2020 that can also provide additional regulatory incentives for advancement of CCU technologies and the market take-up of synthetic fuels. The strategy aims to develop a corresponding regulatory framework to certify carbon removals through robust and transparent carbon accounting to monitor and verify their authenticity by 2023.

Conceding that CCUS uptake has been slow in Europe citing high cost, transport constraints, and public concerns, the strategy recommends an annual CCUS Forum to study options and advance CCUS projects.

EU Stimulus: The European Recovery and Resilience Facility

The European Recovery and Resilience Facility launched on 19 February 2021 supports member state reforms and investments through loans and grants to overcome the economic and social impact of the coronavirus pandemic and prepare European economies and societies for the twin green and digital transition by making them more sustainable and resilient. Part of the EU's long term €1.8 trillion budget to 2027 including the €750 billion Next Generation EU recovery program adopted on 17 December, the facility makes €672.5 billion available to fund member states National Recovery and Resilience Plans for reforms and public investment projects completed before 2026.

This provides EU member states with the opportunity to reform regulatory frameworks that enable CO_2 and hydrogen market development. It also provides for investment projects to build new and strengthen existing infrastructures required by industrial-scale CCUS deployment.

RD&D

The European Strategic Energy Technology Plan (SET Plan) provides guidance for implementation of the European Green Deal and the Next Generation EU Initiative, based on the research and innovation priorities and clean technology targets. In accordance with the 2020 SET Plan progress report covering implementation up to mid-2020, a new implementation plan for CCUS revises targets and adds activities to meet new goals.

Currently 81 CCUS relevant research and innovation projects are ongoing across the full spectrum of the development path. These represent a total value of €645 million and 6.7 percent of the total amount of SET Plan research and innovation implementing projects. Linkages with industry efficiency, deep geothermal, and photovoltaics research and development have also been established while technology advances in CCUS also co-depend on breakthroughs in other areas such as renewable fuels and bioenergy, energy efficiency and energy systems integration.

The Strategy CCUS project funded by the European Union's Horizon 2020 program was launched in 2019. The three-year program supports the development of low carbon energy in South and Eastern Europe. Collaboration among scientists from 10 EU member countries should speed up development of CCUS to reduce emissions from industry and power sectors in eight regions. Carbon intensive industrial clusters in Croatia, France, Greece, Portugal, Romania, and Spain have been identified as promising areas where CCUS solutions can reduce emissions based on the business opportunities they offer for CO_2 storage and use, including hydrogen production. To cost effectively build up CCUS cross-border networks in the EU, the project will also identify CO_2 transport routes between local CCUS hubs and interconnections with CCUS infrastructure in the North Sea region.

North Sea Basin and Other

Outside of the European Union, Norway and the United Kingdom have comprehensive CCUS deployment policies and market initiatives in place. Together with Denmark, the Netherlands and Belgium they are among the most advanced in stimulating investment in CCUS in Europe. The North Sea region provides unprecedented opportunities for CCUS investment. CCUS deployment in North-West Europe is made feasible by proximity to good geological storage sites in depleted North Sea fields offer, well-developed infrastructure and rights of way, and technology and innovation capabilities of advanced industries and knowledge centers. Enhanced government strategies including funding for research and development and public private partnerships to de-risk projects can make the North Sea basin an anchor point for carbon market development in North-West Europe and a blueprint for development in other world regions.

Table 3: Summary of Key Policy Incentives to Scale-Up CCUS

Policy		Details
Financial Incentives	Tax Credits	Tax credits are reductions in the tax liability of firms if they implement CCUS. Credits can be provided for stored carbon but also for capital investment.
	Tax-Exempt Private Activity Bonds	PABs are a form of "tax-exempt bond" that lowers the cost of capital for projects by providing debt financing at more favorable interest rates. Instead of being an incentive that impacts federal taxes of project owners, this incentive affects the federal taxes of the lender (i.e., the bond owner).
	Transition Bonds	Helps the seller issue debt to clean up its operations and present a key financing opportunity for CCUS projects aimed at mitigating emissions in energy-intensive industries.
	Accelerated Depreciation	A capital incentive that lowers the net present value of taxes paid over the life of a project.
	Master Limited Partnerships (MLP) Tax Advantages	An MLP is a special hybrid corporate structure that offers the tax advantages of a partnership combined with the stock market access and liquidity normally available only to corporations.
	Contract for Difference (CfD)	An agreement between two parties whereby one party agrees to pay the other party the difference between the actual value of a commodity at a point in time – the market price – and a value which the parties agreed at the point the CfD was entered into – the strike price.
Government Support	Research Development and Deployment	The government can support research and development through various CCUS R&D programs and initiatives. These can include state-run research institutions or indirectly through grants and other types of subsidies for private activities.
	Infrastructure Development	As a policy catalyst, governments can make the initial investment towards transport and storage infrastructure for an initial anchor customer and then expand the network to service growing demand.
	Equity Ownership	Governments can commit to owning part of a project to support it in its initial stages before handing off to private sector investors. Government can also manage risks in certain CCUS market segments such as CO_2 storage, which can be difficult to finance and insure by private stakeholders alone.
	Public Procurement	Entails the government directly procuring CCUS logistics. It does not imply the government necessarily funds CCUS.

Policy		Details
Market-Based Incentives	Emissions Trading System	An ETS allows industry emitters to trade emission units to comply with their evolving emissions targets. ETS participants can choose to implement internal measures to reduce emissions or purchase emission units in the “carbon” market. A market for GHG emissions is established by creating demand and supply for those emissions allowances that decline over time.
	Carbon Tax	A carbon tax imposes a direct cost on GHG emissions and requires industry and other consumers to pay for each unit of carbon dioxide (CO_2), or equivalent GHG covered, released into the atmosphere.

Regulatory Incentives	Emission Performance Standards (EPS)	An EPS sets minimum emission standards by which emitters must abide. The tradeable certificates function similarly to the obligation scheme and can be used to meet the standard.
	Obligation with CCS Certificates	Emitters or fuel suppliers are obligated by law to ensure a certain amount of CO_2 is captured and stored. Certificates are awarded for storage and can be used to meet the obligation and traded freely.

Sources: IEF, IEA, Atlantic Council, Columbia Center on Global Energy Policy, Element Energy

3.2 Accelerating Deployment in Industry Clusters and Major Ports

The application of CCUS in industrial clusters located in major port cities is one way to accelerate investment in CCUS at scale. Industrial clusters can pool infrastructure to capture, transport and store CO_2 and optimize energy and CO_2 flows through sector coupling.

For example, CCUS projects that involve several small emitters can create integrated circular value chains in major port cities and between regions. This can create new competitive advantages by reducing cost through advancing technologies that create jobs in the clean energy sector and give rise to more resilient and sustainable port cities.

Several projects leverage the strategic location of industrial clusters in the vicinity of port cities and waterways as accelerators for CCUS projects to achieve sustainable development and climate goals. Below are key projects in industrial clusters and ports that will accelerate CCUS deployment.

United Kingdom

- **Northern Endurance Partnership –** BP, Eni, Equinor, National Grid, Shell, and Total form the Northern Endurance Partnership (NEP) that develops offshore CCUS infrastructure in the North Sea. The project aims to accelerate the development of an offshore pipeline network to transport captured CO_2 emissions from both Net Zero Teeside and Zero Carbon Humber, two of the UK's largest industrial clusters, to offshore geological storage beneath the North Sea. The project will decarbonize nearly 50 percent of UK's industrial emissions while creating economic growth for surrounding towns and port cities in northwest England.

Netherlands

- **Port of Rotterdam CO_2 Transport Hub and Offshore Storage (Porthos) –** Porthos is developing a project to capture, transport, and store CO_2 in depleted gas fields beneath the North Sea. The CO_2 will be captured by various companies (Shell, ExxonMobil, Air Liquide, Air Products) and sent through a shared pipeline that runs through the Rotterdam port area. The CO_2 is then compressed, and transported through an offshore pipeline to a platform, approximately 20 km off the coast where it will be stored in an empty gas field more than 3 km beneath the North Sea. The project is expected to store approximately 2.5 million tons (Mt) of CO_2 per year starting in 2024.

Belgium

- **Antwerp@C Project –** The port of Antwerp is home to the largest integrated energy and chemical cluster in Europe making it an ideal industrial hub for CCUS projects. The port has partnered with Air Liquide, BASF, Borealis, ExxonMobil, INEOS, and Fluxys to investigate the technical and economic feasibility of building CO_2 infrastructure to support future CCUS applications. The project plans to capture CO_2 and transport it through pipelines to shared liquefaction and storage facilities. The CO_2 can also be shipped by pipeline domestically and/or internationally. The project has the potential to reduce half of the port's emissions by 2030.

Netherlands/Belgium

- **Carbon Connect Delta –** The project aims to reduce CO_2 emissions in the Belgian-Dutch North Sea area covering the port of Ghent in Belgium and the ports of Terneuzen and Vlissingen in the Netherlands. A consortium of Belgian and Dutch companies is working on a feasibility study after which the project will be further developed for realization. The consortium works simultaneously across industrial sectors (chemicals, petrochemicals, and steel), as well as with relevant governments in both countries to create synergies and opportunities. The project aims to capture 1 Mt of CO_2 in the region starting in 2023 and up to 6.5 Mt in 2030 – a reduction of almost 20 percent.

Norway

- **Longship/Northern Lights –** The Longship project will be the first cross-border, open-source CO_2 transport and storage infrastructure network offering companies across Europe the opportunity to store their CO_2 safely and permanently underground. This will initially include capturing CO_2 from industrial sources in the Oslo-fjord region (cement and waste-to-energy) and shipping liquid CO_2 from these industrial capture sites to an onshore terminal on the Norwegian west coast. From there, the liquefied CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea, for permanent storage. Phase one of the project will be completed in mid-2024 with a capacity of up to 1.5 Mt of CO_2 per year.

United States

- **US Gulf Coast Developments –** The US Gulf Coast (USGC) represents the largest concentration of oil refineries in the US and provides an ideal cluster for highly integrated offshore CCUS solutions. Existing CCUS projects in Texas and Louisiana, a vast network of transport infrastructure, and a large concentration of industrial emissions and offshore storage options, the US Gulf Coast offers the same benefits to CCUS deployment as it did to the refining and petrochemical industries in years prior. Several developments are under way including expansions to USGC ports in 2021, the state of Louisiana pledging carbon-neutrality by 2050, and Texas seeking developers for offshore carbon capture projects. A key development also includes the proposed ExxonMobil CCUS Hub along the

4. Findings

4.1 Preliminary Recommendations

1. **Alleviate cost concerns and provide creative financial incentives to stimulate investment in CCUS.**
   - Governments should improve incentives and enhance investor confidence by developing longer-term CCUS strategies that include a basket of options to attract CCUS investment. These can include tax credits, grants, concessional loans, and accelerated depreciation on CCUS assets.
   - Establish clear and transparent relations among subsidies, regulatory measures, and market incentives, and a consultation mechanism with a duly authorized government body to facilitate investment in CCUS deployment.
   - Encourage private-public partnerships through initial government equity ownership to help de-risk investment.
   - Given CCUS can achieve significant CO_2 emissions reductions, financial institutions should pursue technology-agnostic energy and climate policies and ensure the eligibility of CCUS in sustainable investment policies and financing mechanisms, including ESG.

2. **Explore ways in which CCUS can access markets beyond Enhanced Oil Recovery to grow across sectors and applications.**
   - Governments should improve incentives and enhance investor confidence by developing longer-term CCUS strategies that include a basket of options to attract CCUS investment. These can include tax credits, grants, concessional loans, and accelerated depreciation on CCUS assets.
   - Establish clear and transparent relations among subsidies, regulatory measures, and market incentives, and a consultation mechanism with a duly authorized government body to facilitate investment in CCUS deployment.
   - Encourage private-public partnerships through initial government equity ownership to help de-risk investment.
   - Given CCUS can achieve significant CO_2 emissions reductions, financial institutions should pursue technology-agnostic energy and climate policies and ensure the eligibility of CCUS in sustainable investment policies and financing mechanisms, including ESG.

3. **Improve market and data transparency by assessing ways in which global carbon market and storage data can be made available and beyond.**
   - Achieve greater data transparency on carbon market data, utilization, and storage in collaboration with relevant parties and organizations. This will improve the visibility of CO_2 flows and embodied carbon to inform investment and trade policy decisions over the next decades.
   - Leverage the Fourth Industrial Revolution to take advantage of digitalization, automation, and other technologies that offer more granular and closer to real-time data collection capabilities that can distinguish between different technologies, flows and capacities enhancing CO_2 market signals for all market actors beyond price alone.

4. **Accelerate the deployment of CCUS technologies through dialogue with government and industry stakeholders.**
   - Develop more comprehensive and dependable CCUS strategies and guide best practices. This could include options and goals for governments and investors to reduce the overall risk profile of CCUS projects and showcase how successful projects have overcome obstacles.

- National and regional strategies will help shape international best practices and standards that enable cross border trade and investment and help benchmark performance economy wide CCUS deployment.
- Promote RD&D programs and initiatives that can unlock the economic potential of CO_2 utilization. Pursue large-scale demonstration for CCUS in industry in national and regional programs.

5. **Enhance public outreach campaigns to gain project acceptance.**
    - Lack of public acceptance can cause project delays and, in some cases, can result in cancellation. Political support by governments and ongoing community engagement by market actors fosters acceptance of CCUS projects and helps sustain support from the wider population.
    - Communication must emphasize that CCUS projects are necessary for deeper decarbonization of the energy sector to meet climate goals and mitigate reliance on hydrocarbons that cannot be substituted.

Role of the IEF

6. **Strengthen initiatives to accelerate global CCUS deployment through public-private sector engagement and relevant organisations.**
    - Diverse government and private sector clean technology initiatives can be reinforced with greater policy cohesion across value chains to support investment in CCUS projects, avoid false starts, and accelerate wider deployment.
    - Enhancing government industry engagement on the neutral IEF platform with relevant partner organisations, such as the Clean Energy Ministerial and King Abdullah Petroleum Studies and Research Center, will create clear and dependable long-term strategies to advance CCUS on open markets.
    - Reducing risk will help green light CCUS investment and catalyze the carbon management technology breakthroughs energy security, affordable access, and climate change mitigation call for.

7. **Enhance data transparency on emerging carbon markets with JODI Partners private sector stakeholders, and other relevant organisations.**
    - Carbon markets may well grow into one of the largest new commodity markets to incent investment in clean technologies such as CCUS but global data transparency on carbon remains poor.
    - To reduce price volatility risk that reflect policy cycles rather than fundamentals in emerging markets, greater carbon market data transparency ranging from carbon dioxide to methane can improve the investment and trade decisions of all energy market stakeholders.
    - Assessing how data on CO_2 storage, use, and trade flows and other relevant carbon market data can be made freely available on a single global platform, e.g. through the Joint Organisations Data Initiative (JODI) or other mechanism will reduce risks and uncertainties and help create a level playing field among producer and consumer countries in transition.

4.2 Conclusion

For a swift transition to a more sustainable global energy market, CCUS plays a pivotal role. However, for this suite of technology solutions to forge a dependable link between energy security, affordable access, and climate mitigation goals the current pace of deployment is too slow.

Green growth and circular models such as pursued by the EU and the G20 to avoid the release of additional emissions in the atmosphere by mid-century must lead to greater government-industry engagement on CCUS deployment. A multitude of CCUS projects will have to enter operation to permanently store or use carbon dioxide and reduce the carbon dioxide emissions that renewables and nuclear power cannot displace. At the same time CCUS is vital to accelerate market penetration of new energy carriers such as hydrogen or sustainable jet fuels.

CCUS projects should therefore benefit from far greater government support to accelerate economy wide deployment. More comprehensive CCUS strategies can offer investors the certainty they require and governments the assurances that policy goals will be met reliably at acceptable cost in a changing market environment. An international CCUS de-risking mechanism established on the IEF platform as suggested above can help to broaden support and catalyze investment.

This will broaden access to sustainable finance for carbon management technologies, strengthen physical financial market stability, increase solidarity and inclusion among developing and advanced economies, and broaden public support for energy transitions in both producer and consumer. Reducing real and perceived hurdles to CCUS by formulating comprehensive strategies has never been more important for a swift, secure, and sustainable recovery that meets rising requirements for reliable access to modern and affordable energy services as well as climate change mitigation goals.

The IEF aims to strengthen engagement among producers and consumers to advance carbon management technologies such as CCUS. By leveraging the capabilities and competences of IEF member countries, market stakeholders, JODI Partners and other relevant organizations stakeholders can accelerate circular carbon economies and enhance data transparency of emerging carbon markets on the global and neutral platform that the IEF provides.

The G20 Energy and Climate Ministers Meeting, UN High-Level Dialogue on Energy, UNFCCC, COP 26 Climate Conference, and the 17th session of the International Energy Forum Ministerial all provide important opportunities to strengthen policy cohesion and enhance market confidence to green light and scale up CCUS investment.

Appendix 1

Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

1. Strengths

1.1. CCUS serves energy security, inclusive affordable access, and climate goals by decarbonizing high energy density fuels: coal, oil, gas, and biofuels on which the global economy relies.

1.2. CCUS can accelerate the formation of a hydrogen economy, enable grid scale energy storage, and help decarbonize electricity generation, steel, and cement production, and other hard to abate sectors.

1.3. CCUS is a proven technology enabling rapid, material, and cost-effective CO_2 reduction, with considerable upside potential. Greater policy support and investment in research development and deployment will strengthen market confidence.

1.4. Large-scale deployment of CCS will significantly de-risk the delivery of the world's net-zero ambitions.

2. Weaknesses

2.1. Several obstacles prevent CCUS from reaching the required scale, ranging from, large upfront costs, energy penalties, poor market signals, regulatory hurdles, public acceptance issues, and safety risks.

2.2. Without strong policy support and market incentives CCUS will fail to deliver its share of global emission reductions in time as a world market price on CO_2 will remain elusive.

2.3. Existing Rights of Way moves CCUS forward but permitting investment in new infrastructure to connect diverse points of capture, use, and storage requires better regulation and community engagement.

3. Opportunities

3.1. Ports and adjacent industry clusters harbor many carbon-intensive sectors that can capitalize on shared CCUS infrastructure, optimize CO_2 value chains, and reduce costs.

3.2. Tax credits, financial support, and public equity investment for CCUS projects and related trade flows can help attract private sector finance and allow first movers to build industry scale CCUS projects.

3.3. Stimulating investment in research, development, and deployment (RD&D) of CCUS solutions advances technological prowess, creates jobs, and advances sustainable growth in a more competitive global landscape.

3.4. The application of CCUS enables the manufacturing of low-carbon hydrogen (ammonia, etc) to kickstart the hydrogen economy while capitalizing on valuable natural gas resources.

4. Threats

4.1. The momentum towards ESG requirements combined with questions around safety, liability, and insurance impede CCUS investment.

4.2. Without progress on CCUS in the hydrocarbon sector and CO_2 intensive industries, business and transition costs will increase as public acceptance issues affect the industry's license to operate.

4.3. Disregarding CCUS options narrows solutions to non-fossil, demand side, and nature-based solutions that will not be enough to achieve sustainable development and climate change mitigation goals. Stimulating investment in research, development, and deployment (RD&D) of CCUS solutions advances technological prowess, creates jobs, and advances sustainable growth in a more competitive global landscape.

Recommendations to Overcome Weaknesses

- Avoid approaches that ring-fence markets and resist premature technology choices that lead to diminishing global CO_2 reductions. Instead, ramp up research, development, and demonstration (RD&D) efforts to advance CCUS technologies and improve their marketability including through favorable conditions for investment, trade, and technology transfer on open and interconnected markets (e.g. finalize negotiations on the mechanisms required to implement Paris Agreement Article 6).
- Explore trade-offs and arbitration opportunities among evolving CO_2 price signals and abatement incentives provided by markets (emission trading systems), regulation (caps, fuel quality standards, blending), taxation (credits and levies) or tariffs (carbon border adjustments). Fiscal and legal stability ranging from investment protection, tax holidays and intellectual property rights will help to unlock access to markets. Apply CCUS in high impact areas and stimulate technology transfer for fair and inclusive development between world economies.
- Explicitly validate CCUS solutions and business models in evolving Environmental, Social, and Governance (ESG) standards and Nationally Determined Contributions (NDC) to reduce regulatory risk and obtain financial market backing necessary for industry scale CCUS deployment. Reduce upfront costs by establishing a predictable market context that helps to de-risk CCUS technologies, accelerates permitting, and shortens lead times to generate revenue.

Expanding Prospects

Regulate and target

- Tailor regulations for CO_2 transport and storage (safety, site selection, monitoring, and verification). Set ambitious targets for CO_2 storage and productive uses and establish procedures for the collection of necessary data to map CO_2 flows, apply CO_2 risk management tools, and measure progress.

Pool and network

- Lower energy and other costs of capturing CO_2 from power generation and more diluted streams of industrial processes through sector coupling between major industrial ports and economic clusters. Collectively invest in CO_2 infrastructure to match various sources with productive uses and storage options. Achieving economies of scale by creating diverse CO_2 capture, transportation, and storage networks reduces both risk and costs.

Research and market

- Enhance investment in CCUS RD&D through public private partnerships that help create CO_2 demand for new productive uses. Collaborative CCUS RD&D efforts (e.g. under post-COVID-19 relief and stimulus packages) help shorten lead times for new CCUS technologies and applications to breakthrough on international markets.

Reducing Threats

- Liability and ESG standards work best when public and private sector stakeholders can share risk and rewards in response to clearly formulated energy and climate policy objectives, regulatory standards, and insurance requirements. Technology-neutral energy and climate policies will help create a stable and more competitive environment for CCUS deployment to achieve global CO_2 emission reductions and energy access goals.
- Slow development of environmental risk management guidelines and rules create uncertainty for CCUS project proponents. Very low or unnecessarily high design and operating standards expose CCUS projects to increased risk and investment costs. CCUS environmental and safety guidelines

should allow operators to manage risk effectively. This includes limited liability regimes and long-term insurance mechanisms that channel operator liability to public private indemnification pools when damages exceed agreed thresholds.

- CCUS is perceived as a temporary measure rather than the main technology pathway available in the hydrocarbon sector to respond to the challenges of balancing energy security, affordability, and climate-neutral growth. Policy and business leaders should communicate that CCUS does not affect fossil fuel demand but enhances resource efficiency by reducing CO_2 emissions, including enhanced oil recovery in combination with permanent geological storage.

Appendix 2

Assumptions that govern the diverse CO_2 emission scenarios

2020 BP (Net Zero) – Assumes that the policies in the Rapid Scenario (energy consumption falls by around 70 percent by 2050) are reinforced by significant shifts in societal behaviors and preferences which further accelerate the reduction in carbon emissions.

2020 IRENA (Planned) – The primary IRENA reference case on energy system developments based on governments' current energy plans and other planned targets and policies (as of 2019), including Nationally Determined Contributions under the Paris Agreement unless the country has more recent climate and energy targets or plans.

Grubler (Historical) – Historical carbon emissions data.

IEA (SDS) – The IEA's Sustainable Development Scenario (SDS) outlines a major transformation of the global energy system, showing how the world can change course to deliver on the three main energy-related SDGs simultaneously –universal access to energy (SDG 7), reduce the severe health impacts of air pollution (part of SDG 3), and tackle climate change (SDG 13).

2020 IRENA (Transforming) – An ambitious, yet realistic, energy transformation pathway based largely on renewable energy sources and steadily improved energy efficiency (though not limited exclusively to these technologies). This would set the energy system on the path needed to keep the rise in global temperatures to well below 2 degrees Celsius (°C) and towards 1.5°C during this century.

IEA (Historical) – Historical IEA carbon emissions data starting in 1971.

IEA (STEPS) – The Stated Policies Scenario reflects the impact of existing policy frameworks and today's announced policy intentions. The aim is to hold up a mirror to the plans of today's policy makers and illustrate their consequences for energy use, emissions, and energy security.

OPEC (Reference Scenario) – A baseline case with new policies being considered by countries.

The IPCC scenarios given below are based on the following assumptions:

SSP1 – Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation)
SSP2 – Middle of the Road – (Medium challenges to mitigation and adaptation)
SSP3 – Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation)
SSP4 – Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation)
SSP5 – Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation)

Reference List

1. Asian Development Bank, Promoting Carbon Capture and Storage in The People's Republic of China and Indonesia - Background Study on CCUS Readiness in Power, Iron and Steel, Cement and Petroleum Sectors, August 2019.

2. Al-Fattah, S.M., Barghouty, M.F, Dabbousi, B.O, et alia, King Abdullah Petroleum Studies and Research Centre (KAPSARC), Carbon Capture and Storage Technologies, Policies, Economics, and Implementation Strategies, CRS Press, 2012.

3. Bhardway, A., McCormick C., Friedmann J., Opportunities and Limits of CO_2 Recycling in a Circular Caron Economy, Center on Global Energy Policy, Columbia School of International Public Affairs, May 2021

4. Bourgeault, E.,Carbon will become one of the largest commodities in the world, An interview with Dirk Muench, Director of Climate Funds & Ventures, South Pole, 9 June 2021

5. Budinis S., Krevor S., Dowell N., Brandon N., Hawkes A., Imperial College London, An Assessment of CCS costs, barriers, and potential, November 2018.

6. Burlinghaus, E., Blakemore R., Beck L., Atlantic Council, Scaling CCUS: Catalyzing policy and financial innovation, September 2020.

7. Brisson, J.P., Cole, J., et al., Treasury Finalizes Carbon Capture Tax Credit Regulations, Latham & Watkins, Client Alert Commentary, 21 January 2021, No 2851

8. California Air Resources Board (CARB), Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard, August 2018.

9. California Air Resources Board (CARB), Carbon Capture and Sequestration Project Eligibility FAQ, September 2019.

10. Cho, R. Why we need green hydrogen Columbia Climate School State of the Planet,7 January 2021

11. Connors P., Ditzel K., Emmett J., Li F., FTI Consulting, Review of Federal, State, and Regional Tax Strategies and Opportunities for CO_2-EOR-Storage and the CCUS Value Chain, September 2020.

12. Debarre R., Gahlot P., Grillet C., Plaisant M., Kearney Energy Transition Institute, Carbon Capture Utilization and Storage – Towards Net-Zero, 2021.

13. Element Energy, Policy Mechanisms to support the large-scale deployment of Carbon Capture and Storage (CCS), May 2018.

14. European Gas Regulatory Forum, Report to the thirty second meeting of the European Gas Regulatory Forum, 5-6 June 2019

15. Friedmann, J., Ochu E., Columbia Center on Global Energy Policy, Capturing Investment: Policy Design to Finance CCUS Projects in the U.S. Power Sector, April 2020.

16. Global CCS Institute, Carbon Capture and Storage: A vital low carbon technology that can deliver on economic development, energy security, and climate goals, 2015.

17. Global CCS Institute, Insights and Commentaries: Carbon capture and storage in de-carbonising the Chinese economy, June 2018.

18. Global CCS Institute, Brief – The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update, April 2020.

19. Global CCS Institute, Insights and Commentaries: Carbon capture Storage: Challenges, enablers and opportunities for deployment, July 2020.

20. Global CCS Institute, Global Status of CCS: 2020, 2020.

21. Gas Exporting Countries Forum, GECF Global Gas Outlook 2050, 2021.

22. Guldimann C., RBC Economics, How Carbon Capture Can Help a Net Zero Strategy, and Boost the Economy, November 2020.

23. International Association of Oil and Gas Producers, The Potential for CCS and CCU in Europe, June 2019.

24. Havercroft, I., Consoli, C., Is the World Ready For Carbon Capture and Storage? Global CCS Institute, 2018 Thought Leadership Report CCUS Readiness Index 2018

25. International Energy Agency, CCUS in Clean Energy Transitions, September 2020.

26. International Energy Agency, The role of CCUS in low-carbon power systems, July 2020.

27. International Gas Union (IGU), Global Gas Report 2020, 2020.

28. International Panel on Climate Change (IPCC), Global Warming of 1.5°C., 2018.

29. International Renewable Energy Agency (IRENA), Reaching Zero with Renewables, September 2020.

30. IRENA, Green Hydrogen Cost Reduction Scaling up Electrolysers to Meet the 1.5°C Climate Goal, 2020

31. Jaruzel, M., Carbon capture in the U.S. is growing like never before, but further policy support is crucial, Clean Air Task Force, 28 June 2021

32. Debarre, R., Gahlot, P., Grillet, C., and Plaisant, M., Carbon Capture Utilization and Storage, Towards Net Zero, Kaerney Transition Institute,2021

33. Lipponen, J., McCulloh, S., Keeling, S., Stanley, T., Berghout, N., Berly, T., the Politics of Large Scale CCS Deployment, Elsevier ScienceDirect, Energy Procedia 114 (2017) 7581 – 7595

34. Larsen, J., King, B., Hiltbrand, G., Herndon, W., Capturing the Moment: Carbon Capture in the American Jobs Plan, Rhodium Group, April 21, 2021.

35. Mollet P., Heidug W., Zakkour P, Williams E., King Abdullah Petroleum Studies and Research Center (KAPSARC), Carbon Sequestration Units (CSUs): A New Tool to Mitigate Carbon Emissions, January 2020.

36. Mollet P., Heidug W., King Abdullah Petroleum Studies and Research Center (KAPSARC), A Mechanism for CCS in the Post-Paris Era: Piloting Results-Based Finance and Supply Side Policy Under Article 6, April 2019.

37. Napp T., Shan Sum K., Hills T., Fennell P., Imperial College London, Grantham Institute for Climate Change, Attitudes and Barriers to Deployment of CCS from Industrial Sources in the UK, February 2014.

38. National Petroleum Council, A Roadmap to At-Scale Deployment of CCUS – Meeting the Dual Challenge, 2019.

39. Oil and Gas Climate Initiative (OGCI), CCUS in Saudi Arabia, the value and opportunities for deployment, March 2021.

40. Palmer T., Brabben J., Miller G., Cornwall Insight, Market-based Frameworks for CCUS in the Power Sector, April 2019.

41. Pradhan, S., Shobe, W. M., Fuhrman, J., et al., Effects of Direct Air Capture Technology Availability on Stranded Assets and Committed Emissions in the Power Sector, Frontiers In Climate, Negative Emissions Technologies, 3 June 2021

42. Public Policy Forum, Forum Des Politiques Publiques, Energy Future Forum, Carbon, Capture, Utilization and Storage – The Time is Now, March 1, 2021.

43. Rassool D., Havercroft I., Zapantis, A., Nabeela R., CCS in the Circular Carbon Economy: Policy & Regulatory Recommendations, Global CCS Institute, July 2021.

44. Rodgers, M., Dubov, B., US tax credit encourages investment in carbon capture and storage, White & Case Insight, 29 January 2021

45. Tamme E., Global CCS Institute, Brief: Carbon Removal with CCS Technologies, January 2021.

46. Tarufelli B., Louisiana State University (LSU) Center for Energy Studies, Overlooked Opportunity: Incentivizing Carbon Capture through Carbon Tax Revenues, 2020.

47. Thompson, J., Beck, L., Scaling Up Climate Ambition: Carbon Capture, Removal, and Storage Priorities in the 117th Congress, Clean Air Task Force, 25 May 2021

48. Townsend A., Havercroft I., Global CCS Institute, The LCFS and CCS Protocol: An Overview for Policymakers and Project Developers, 2019.

49. US Department of Energy, Carbon Capture Opportunities for Natural Gas Fired Power Systems, 2017.

50. Wei, Y., Kang, J., Liu, L., et al., A proposed global layout of carbon capture and storage in line with a 2 degrees climate target, Nature Climate Change, vol. 11, February 2021, 112-118

51. White House Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration, White House Council on Environmental Quality, June 2021.

52. Wijk A., Oesterholt F., Water demand in a hydrogen economy, KWR, 2016.

53. Zakkour P., Heidug W., King Abdullah Petroleum Studies and Research Center (KAPSARC), Supply-Side Climate Policy for Crude Oil Producers: Exploring Policy Pathways for Decarbonizing Fossil Fuels, August 2020.

54. Zapantis A., Townsend A., Rassool D., Global CCS Institute, 2019 Thought Leadership, Policy Priorities to Incentivise Large Scale Deployment of CCS, 2019.

55. Zapantis A., Townsend A., Rassool D., Global CCS Institute, Policy Priorities to Incentivise Large Scale Deployment of CCS, April 2019.

56. Zero Emissions Platform, CCS and CCU in the JRC Science for Policy Report: The POTEnCIA Central scenario: An EU energy outlook to 2050, November 2019.

CIRCULAR
CARBON
ECONOMY

Carbon Management Technologies Initiative

Strategies to Scale Carbon Capture,
Utilization and Storage

IEF

www.ief.org/circular-carbon-economy