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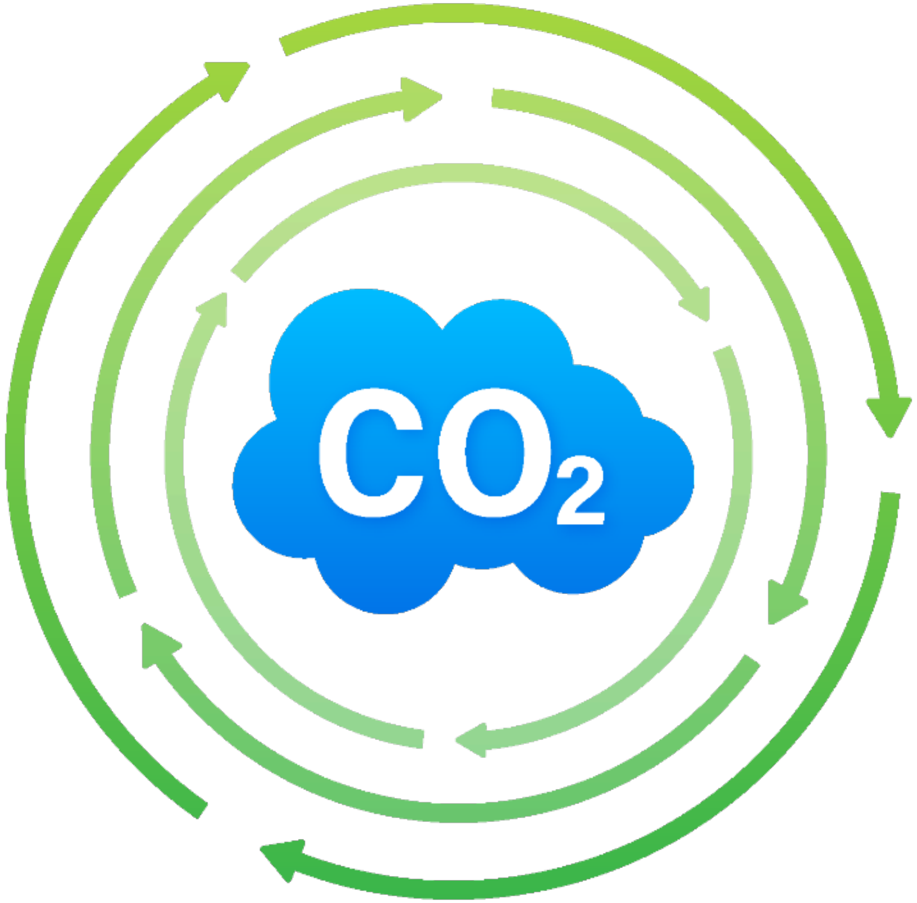


Carbon Capture Usage and Storage

State of the market in 2022

MAKING AN IMPACT THAT MATTERS since 1845

Monitor Deloitte - Point of view - December 2022

Introduction

There have been several conversations and questions surrounding the topic of Carbon Capture Usage & Storage (CCUS). Many of them are skeptical about the viability of CCUS, thereby generating doubts across different industries regarding the role of CCUS in addressing the enormous challenge of carbon emissions reduction. The common arguments are that: prevailing technologies are expensive and/or do not work optimally; taxpayers should not fund unproven technologies with dubious results; investments in renewables are preferable to CCUS; such a technology protects the status quo of hydrocarbon producers; and so on.

This paper's intent is not just to objectively explore this skepticism, but also to understand the actual market situation of CCUS in 2022, in order to provide answers to concerned industries and governments. These answers pertain to the potential of CCUS as part of our arsenal of carbon offset solutions; to the validation of governments' support of CCUS developments; and to the eventual long-term viability of the CCUS technology and business model.

Our study concludes that CCUS can be instrumental in compensating residual CO_2 emissions that are hard to abate in Energy-Intensive Industries, Power Generation and Refined Hydrocarbons. Furthermore, based on all types of CCUS projects in 2022, we believe that we are off to a running start.

Recently, revisions in governments' policies are enabling more-effective Public-Private Partnerships, which provides strong potential for CCUS industry to gain momentum, while ensuring investment stability. We increasingly observe public signals of confidence and collaboration from industry leaders, governments and investors with regards to CCUS - which we believe will gradually drive public acceptance of this technology.

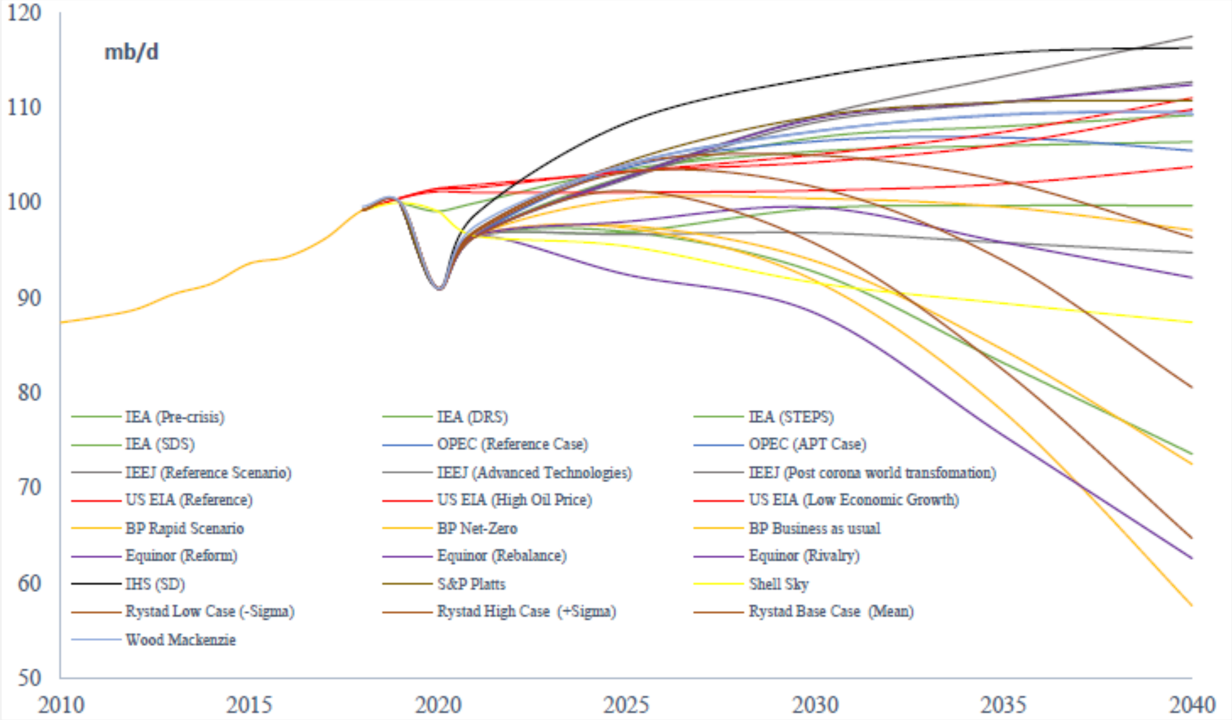
We are still on the path of cost reduction, but we expect to observe further technology innovations, positive effects of a projects' scale up and efficiencies, as well as the entrance of tier-1 players into this landscape. As CCUS expands in hubs to leverage CO_2 emission clusters and combined expertise, we propose Public-Private Partnerships to focus on mega clusters as a solution to bridge the 0,6Gt CO_2 gap in carbon capture capacity by 2030.

Agenda

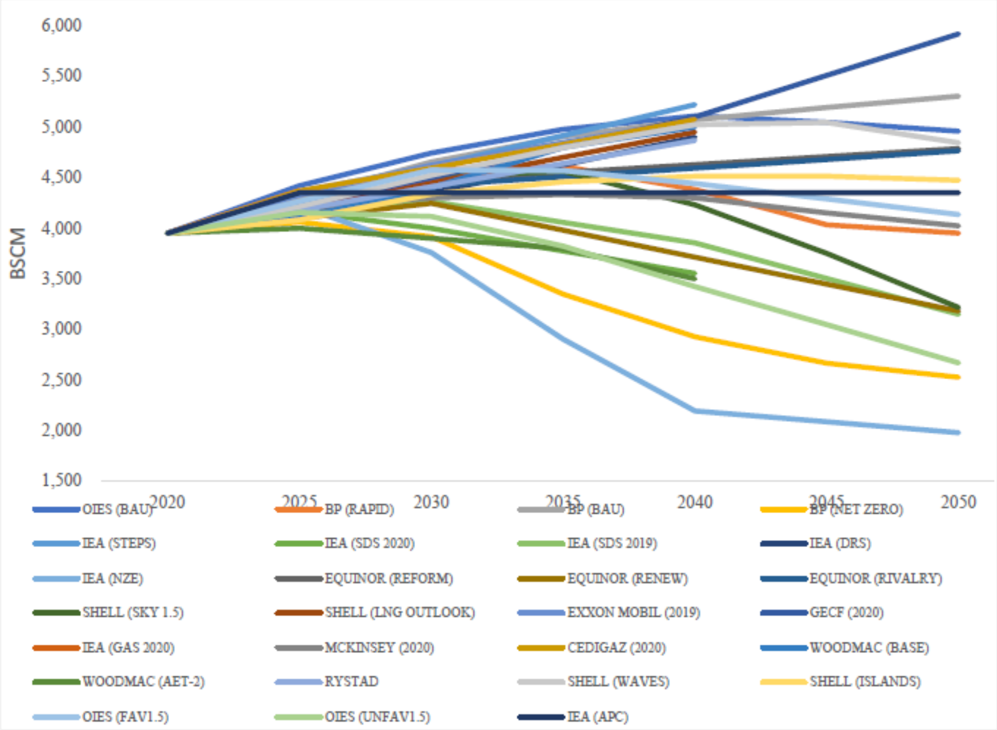
01 Context

Even in the most aggressive scenarios, hydrocarbon demand will remain part of the energy mix

Selected Global Oil Demand Scenarios,
mb/d (Million barrels per day)



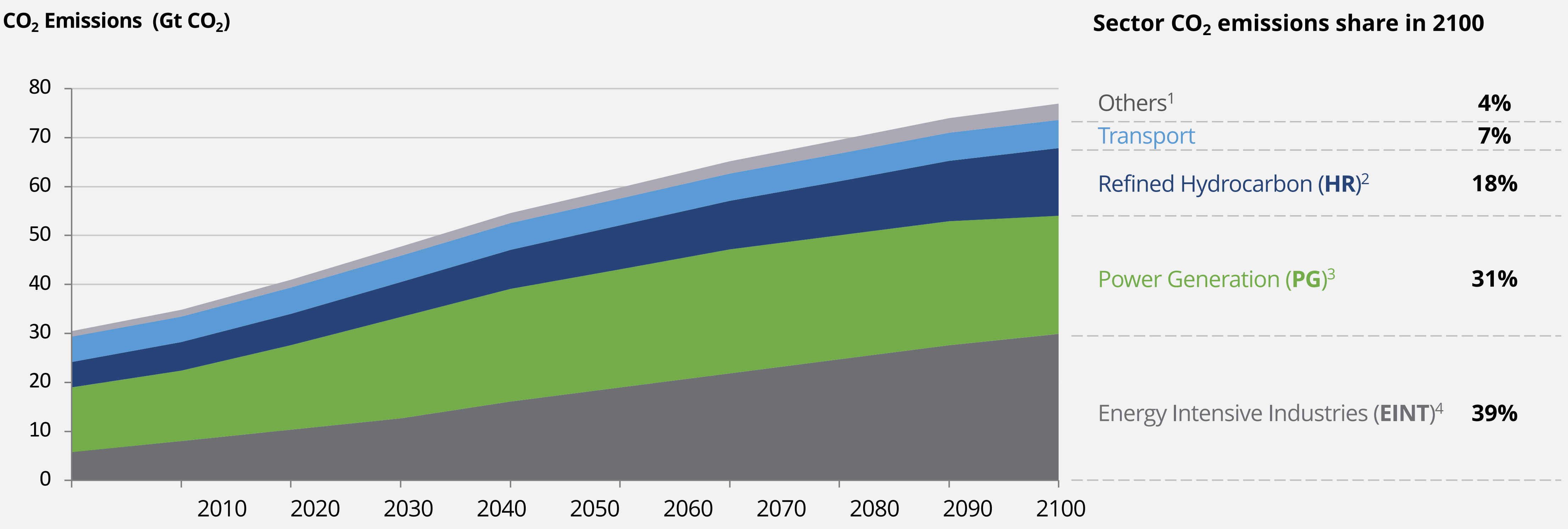
Selected Global Gas Demand Scenarios,
BSCM (Billion Standard Cubic Meter)



Source: Oxford Institute For Energies Studies (2021)

Oil and gas, coupled with coal demand, may eventually generate ~50Gt of CO_2 emissions per year in 2050

Expected world CO_2 emissions by sector without climate action policy



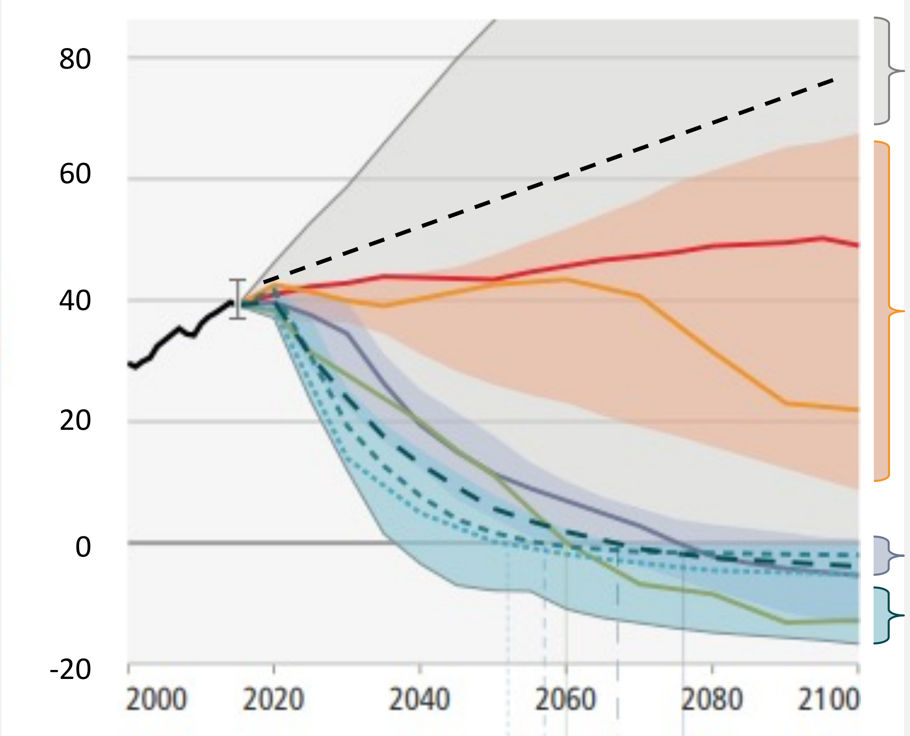
1) Includes Service and Food; 2) Includes Petrochemicals, Refining, Coal-to-liquid (CTL), Gas-to-liquid (GTL), Liquefied Natural Gas (LNG); 3) Includes Coal-fired plant, Natural Gas-fired plant, Waste-to-energy, Biomass; 4) includes Iron & Steel, Cement, Chemicals and O&G energy intensive extractions

Source: MIT – Farrell et all. (2018); Monitor Deloitte Analysis based on updated research

This may drive the planet into a +3.7°C warming trajectory unless we intervene with a sustainable development plan

Net global CO_2 emissions (2000-2100, Gt CO_2)[1]… … and the consequent 2100 Warming

CO_2 Emissions (Gt CO_2)



Global Temp Change (50% likelihood; °C)	**Scenario**
[3.7-5.9]°C	No climate action
[2.8-3.9]°C [2.4-2.9]°C	Implemented policies and 2030 pledges
[1.5-1.8]°C	Limit warming to 2°C (>67% likelihood)
[1.1-1.5]°C [1.2-1.5]°C	Limit warming to 1.5°C (>50% likelihood)

Mandatory conditions for IEA Sustainable Development Scenario (SDS) below 2°C Scenario

- All current net zero pledges are achieved in full
- It includes extensive efforts to realize near-term emissions reductions

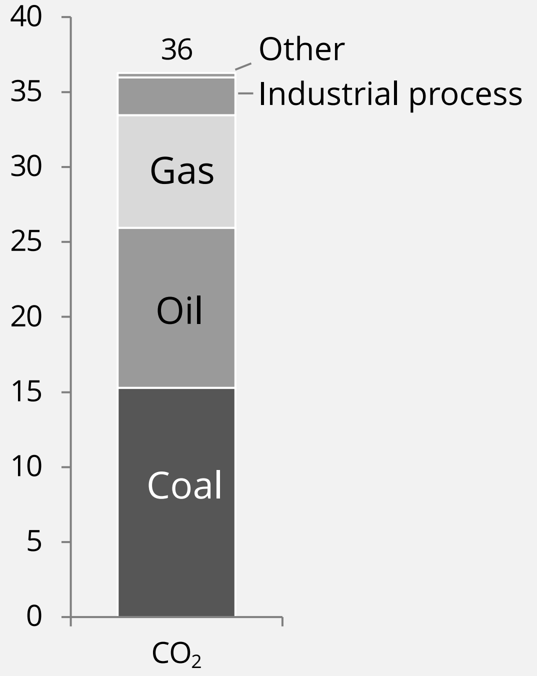
1) IPCC CO2 emissions calculation include CO2 -FFI (CO2 from fossil fuel combustion and industrial processes) and CO2 -LULUCF (CO2 from land use and land-use change and forestry)

Source: IPCC (2022), IEA, Monitor Deloitte Analysis

At current emission (36 Gt CO_2/y), we should reach +1.5°C in 9 years – It seems more realistic aiming the +2°C scenario, though remains an enormous challenge

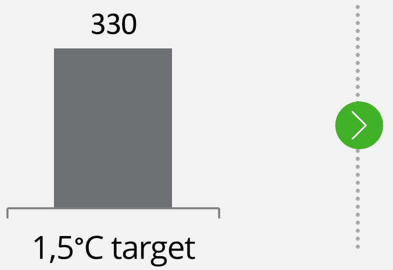
World CO_2 emissions (2021, Gt CO2)[1]

CO_2 Emissions (Gt CO_2)



Remaining CO_2 Gt Carbon Budget for a +1.5°C target (2022, Gt CO_2)[2]

CO_2 Emissions (Gt CO_2)

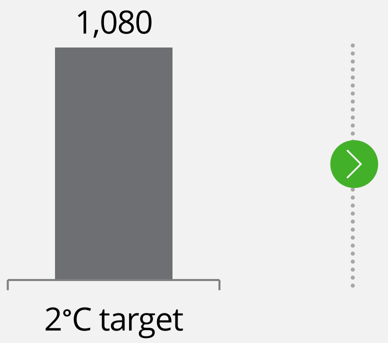


~9 years

Before carbon budget runs out at current **CO_2** emissions level

Remaining CO_2 Gt Carbon Budget for a 2°C target (2022, Gt CO_2)[2]

CO_2 Emissions (Gt CO_2)



~30 years

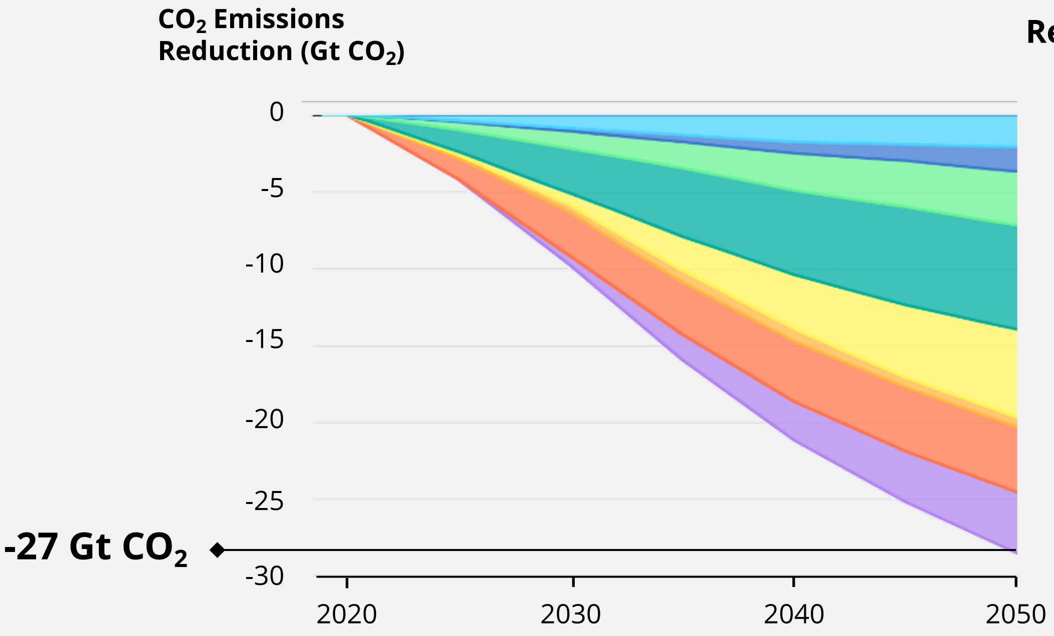
Before carbon budget runs out at current **CO_2** emissions level

1) IEA CO_2 emissions calculation only include CO_2 from fossil fuel combustion and industrial processes; 2) Remaining CO_2 budget for >67% likelihood of achieving 1,5°C (respectively 2°) from start of 2020 was 400Gt CO_2 (1,150 Gt CO_2). Cumulative emissions over CO_2 Emissions over 2020-21 are ~70Gt CO_2

Source: IEA (2021), IPCC (2022), Monitor Deloitte Analysis based on updated research

We have multiple solutions to tackle this challenge, including CCUS, which scientists have stated could account for ~15% of expected CO_2 reductions

IEA Sustainable Development Scenario (SDS) CO_2 emissions reductions by source by 2050[1]



Reduction source % share in 2050

Avoided demand	7%
Hydrogen	6%
Bioenergy	12%
Other Renewables	24%
Electrification	20%
Other fuel shifts	2%
Technology performance	15%
CCUS	14%

1) Include Stated Policies Scenario CO_2 reductions (i.e., government policies and commitments that have already been adopted or announced with respect to energy and the environment, including commitments made in the nationally determined contributions under the Paris Agreement)

Source: IEA (2020), Monitor Deloitte Analysis

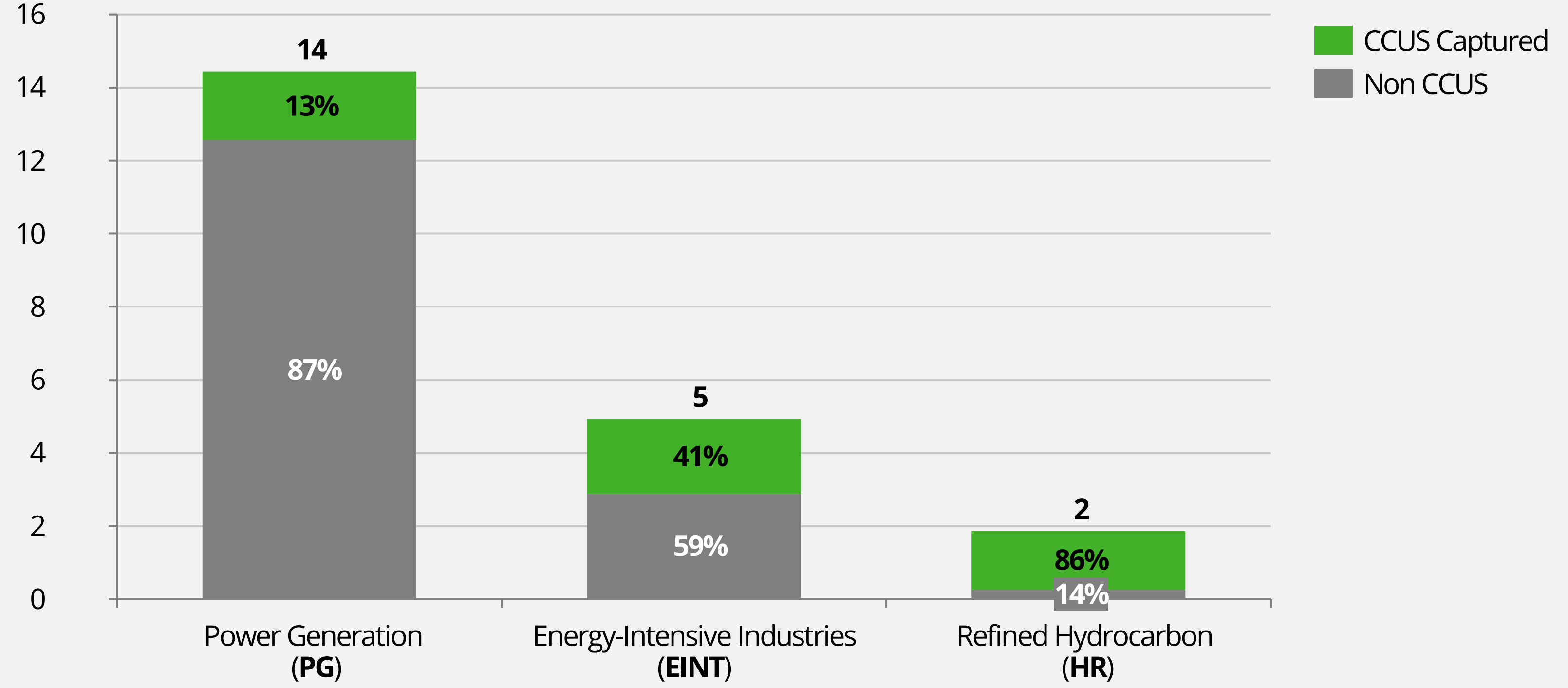
- CCUS is not a magic bullet, yet neither is any of the available technologies
- As per the CO_2 abatement solutions, we could see an order of priority, however given the amplitude of the challenge all solutions require similar consideration
- In a hypothetical prioritization, CCUS could be used as a last resort to compensate for residual emissions that are hard to abate

02 CCUS and its outlook

CCUS is instrumental in compensating residual emissions that are hard to abate in Energy-Intensive Industries, Power Generation and Refined Hydrocarbons

CCUS Contribution to relevant sector CO_2 emissions reductions in 2050 to achieve SDS[1]

CO_2 Emissions Reduction (Gt CO_2)

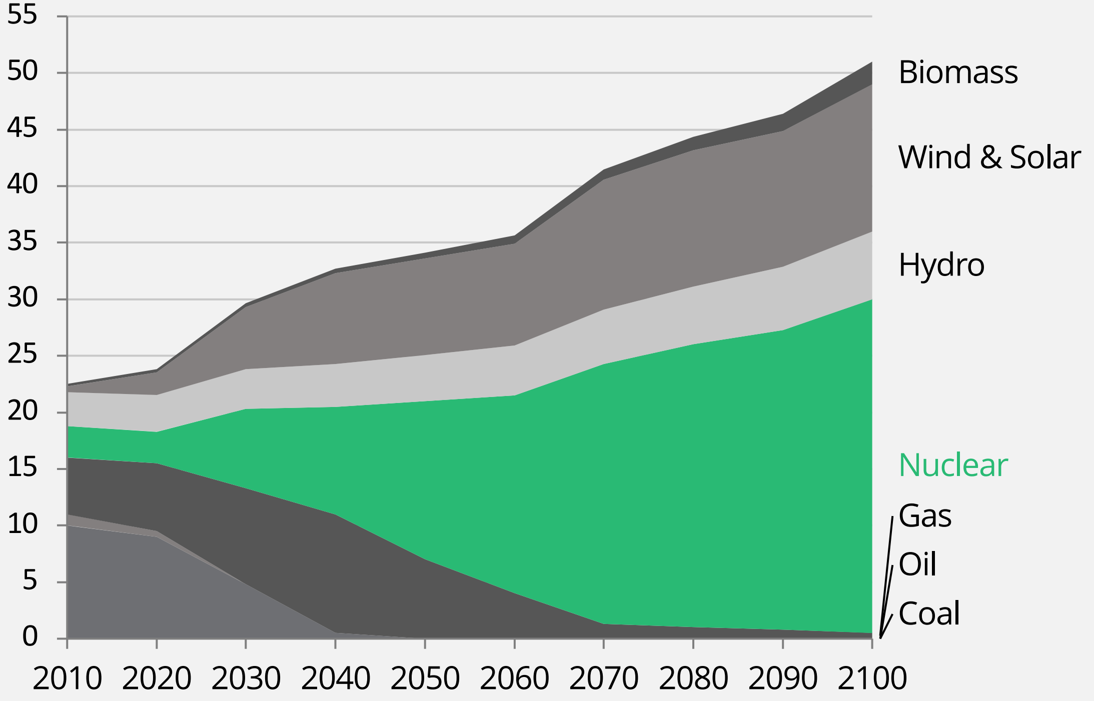


1) Exclude CO_2 emissions reductions from other sectors including Transport and Others and exclude CO_2 emissions reductions from Stated Policies Scenario
Source: IEA (2020), Monitor Deloitte analysis

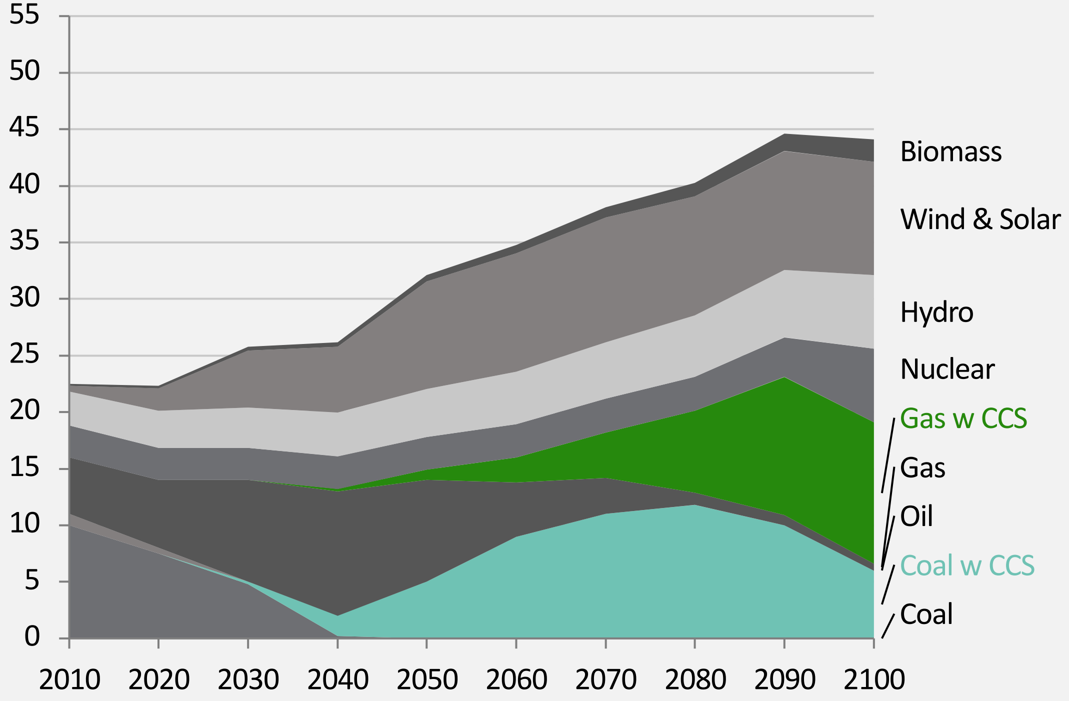
- In a sustainable development scenario, EINT, PG and HR will contribute to the reduction of ~21 Gt CO_2 in 2050
- Out of the 21 Gt CO_2 reduction, CCUS technology would be responsible for abating 5,6 Gt CO_2 in 2050
- In Refined Hydrocarbons, CCUS would account for most of the emission reduction (86%; 1,6 Gt CO_2)
- CCUS would account for roughly half in Energy-intensive Industries (41%; 2 Gt CO_2)
- A lower share of emission reduction in Power Generation would stem from CCUS (13%; 1,9 Gt CO_2)

In the absence of a "more-efficient nuclear scenario" in power generation, CCUS will decarbonize the residual electrons in Gas and Coal fire-based power plants

Power Generation mix in a 2°C scenario with a "more-efficient nuclear scenario" (2010-2100, Twh)



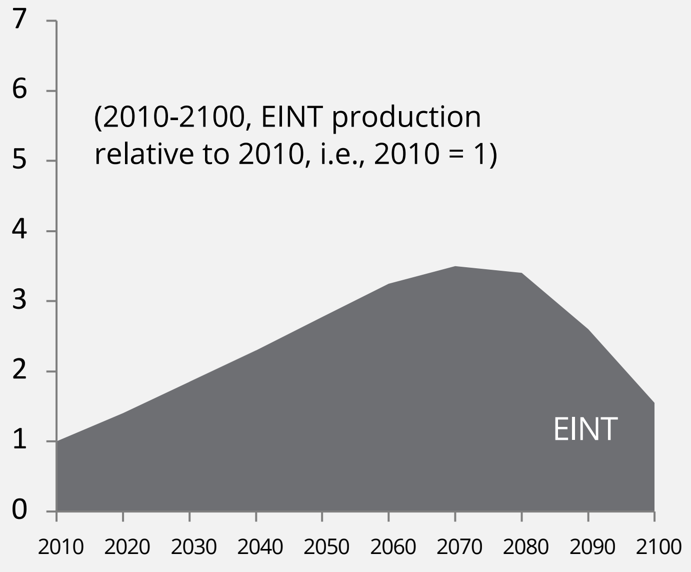
Power Generation mix in a 2°C scenario with CCUS contribution (2010-2100, Twh)



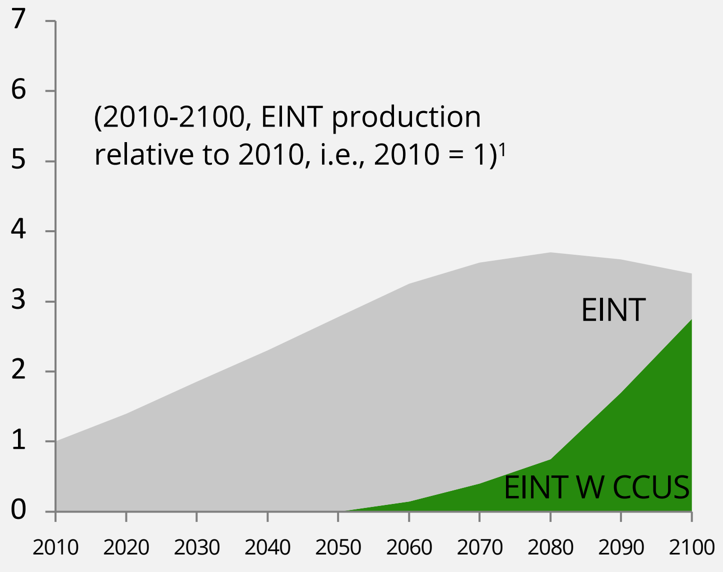
Note: Backup for non-dispatchable renewables at 100%
Source: MIT – Farrell et all. (2019); Monitor Deloitte Analysis

CCUS' role in EINT* is dual: allowing production's decarbonation and its increase. This facilitates a socio-economic transition - increasing # of jobs in these industries

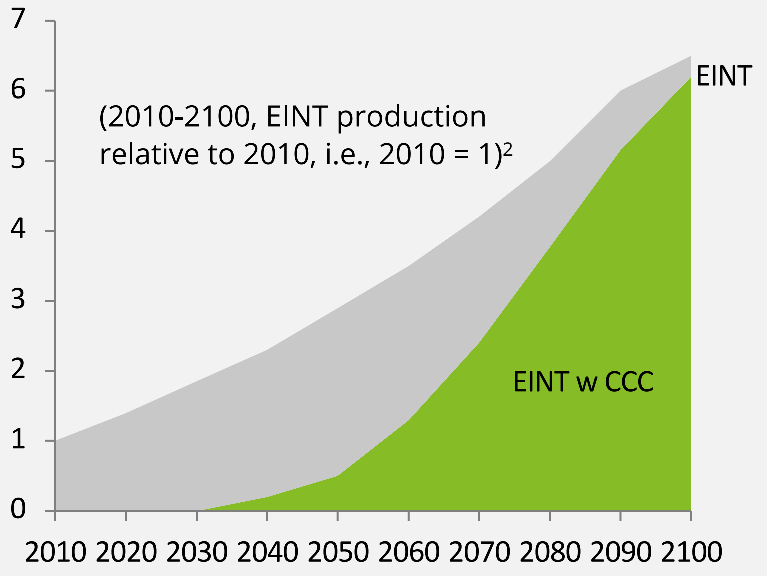
Estimated EINT production in a 2°C scenario without CCUS



Estimated EINT production in a 2°C scenario with CCUS applied to natural-gas fired units



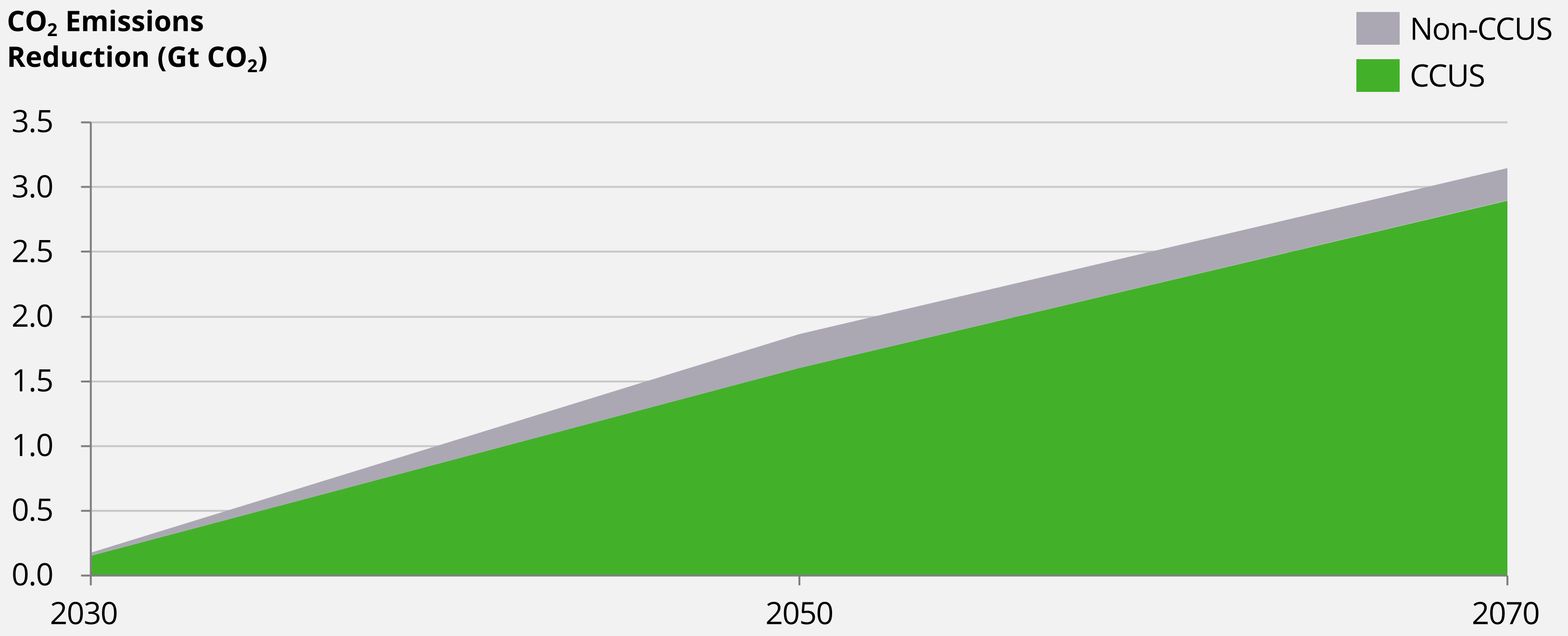
Estimated EINT production in a 2°C scenario with Cryogenic Carbon Capture (CCC) technology



1) Similar EINT production and CCUS contribution is obtained if CCUS is applied to coal-power fired units;
2) CCC is a highly innovative technology with high potential but still at development stage;
(*) energy intensive industries
Source: MIT – Farrell et all. (2018); Monitor Deloitte Analysis

In Refined Hydrocarbons, CCUS would almost entirely decarbonize operations

CCUS contribution to relevant sector CO_2 emissions reductions in 2050 to achieve SDS[1]

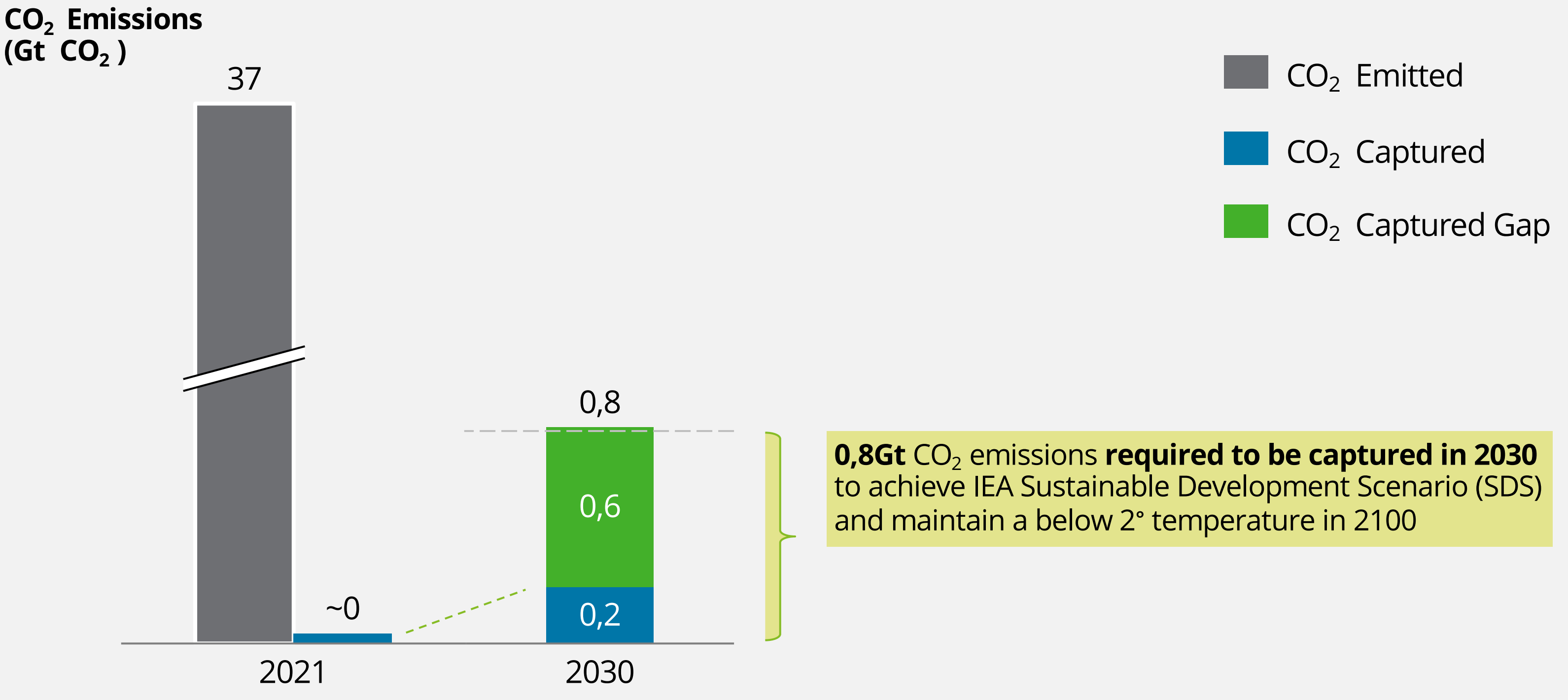


Note: Includes Petrochemicals, Refining, Coal-to-liquid (CTL), Gas-to-liquid (GTL), Liquefied Natural Gas (LNG)
Source: IEA (2020), Monitor Deloitte analysis

- This decarbonization activity is notably in the hands of Oil & Gas and Petrochemical Companies, both National and International
- It refers to typical Scope 1 emissions
- These emissions specifically refer to :
  - Stationary combustion (e.g., fuels, heating sources)
  - Process emissions that are released during industrial processes (e.g., refining hydrocracking/steam reformer, crude/vacuum heaters, etc.)
- The reporting of these emissions is mandatory for companies

Where do we stand? Pipelined CCUS capacity in 2030 is lagging with 0,2 Gt CO_2 expected to be captured by 2030 against the planned 0,8Gt CO_2

CCUS Facilities Capture Capacity Gap to achieve IEA Sustainable Development Scenario

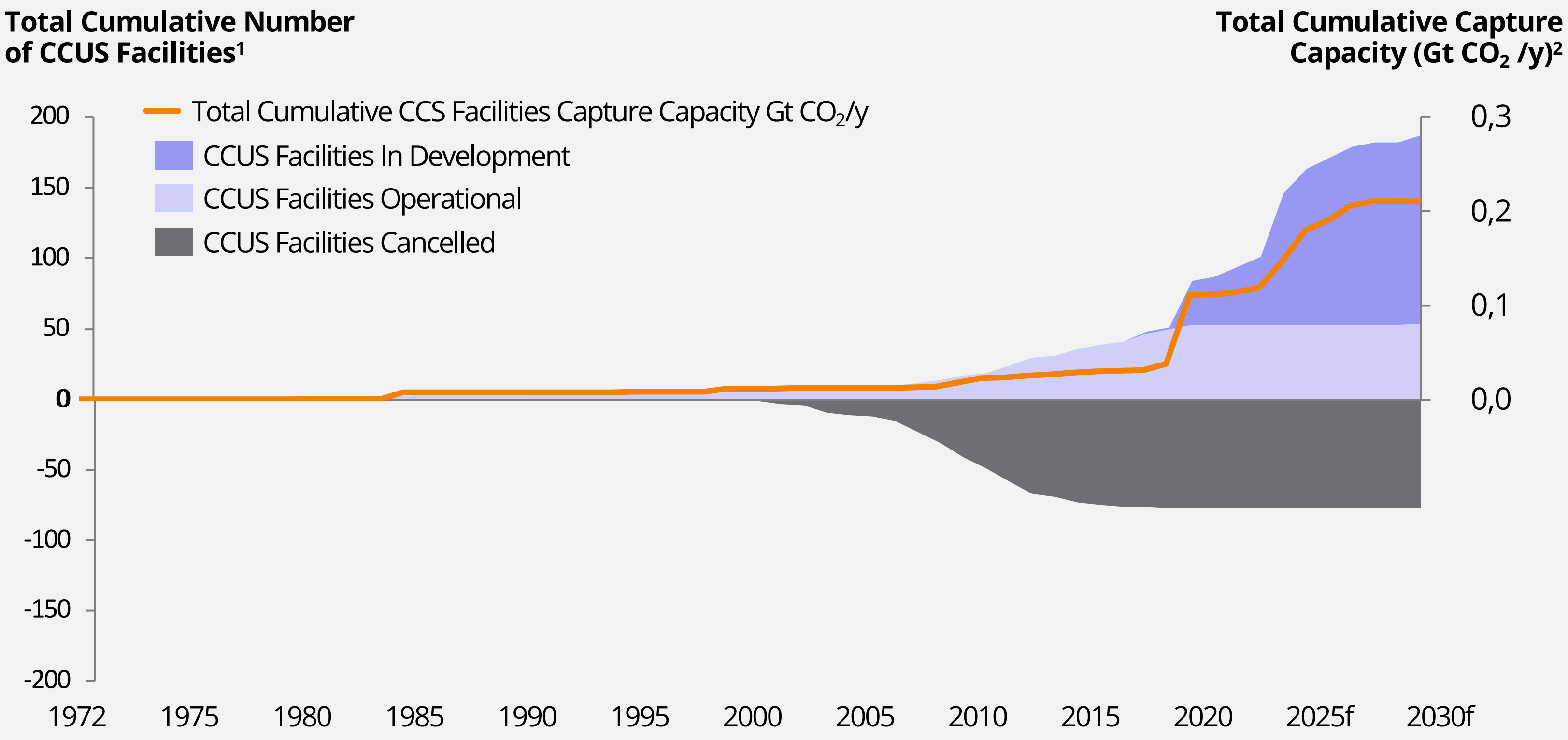


Source: IEA (2021), GCCSI, Monitor Deloitte Analysis

- CCUS is still a niche in the pursuit of net zero
- The power generation industry achieved minor gains after ~US$10B of investment testing CCUS technology & commerciality
- Yet, it will need to work because it's the only hope of addressing hard-to-abate emissions

The overall picture of all types of CCUS projects in 2022 shows that we are off to a running start

Overview of the historical development of CCUS facilities



1) All types of CCUS Facilities including Pilot, Demonstration and Commercial; 2) Commercial CCUS Facilities only
Note: "In Development" refers to CCUS projects status including Announced, Early Development, Advanced Development and In Construction
Source: IEA (2021), GCCSI, Monitor Deloitte Analysis

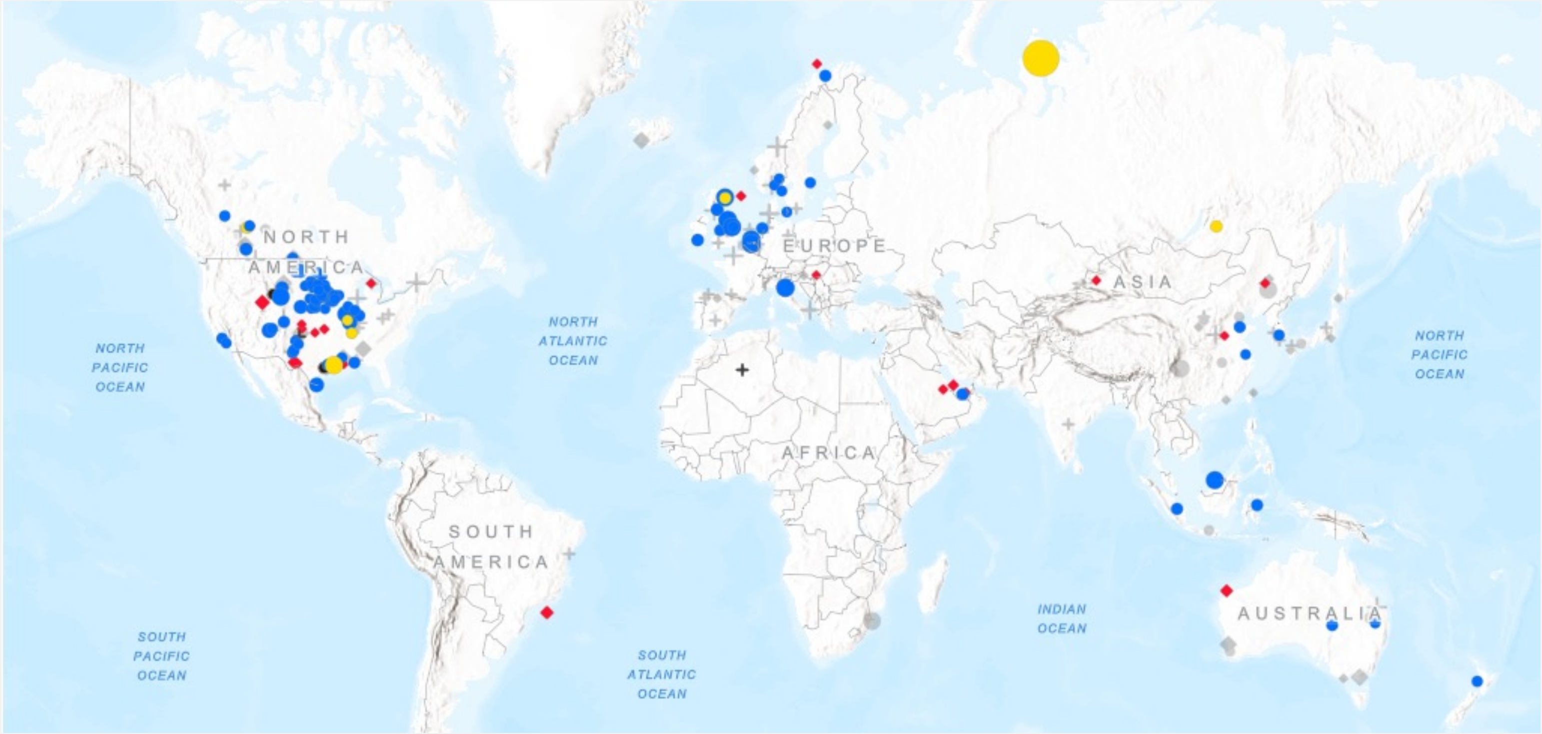
A new, large industry must be built almost from scratch, but there are reasons to be optimistic about CCUS' prospects:

- There was a flood of new CCUS projects over the past few years
- New CCUS projects are scaling up after successful deployment of the pilot/demo
- The high setup costs are gradually declining
- Policies are evolving rapidly to reinforce future CCUS investments

03 Lessons learned

While analyzing all 241 CCUS projects, we learned that CCUS would need three avenues of improvements to offset the _No Business Value_ of CO_2 abatement…

Overview of world CCUS facilities, by Development Stage and Capture Capacity



Facility Status	Number of CCUS Facilities	Capture Capacity (Gt CO_2/y)
Commercial CCUS Facilities Operational	27	0,04
Commercial CCUS Facilities In Development	106	0,1
Commercial CCUS Facilities Announced	11	0,04
Commercial CCUS Facilities Operation Suspended	2	~0
Pilot & Demonstration Facilities Operational	29	~0
Pilot & Demonstration Facilities In Development	16	~0
Projects Completed[1]	50	~0
Total	**241**	**0,2**

Capture Capacity Scale (Mt CO_2/y)

>33 | 25 | 15 | 8 | < 0

1) Refers to Pilot & Demonstration CCUS facilities, including 2 Commercial CCUS facilities marked with dark cross
Source: ArcGIS Online Open Library, Monitor Deloitte Analysis

…(A) further decrease of cost through technology & financing, (B) enhance regulatory and political support and (C) expand access to markets

A

Reduce technical and financial cost

1. We are learning by doing -- Early projects for coal power based CCUS had a capture cost between 60-120USD/t. Learnings have led to a **25-35% reduction in costs** (e.g., Boundary Dam vs Petra Nova) and new tech appear to be improving on that trend with predictions of **30-35% reduction/t**
2. CCUS is capital intensive. The lower the CO_2 emissions, the higher the CAPEX required to capture CO_2 and the less the achievable economies of scale. We are moving from a demo/pilot phase into a scaled commercial one and we believe that there will be **important financial savings *via*** restructuring of projects' **cost of capital** and access to multiple financing components
3. APAC region reports fewer projects terminated or cancelled as they are learning from the US/EU demos and mistakes. Australia, China, and Japan lead the **APAC CCUS development and are catching up with # of operational and in-development projects** but have fewer completed projects so far

B

Enhance regulatory and political support

1. Regulatory drivers are critical to creating markets for CCUS and there are different mechanisms across the world (EU ETS carbon price, US 45Q tax credit, Canada GGPPA, China National ETS…) however, only recent revisions in few countries seem to have found the mechanism of **incentives & penalties to allow CCUS to gain momentum**
2. Policies that qualify CCUS for **access to electricity markets** would be beneficial. Two of the three successful CCUS demonstrations on power plants (Boundary Dam and Kemper) did access electricity markets by gaining approval of their utility regulators to put some or all the costs in the rate base
3. Unlike renewables, CCUS does not have a strong support base that can sway political support. There are several examples of how this has adversely impacted CCUS projects. Going forward, politics will play an important role in the adoption of CCUS. To gain **political support,** it is important to define the role of **CCUS as complementary to renewables and not in competition**

C

Expand access to markets

1. CCUS' projects are expanding in **regional clusters,** where multiple companies collaborate for a regional common business and social driver: abating regional CO_2 . **Public/Private Partnerships** are forming where Governments incentive industry emitters to capture the CO_2, which is transported and stored by major O&G players
2. Oil and gas **EOR market** has mainly driven the few successful CCUS commercial applications. There is a need to target industries with a nearby relevant EOR market for decarbonization via CCUS. E.g., we expect a rapid ramp up in the GCC region where the relevant EOR market may replace gas with CO_2
3. As the **hydrogen market** expands, new Green Hydrogen facilities will have to be coupled with **existing and new blue/grey hydrogen facilities with CCUS**
4. Innovative **CCUS poly-generation (PG)** projects are complex, but they are potential pathways to explore new markets. Few successful CCUS applications are classified as PG projects that are based on coal gasification technology but produce sellable additional products in addition to electricity and CO_2

Source: Monitor Deloitte Analysis

04 Reduce technical and financial costs

CCUS amine-based capture technology is the most used across all applications – we expect to report cost reductions through gathered knowledge & experience

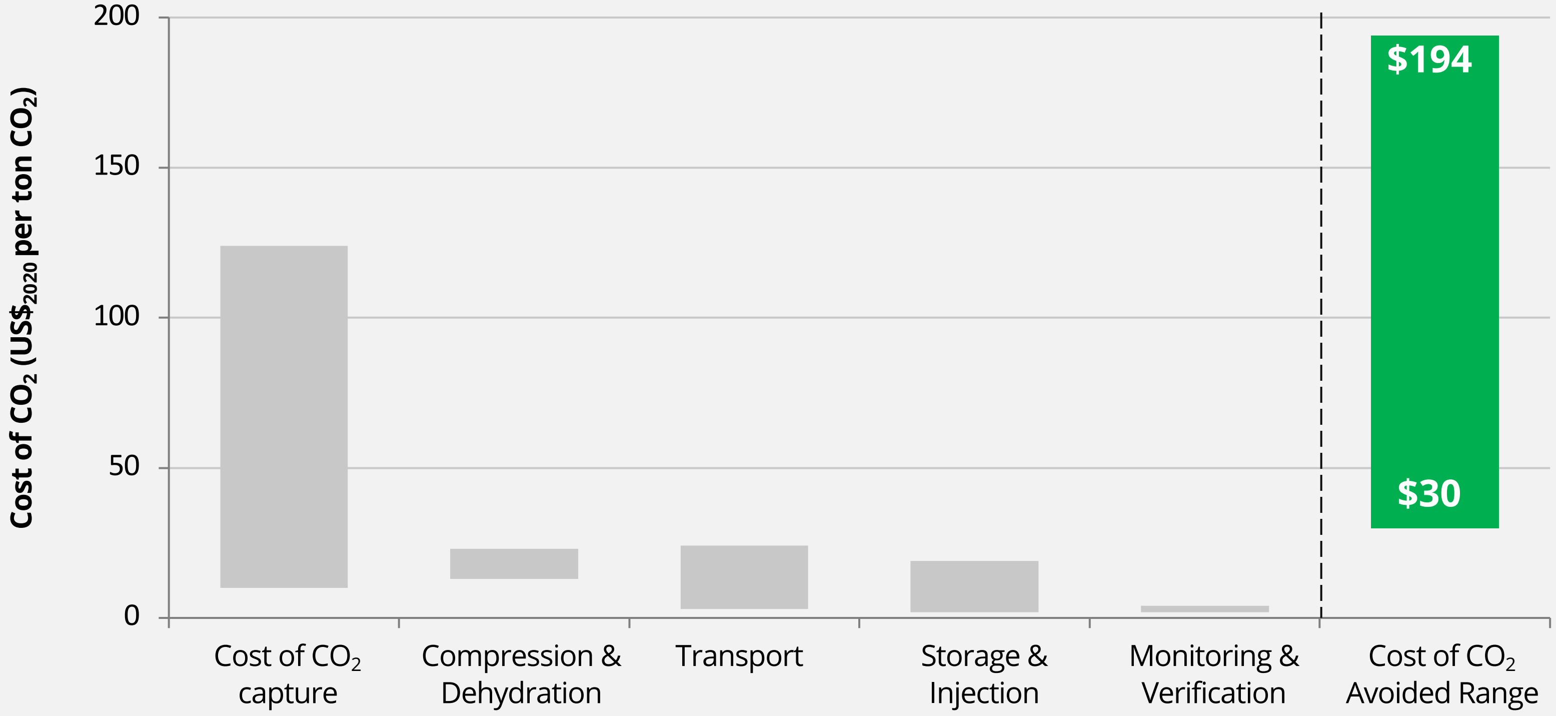
Mapping of CO_2 capture type and technologies across Commercial and Pilot CCUS project (2021)

Industry	Application	CO_2 Capture Pathway and Separation Technologies				
		Industrial Separation	Post-combustion	Pre-combustion	Oxy-fuel combustion	Inherent Separation
Power Generation	Coal Power	Chemical Absorption (CAP)	(CAwA), Membrane, Solid Looping (CaL)	Chemical Absorption (Amine)	-	
	Natural Gas Power	Chemical Absorption w/Amine (CAwA)	Chemical Absorption (CAP), Physical Absorption	Physical Absorption (Selexol)	Sour Gas	Allam-Fetvedt Cycle
	Waste to energy		Chemical Absorption (Amine)		Cryogenic (CCC)	
	Bioenergy	*Under evaluation*	-			
Energy Intensive Industry	Cement Production	(CAwA), Membrane, Solid Looping				
	Chemical Production	(CAwA), Physical Absorption (Rectisol)	Chemical Absorption (CRDMax®)			
	Fertilizer Production	(CAwA), Physical Absorption (Selexol), Compression & Dehydratation				
	Iron & Steel Production	(CAwA), Physical Absorption				
	Natural Gas Processing	(CAwA), Physical Absorption (Selexol, PC), Membrane		Chemical Absorption (Amine)		Allam-Fetvedt Cycle
	Ethanol Production	Compression & Dehydration, Fermentation				
	Hydrogen Production	(CAwA), Physical Absorption, Physical Adsorption			Clean Energy System	
	Methanol Production	Chemical Absorption (AEA)				
Refined hydrocarbons	Refining - Petrochemical	Physical Absorption (Rectisol)	Physical Absorption (VeloxoTherm™)			
	GTL / CTL					
	LNG					

Source: GCCSI, Monitor Deloitte Analysis

CO_2 avoided cost per ton ranges from ~US$30 to US$200 across all CCUS applications

Cost of CO_2 across its value chain (2021)

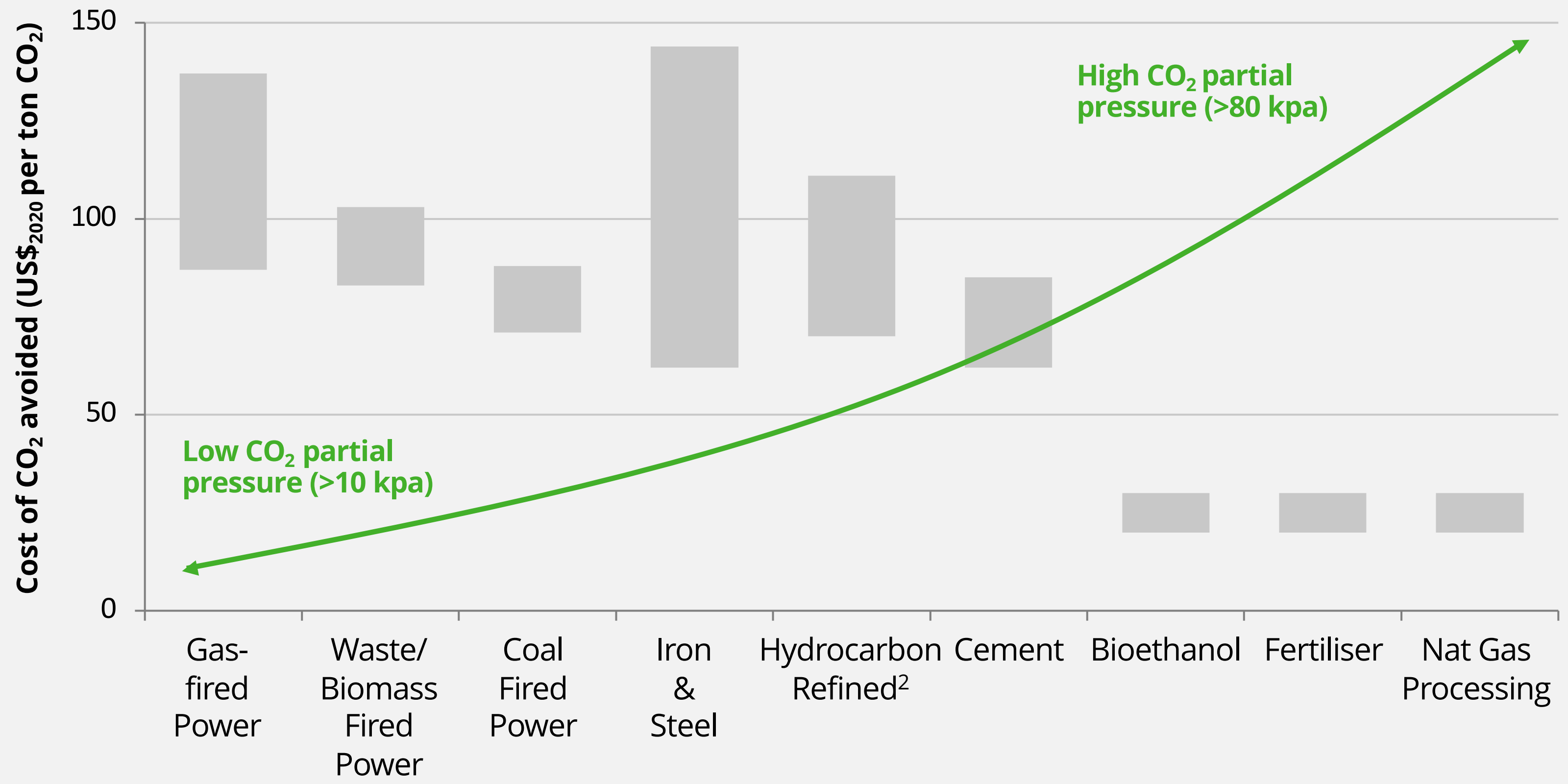


Note: Excluding sectors with high CO_2 pressure (i.e., natural gas processing, bioethanol and fertilizer), Cost of CO_2 range is between US$62-US$194
Source: GCCSI (2021), Monitor Deloitte Analysis

- CO_2 capture costs are 70% of the CO_2 cost avoided
- The remaining 30% of CCUS costs are for compression, dehydration, transportation, storage and monitoring

CO_2 avoided costs differs by applications but are also inversely correlated with emitted CO_2 concentration

Cost of CO_2 avoided per industry (2021)[1]



1) Cost of CO_2 avoided includes CO_2 cost of Capture, Compression & Dehydration, Transport and Storage. A floor cost of US$20 is assumed for cost of Compression & Dehydration and Transport and Storage ; 2) Excluding Ethylene Oxide Production cost of CO_2 avoided between US$20-US$30; 3) Excluding lime calcining and sinter plant; 4) Excluding SMR Hydrogen production, and Ethylene Oxide Production

Source: GCCSI (2021), Monitor Deloitte Analysis

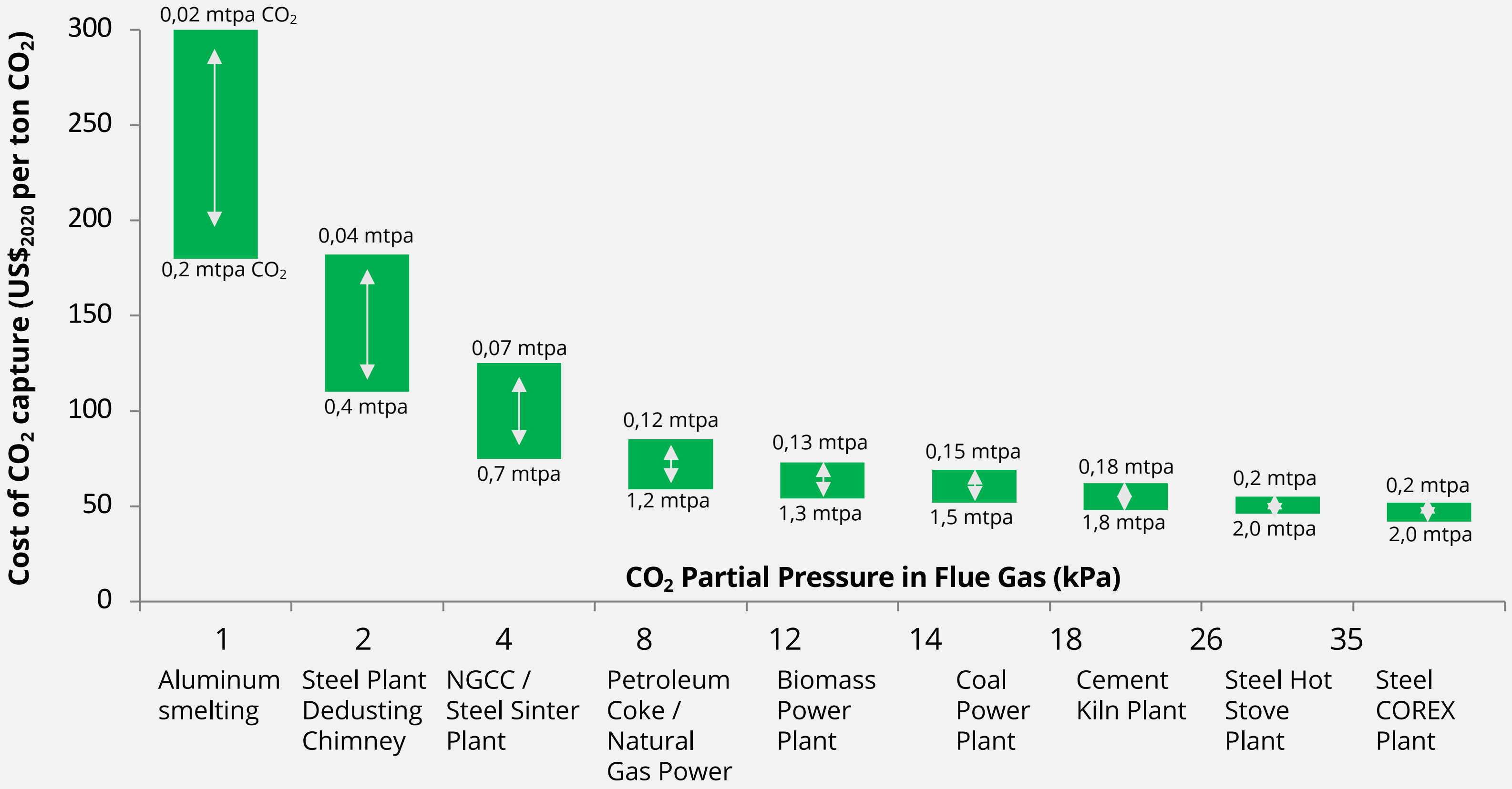
CO_2 concentration in stream

CO_2 partial pressure	**Low** < 10 kpa	**Medium** 10 kpa - 40 kpa	**High** >80 kpa
Applications	• *Ambient air* • *Aluminum* • *NG power plant*	• *Coal-fired power plant* • *Cement* • *Steel & Iron*[3] • *Refinery*[4]	• *Natural Gas* • *Fertilizers* • *Bioethanol*

- CO_2 concentration or partial pressure determines (i) process equipment sizing, (ii) energy requirements and (iii) applicable capture technologies
- At higher CO_2 concentration or partial pressures, the capture of CO_2 is easier and more efficient
- At lower CO_2 concentration or partial pressures, we require higher energy to increase CO_2 partial pressure in the final captured CO_2 stream

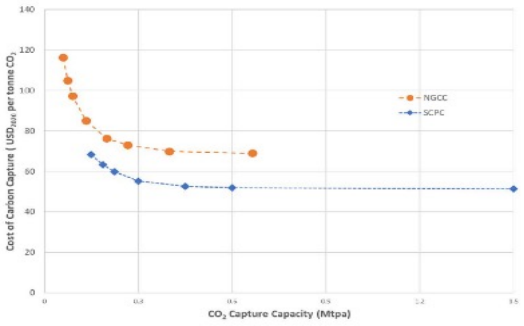
CO_2 capture costs are not only correlated with the CO_2 concentration but also with the quantity of CO_2 captured – higher Qty, lower the cost per ton of CO_2

CCUS Institute modelling of expected capture cost across a range of applications, scales and CO_2 partial pressure



Source: GCCSI (2021), Monitor Deloitte Analysis

- In applications where the CO_2 partial pressures (PCO_2) is low (e.g., Aluminum smelting) we observe a higher effect of economies of scale (larger range of cost/ton)
- As example, the NGCC technology in a coal-fired power plant (see below picture) that deals with lower PCO_2 has a more vertical cost curve than the SCPC one
- These cost per ton curves are key to understand the minimum Qty of CO_2 captured at which each technology must be set up



The CCUS industry is still pursuing cost reduction -- technologically, we observed three avenues: Innovation, Scale and Efficiency

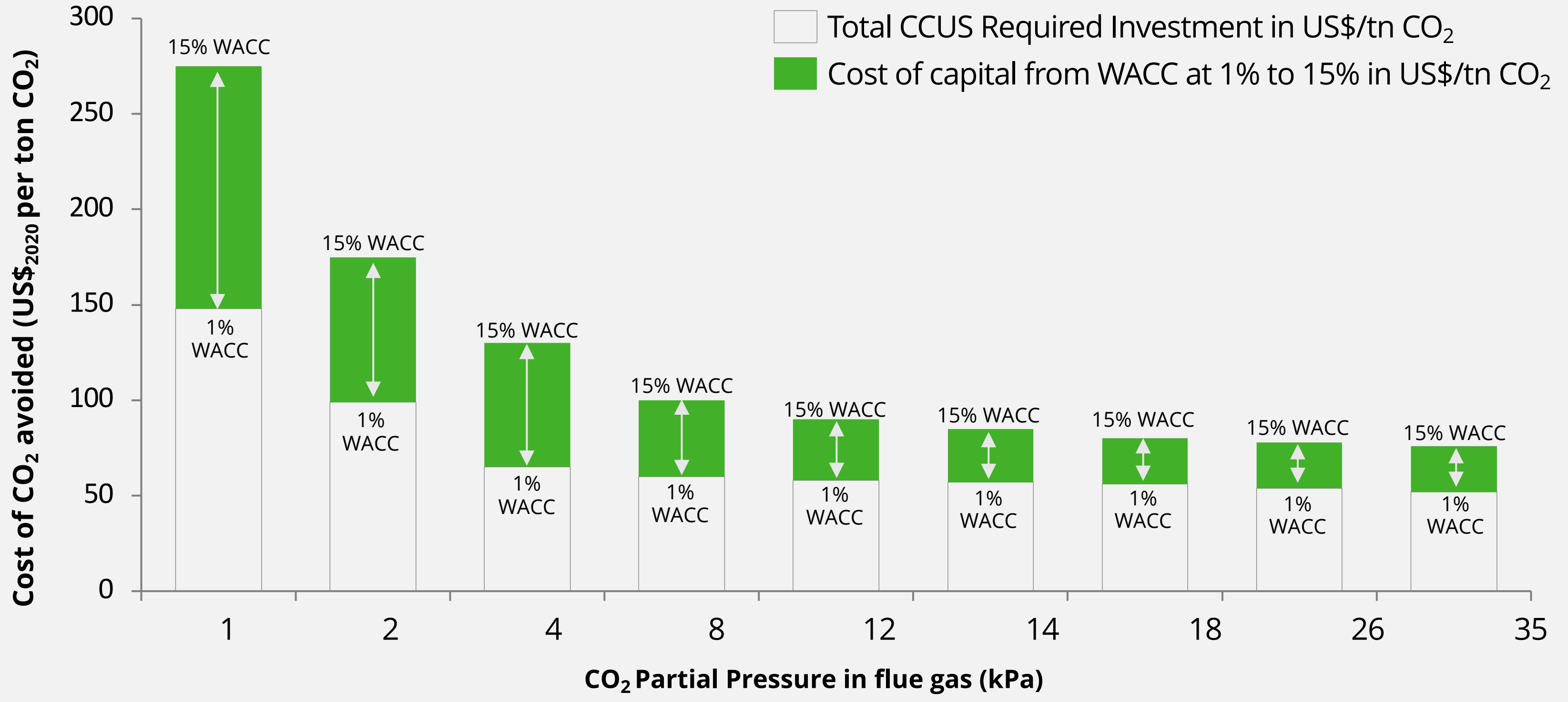
Cost Drivers	Carbon Capture technology	Transport & Storage technology	Cost Reduction Avenues
CO_2 concentration level	Higher the concentration of CO_2 in the gas stream, lower the capture cost		1 **Innovation:** Keep enhancing with focus '*humidification method*' EvGT together with EGR, SFC and EFC (*)
CO_2 capture technology	Technology costs are related to type of used materials and required processes and equipment		2 **Innovation:** Keep enhancing the most used Chemical Absorption with Amine and allow equip Modularization
Scale of CO_2 capture capacity	Higher the capacity of the CCUS plant, lower the costs per ton of captured CO_2 (especially for dilute sources)	Higher the capacity of the pipeline infrastructure, lower the costs transported CO_2	3 **Scale:** Public-Private Partnership allowing clusters setup that will scale up the CO_2 tons to capture and share transport and storage infrastructure
Cost of energy	CCUS requires significant energy to regenerate CO_2 capture media and to compress CO_2 to very high pressures necessary to achieve a dense phase suitable for transport and geological storage		4 **Efficiency:** Utilize lower-cost energy supply
Characteristics of geological storage		Lower costs storage resources that are well characterized (requiring less data to collect); that are closer to the CCUS plant (capture facility); that are onshore rather than offshore; that have high injectivity (requiring fewer wells); and for which existing infrastructure may be re-tasked for storage purposes	5 **Efficiency:** Select CCUS project while assessing its entire value chain

Source: Monitor Deloitte Analysis

(*) (EGR) exhaust gas recirculation, (EvGT) humidification, (SFC) supplementary firing and (EFC) external firing

As financial costs matter, the impact of the cost of capital on CCUS projects may be a key deciding factor in the final investment decision

CCUS Institute modelling of expected CO_2 avoided cost across a range of interest rate and CO_2 partial pressure

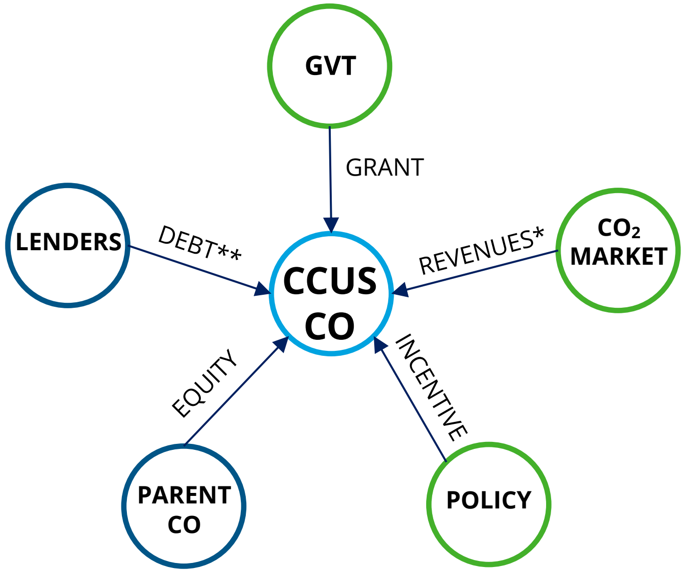


Note: 30Y lifetime project assumed; WACC refers to Cost of Capital of a project; Cost of CO_2 avoided includes CO_2 cost of Capture, Compression & Dehydration, Transport and Storage
Source: GCCSI (2021), Monitor Deloitte Analysis

- For low CO_2 partial pressure (PCO_2) in flue gas conditions (1kPa PCO_2 = aluminum smelting), higher the required CAPEX, higher the economies of scale at different levels of cost of capital
- In high PCO_2 conditions (e.g., natural gas processing, fertilizer…) where the CAPEX required is lower, the cost of the capital still seems to play an important role, bringing the overall cost above the breakeven point

We observed that the most successful CCUS projects used multiple financing, allowing multiple equity investors to participate in a single CCUS project

Under project finance, the CCUS project can be set up through a standalone company CCUS CO



* Revenues may be insufficient to meet some projects' costs. This will have the effect of reducing the amount of debt such projects can raise.
* * Debt payments will use an escrow agent given the nature of the CCUS CO

Financiers and specialist areas of financing

FINANCING TYPE OR SOURCE	EXAMPLES OF SPECIALIST AREAS OF FINANCING
Commercial Banks	Long-term debt Medium-term debt
Export Credit Agencies	Medium-term debt Political or commercial risk insurance Guarantees Concessional financing
Multilateral Agencies & Development Financial Institutions	Equity Long-term debt Medium-term debt Political or commercial risk insurance Guarantees Concessional financing
Developmental Financial Institutions	Equity Long-term debt Medium-term debt Political or commercial risk insurance Guarantees Concessional financing

Cost Drivers	Carbon Capture technology	Transport & Storage technology	Cost Reduction Avenues
Cost of Capital	**Economies of scale are critical:** CCUS is capital intensive so increased output leads to lower average costs. The lower the CO_2 emissions to capture, the higher the CAPEX required on each captured ton of CO_2		6 **Efficiency**: Restructuring projects' cost of capital while scaling up CCUS projects

Source: Monitor Deloitte Analysis

05 Revise regulatory & political support

Public support for CCUS has always existed, but not always delivered

Drivers of CCUS Public Policy failures	Rationale	Illustration
Tight financing deadlines	A series of CCUS projects have not been able to match the stimulus programs due to spending milestones designed over too short a period	FutureGen project in the United States was awarded up to US$1b in support with a 5Y spending deadline. The project took 4Y to secure a CO_2 injection permit and missed the deadline. In 2015, the department of energy (DOE) pulled out
External Budget Pressure	Multi-year grant funding schemes have been highly sensitive to external budget pressure	In 2015, the UK Conservative government cancelled a £1b grant for developing new CCUS technology, 6 months before it was due to be awarded
One-off capital grant	The absence of a CCUS framework for investment and one-time capital grants for selected projects limited CCUS projects scaling opportunities	-
Lack of effective communication to local population	Lack of proactive communication on CCUS role for decarbonization and its related CO_2 storage implications for safety fuel the risk of local public opposition	In 2010, Citizens of the town of Barendrecht showed huge opposition to the sequestration project. After an initial delay in the start date by 3 years to 2013, the project was eventually cancelled by the Dutch Government in 2010

Source: Monitor Deloitte Analysis

Today, the most advanced CCUS industries are in countries where the private sector benefits from solid and ad-hoc CCUS public support

Policy Impact on CCUS deployment: Strong | Medium | Limited

	United States	Canada	United Kingdom	Netherlands	Norway
Well known CCUS Development[1]	17 Commercial CCUS facilities Operational	4 Commercial CCUS facilities Operational	2 CCUS Clusters: HyNet, East Coast (incl. 6 CCUS Hubs)	4 CCUS Hubs – (incl. Porthos, Athos, Antwerp, Greensand)	1 CCUS Hub – Langskip
Net-zero CO_2 policy implementation	Proposed legislation: Net zero by 2050	In law: Net-zero target by 2050	In law: Net-zero target by 2050	In law: Target reduction of 95% GHG by 2050	Target reduction of 90%-95% GHG by 2050
Carbon Tax	No carbon tax	Canada Carbon tax US$40[3,4]	UK Carbon tax US$24[3]	Netherlands Carbon Tax US$46[3,5]	Norway Carbon Tax US$88[3]
Carbon Tax Credit (ex-ETS)	45Q Tax Credit US$60-US$85/tn CO_2 for 12Y California Low Carbon Fuel Standard (LCFS) US$68[2] (vs. 1YTD US$171) for duration of the injection period	Refundable Investment Tax Credit (ITC) at 37.5%-60% for 20Y Alberta Province royalty relief for CO_2 -EOR			
ETS	California ETS Cap and Trade (CaT) US$31[3]	Canada ETS US$40[3]	UK ETS US$88[2] (vs. 1YTD US$67)	EU ETS US$77[2] (vs. 1YTD US$59)	EU ETS US$77[2] (vs. 1YTD US$59)
Public Finance Support (National/ Federal/Regional)	Grant/loan: 2022 DOE US$7b with ~US5b to drive demonstration and deployment of CCUS; ~US2b for shared carbon transport infra	2022 Energy Innovation Program CA$319m (i.e. US$235m) for innovation in CCUS over 7 years 2021 Net Zero Accelerator to provide CA$3b (i.e. US2,2b) over the next 5 years to fund decarbonization initiatives	2020 UK CCUS Infrastructure Fund (CIF) £1b (i.e. US$1,2b) to develop 4 CCUS clusters by 2030 capturing 10Mt CO_2 /y	Grant: 2022 SDE++ Fund provides a 15Y subsidy support covering the cost of CCUS operation above the EU ETS price[6]	Norway Sleipner and Snohvit CCUS Facilities are operated by Equinor (previously a state-owned company likely to have enabled to borrow at lower rate with a longer-term investment horizon) In 2020, Norway Government funded EUR2,1b to build CCUS facilities at a cement and waste-to-energy power plant

Note: i) Non-exhaustive list of policies per country; ii) Exchange rate as of 26th Oct'22: US$1 = EUR1; US$1 = CA$1,36; US$1 = £0.86
1) CCUS Clusters refers to a series of CCUS Hubs. CCUS Hubs refers to a network linking multiple CCUS projects; 2) As of 25th Oct 2022; 3) As of 01st April 2022; 4) Canada carbon tax will increase from CA$50/tn CO_2 to CA$170/tn CO_2 by 2030; 5) Netherlands carbon tax will increase from EUR30/tn CO_2 to EUR125/tn CO_2 by 2030; 6) No new industrial subsidy will be granted after 2035 to reflect CCUS role as a transitionary technology
Source: Energy & Climate Net Zero Tracker; Govt of Netherlands, Govt of Canada, Govt of the United States, California Air Resource Board, Ember Climate, World Bank, GCCSI 2021, Monitor Deloitte Analysis

US 45Q is tailored around CCUS specifics - this allowed US leadership and with the recent threshold revision we expect a further increase in # of projects

Updated 45Q provides strong incentives for CCUS deployment in the US[1]

1 Extension of the Commence Construction Window

	45Q Tax Credit Future Act 2018	New 45Q Tax Credit IRA 2022
Construction date deadline to qualify for 45Q	Start before 1st Jan'2026	Start before 1st Jan'2033

2 Tax credit upscale

Type of CO_2 storage/use	45Q Tax Credit Future Act 2018 (US$/Tn CO_2)	New 45Q Tax Credit IRA 2022 (US$/Tn CO_2)	
		Power & Industry	Direct Air Capture
Dedicated Geological Storage	50	85	180
Storage via EOR	35	60	130
Other Utilization Process[2]	35	60	130

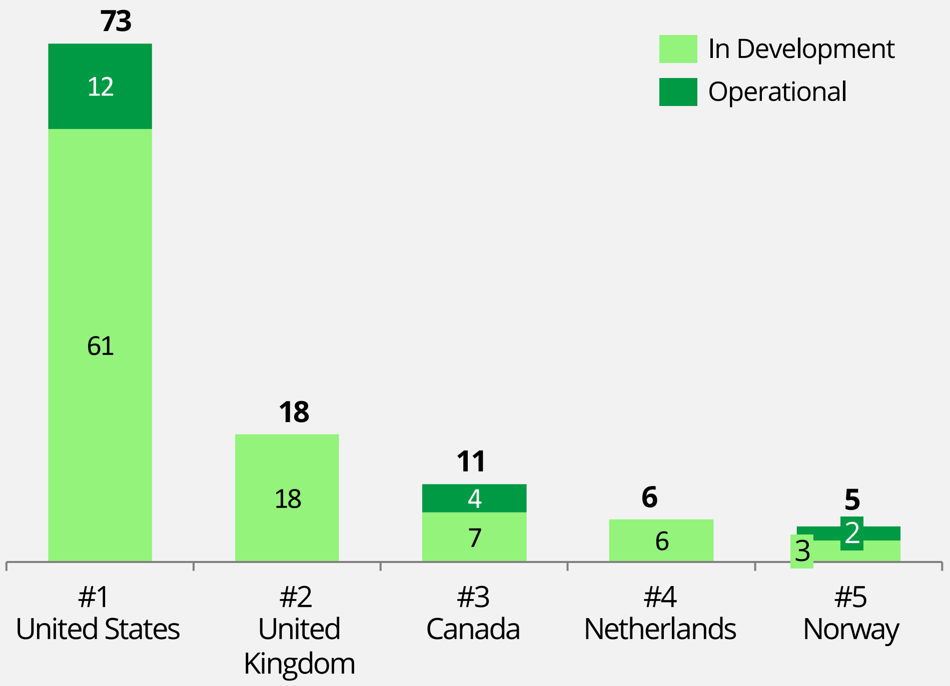
3 Capture thresholds downsize

	Carbon Capture Threshold Future Act 2018 (Ktn CO_2 /y)	New Carbon Capture Threshold IRA 2022 (Ktn CO_2 /y)
Power Generation	500 or more	18.75
Industrial Facilities	100 or more	12,5
Carbon Utilization projects	25-500	*Subject to the individual project thresholds*
Direct Air Capture	100 or more	1 or more

1) US45Q was updated following 2022 Inflation Reduction Act. It applies to facilities in service after December 2022; 2) Including fuels, chemicals, products

The United States dominates the ranking of the top 5 countries by number of CCUS projects

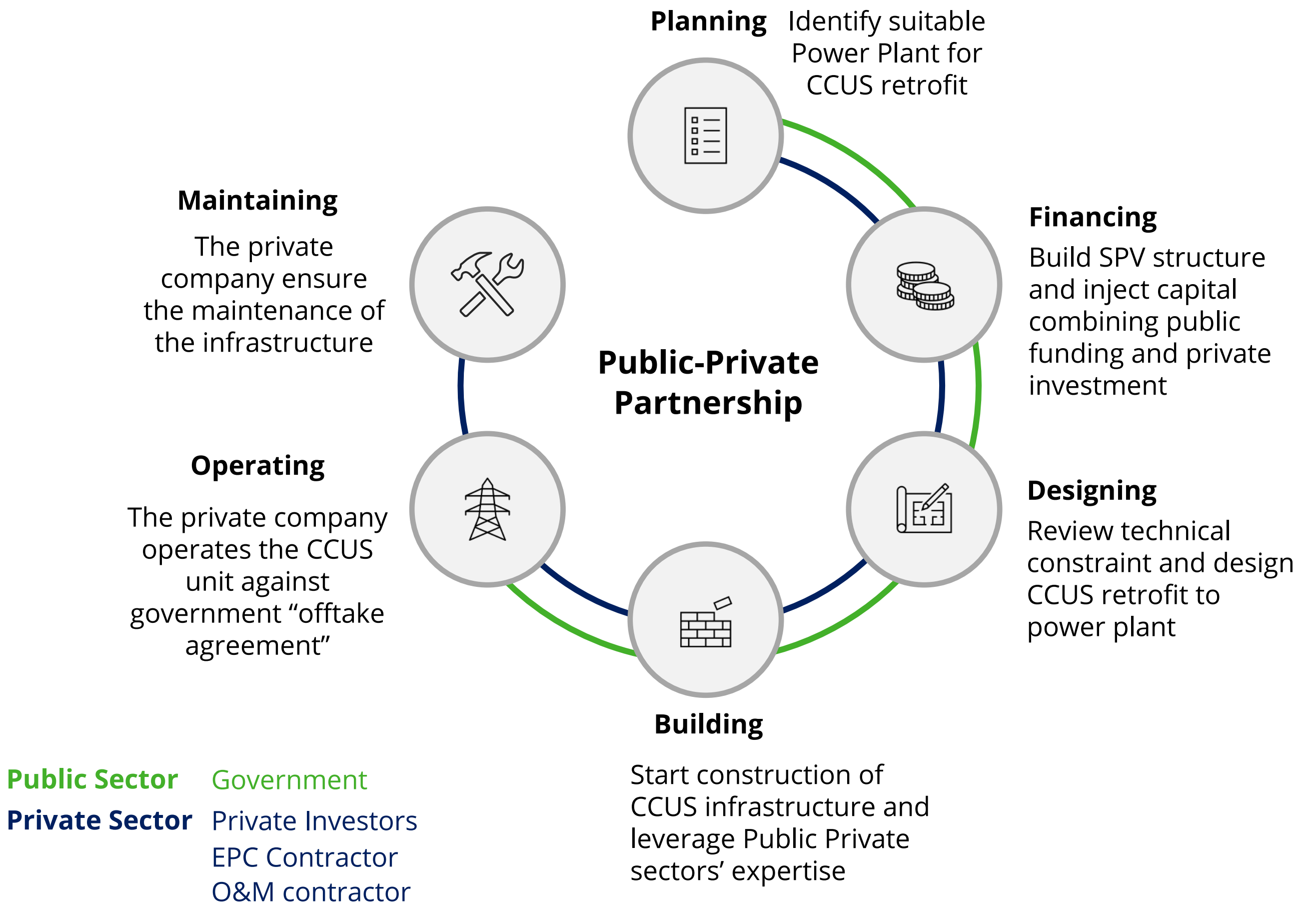
Country ranking by total number of CCUS Facilities Operational or in Development[1], 2021



1) China is excluded from the ranking since Norway total expected capture capacity by 2030 is superior to China and Norway has a historical footprint in the CCUS market

We learned that public-private partnerships (PPPs) seems to offer strong opportunities for CCUS projects to gain momentum

Illustration of Public-Private-Partnership at a CCUS Power Plant



Key benefits of PPP for CCUS Development

- Decrease the level of risk associated with a general CCUS project by building confidence through government support
- Improve access to capital by reducing lending risk and, consequently, the cost of debt
- Offtake agreement (e.g., a 10Y carbon removal purchase agreement) allows to plan for stable stream of revenues and de-risk the financing
- Complementary funding combining public grants and private investments
- Share knowledge and accelerate the government's learning curve on the potential of CCUS to decarbonize Power, EINT and HR sectors
- Democratize CCUS potential to the local population

Source: Monitor Deloitte Analysis

06 Expand access to market

The growing presence of major oil, gas and chemical IOC and OFS companies leads us to believe that the market and technology can only get better

Mapping of CCUS Ecosystem

Illustrative
Non-exhaustive

Key service providers

Separation & Capture

- Post-Combustion: Fluor, Mitsubishi Heavy Industries France, BASF, Shell, Aker Solutions
- Pre-combustion: Fluor, Air Liquide, Honeywell UOP, Axens Solutions
- Oxy-fuel: Jülich Forschungszentrum, Clean Energy Systems

Compression

- Compressor & Pump: MAN Energy Solutions, Svanehøj, Torishima

Transport

- Pipeline: National Grid, Gassco, Kinder Morgan
- Ship: K Line, KNCC, Larvik Shipping

Utilization & Storage

- Storage: MaxTube, Dril-Quip
- EOR: Oxy, Denbury, Halliburton
- Other Utilization:
  - Fuels: Etogas
  - Chemicals: Succinity
  - Building Materials: Carbon Cure

Full Value-Chain: SLB, Chevron, Baker Hughes, Linde

Key project owners

- O&G Companies: ExxonMobil, Shell, Equinor, TotalEnergies, bp, eni, Sinopec, Petrobras, ADNOC
- Utilities: Engie, Drax, nrg, SaskPower, Masdar, KEPCO
- Chemicals: BASF, INEOS, Borealis
- Steel: ArcelorMittal, Nippon Steel
- Cement: Hanson, Norcem, LafargeHolcim

Source: GCCSI, Concawe, Press research, Monitor Deloitte Analysis

Recently, we have witnessed several positive signals from industry leaders, Governments bodies and investors highlighting CCUS' potential as a viable decarbonation solution

1 United Kingdom

Storage License Bid (Sep'22)
Eni entered a bid for a license to store ~330Mt CO_2 in the depleted Hewet gas field sourced from UK's Bacton Eni natural gas import terminals and the industrialized Thames Estuary area

New investments (Jul'22)
The UK CCUS infrastructure fund aiming at the deployment of 4 CCUS clusters by 2030, selected 20 bids in Phase 2 of its Cluster Sequencing Process. Shortlisted bids include Power, Industrial and CCUS-enabled hydrogen projects.

2 Belgium

Cross-border agreement (Oct'22)
Belgium and Denmark government agreed that CO_2 captured by INEOS from its plant in Belgium can be shipped via the port of Antwerp to the company's Nini West oil platform 200 km off western Denmark in the North Sea

Feasibility study assessment (Oct'22)
TotalEnergies and Holcim in Belgium signed a Memorandum of Understanding (MoU) to work together on the full decarbonization of a cement production facility in Obourg

3 Germany

Cross-border agreement (Oct'22)
Wintershall Dea and Norwegian oil major Equinor announced an agreement to jointly develop CCUS infrastructure, including a 900-km pipeline to connect CO_2 collection sites in northern Germany to storage sites offshore Norway

4 France

Feasibility study assessment (Jul'21)
TotalEnergies and Esso explore the feasibility of deploying CO_2 storage infrastructure in North Sea by capturing 3Mtn CO_2 /y by 2030 in Normandy industrial basin

5 United States Golf Coast

New Partnership Project (Sep'22)
ExxonMobil will work with EniLink Midstream to transport and store 2Mt CO_2 /y from CF Industries blue ammonia production complex, driven by favorable economics linked to the Inflation Reduction Act

M&A (Oct'22)
ExxonMobil expressed preliminary interest in taking over Denbury Resources driven by its knowledge in CO_2 for EOR and operating CO_2 pipeline infrastructure in the US Golf Coast

Note: Not exhaustive list of CCUS industry recent developments over 2021-22, excluding APAC
Source: Press Review Monitor Deloitte Analysis

CCUS expand in hubs to leverage CO_2 emission clusters and combine expertise, hence mega clusters are a potential solution to bridge the 0,6Gt gap by 2030

Hubs	Emitters	Transport & storage	Government
1 Porthos CO₂ TRANSPORT & STORAGE	Port of Rotterdam, ExxonMobil, Shell	ebn, gasunie	Ministerie van Economische Zaken en Klimaat
2 ZEROCARBON HUMBER	drax, British Steel, sse Thermal, nationalgrid, uniper, Mitsubishi Power, INEOS Acetyls, ABP Associated British Ports, centrica	equinor, H2H Saltend	Department for Business, Energy & Industrial Strategy; Industrial Strategy; UK Research and Innovation
3 Northern Lights	fortum, NORCEM HeidelbergCement Group, BORG HAVN, YARA	equinor, TotalEnergies, Shell	Norwegian Government

Note: Not exhaustive list of CCUS hubs in Europe
Source: Deloitte, Monitor Deloitte Analysis

Building CO_2 emissions mega clusters

Disclaimer: This analysis assumes no constraint on volume of CO_2 captured and transported, no constraint on storage capacity and no financial barriers. Further study is required to assess technical and financial feasibility.

- The analysis of **CCUS facilities expected operational capabilities by 2030** reveals a **gap of 0,6Gt of CO_2** to achieve the 0,8Gt CO_2 captured in 2030 in the Sustainable Development Scenario
- CCUS Hubs targeting **CO_2 emissions clusters** allow to **optimize CCUS value chain economics** by targeting large volume of CO_2 emissions and sharing expertise across counterparties
- With that prospect in mind, Monitor Deloitte analyzed worldwide CO_2 emissions clusters, potential storage areas, and derived **potential mega-clusters implementations**[1]. A mega-cluster refers to a combination of several large, medium or small size CO_2 emissions clusters
- The implementation of CCUS to the **3 identified mega clusters** respectively located in the US Gulf Coast, South-West of Poland and Eastern China could bring total CO_2 emissions captured to **~365tn CO_2 /y**, or **~60%** of the additional CO_2 required to be captured in 2030 to reach SDS

1) Assuming no constraint on volume of CO2 captured and transported, no constraint on storage capacity, no financial barriers

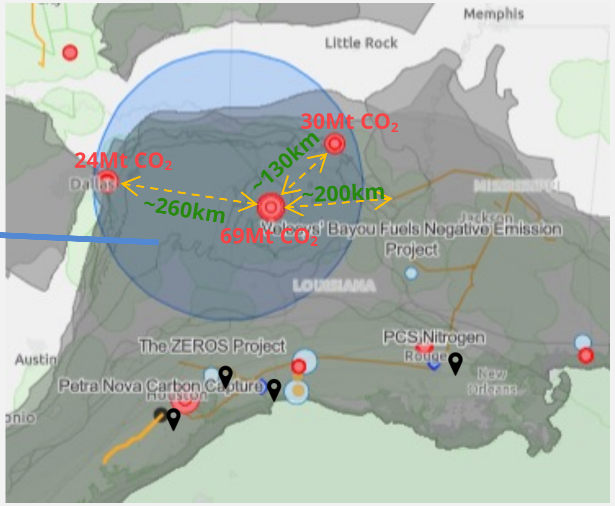
A mega cluster in North America could capture 0,1Gt of CO_2 /y, almost 1/6th of the additional 0,6Gt capture capacity required by 2030

Location of CO_2 emission clusters

- CO_2 Emissions Clusters (estimated in Mt CO_2 /y)
- Oil & Gas Fields
- Saline Aquifers
- Potential Mega Cluster CCUS Implementation
- Commercial CCUS Facilities In Development
- Commercial CCUS Facilities Operational
- Existing and Planed CO_2 Pipelines
- New Required CO_2 pipelines
- Commercial CCUS Facility with Enhanced Oil Recovery (EOR) storage

Disclaimer: This analysis is theoretical and requires further study in terms of technical and financial feasibility.

Zoom on Gulf of US Mexico Mega Cluster



~0,1Gt of CO_2 emissions potential to be captured per year

~15% of the required 0,6Gt additional capture capacity to reach the 0,8Gt capture capacity by 2030 and reach SDS

EOR storage opportunities by connecting new required pipelines to existing CO_2 pipelines

US Gulf of Mexico Mega Cluster

- The Gulf of Mexico mega cluster combines **1 large CO_2 emissions cluster** in Shreveport and **2 medium-size CO_2 emission clusters** close to the city of Dallas and Smackover, connected by **~390km** of CO_2 pipeline
- The mega cluster total CO_2 emissions are 122Mt (95% power generation, 3% cement, 1% refining, 1% O&G and ~1% others) with **110Mt** CO_2 potential to be captured at 90% capture rate

Identified Opportunities — **Feasibility**

EOR storage by building additional ~200km of pipeline to connect to existing infra [1]
Store CO_2 in surrounding saline aquifers [2]
Achieve synergies of cost and knowledge with neighbored CCUS facilities

1) Potential to connect to existing onshore EOR storage or offshore wells in the Gulf Coast
2) Prospective aquifer storage capacity requiring further analysis to qualify area size, reservoir thickness and porosity

Source: ArcGIS Online Open Library, OGCI CCUS HUB Base Case, Monitor Deloitte Analysis

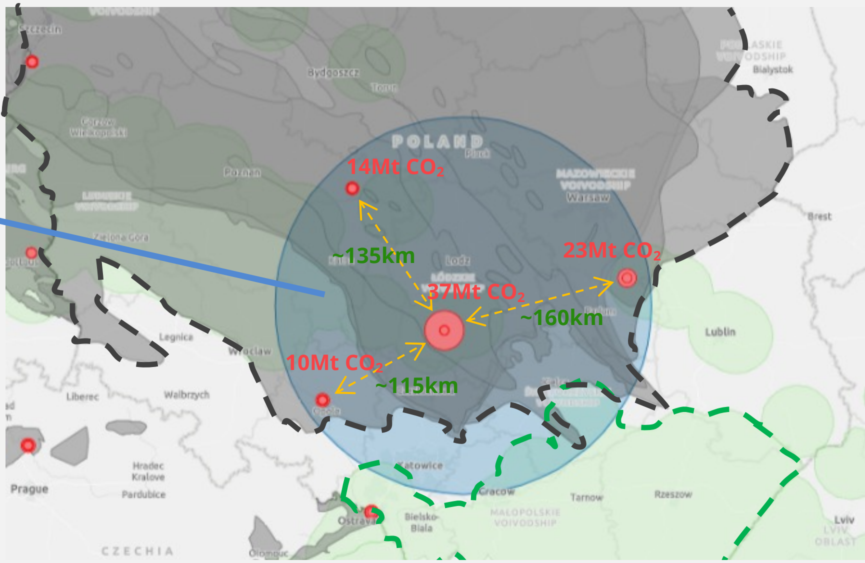
Another mega cluster in Poland could capture 0,1Gt of CO_2 per year, almost 1/6th of the additional 0,6Gt capture capacity required by 2030

Location of CO_2 emission clusters

- CO_2 Emissions Clusters (estimated in Mt CO_2/y)
- Oil & Gas Fields
- Poland Carpathian hydrocarbon fields
- Saline Aquifers
- Poland Jurassic and Triassic Formations
- Potential Mega Cluster CCUS Implementation
- Commercial CCUS Facilities In Development
- Commercial CCUS Facilities Operational
- New Required CO_2 pipelines

Disclaimer: This analysis is theoretical and requires further study in terms of technical and financial feasibility.

Zoom on Poand Mesozoic Mega Cluster



~0,1Gt of CO_2 emissions potential to be captured per year

~15% of the required 0,6Gt additional capture capacity to reach the 0,8Gt capture capacity by 2030 and reach SDS

Aquifers storage opportunities in nearby area

Poland Mesozic Mega Cluster

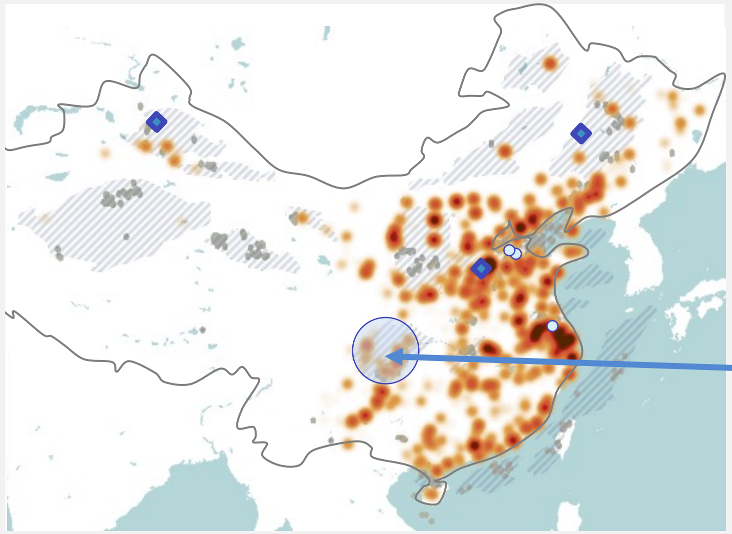
- The Mesozoic mega cluster combines **4 medium size CO_2 emissions cluster** in the Polish cities of Piotrkow Trybunalski, Radom, Konin and Opole, connected by **~400km** of CO_2 pipelines
- The mega cluster total CO_2 emissions are 83Mt (86% power generation, 10% cement, 3% ammonia, 1% lime and ~1% others), with **74Mt** CO_2 potential to be captured at 90% capture rate

Identified Opportunities	Feasibility
Store CO_2 in surrounding saline aquifers	1
Store CO_2 in nearby Carpathian hydrocarbon fields	2

1) Lower Jurassic and Lower Triassic Formations estimated storage capacity is 44Gt and 8Gt respectively. Research find that these formations are the most adequate sites reservoir in Poland; 2) Carpathian hydrocarbon fields count 12 medium-size depleted/depleting gas fields and 2 small oil fields
Source: ArcGIS Online Open Library, OGCI CCUS HUB Base Case, EU GeoCapacity, Monitor Deloitte Analysis

A third mega cluster in China could capture 0,2Gt of CO_2 per year, almost 1/3rd of the additional 0,6Gt capture capacity required by 2030

Location of CO_2 emission clusters

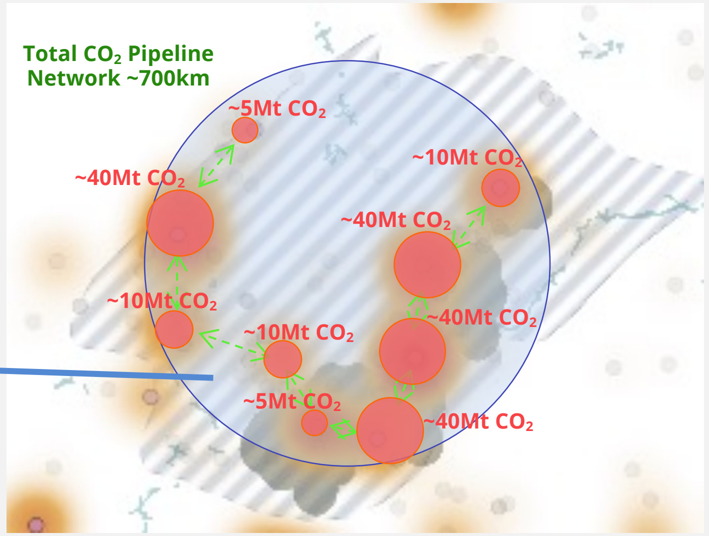


CO_2 Emissions (Mt/y)
0 225

- CO_2 Emissions Clusters (estimated in Mt CO_2/y)
- Hydrocarbon Fields
- Saline Aquifer
- Potential Mega Cluster CCUS Implementation
- Commercial CCUS Facilities In Development
- Commercial CCUS Facilities Operational
- Required CO_2 pipelines

Disclaimer: This analysis is theoretical and requires further study in terms of technical and financial feasibility.

Zoom on China Sichuan Mega Cluster



~0,2Gt of CO_2 emissions potential to be captured per year

~33% of the required 0,6Gt additional capture capacity to reach the 0,8Gt capture capacity by 2030 and reach SDS

Depleted hydrocarbon fields storage opportunities

1) Estimated storage capacity in depleted hydrocarbon fields is ~5,5Gt of CO_2
2) EOR storage opportunities mentioned in scientific literature requiring further analysis
3) Sichuan Saline Aquifers are of low quality (low porosity and tight characteristics due to their deep burial)
4) Abundant boreholes, seismic data and other geological data from O&G Industry started in 1953 in the Sichuan basin

China Sichuan Mega Cluster

- The Sichuan mega cluster combines **4 medium size and 5 small size CO_2 emissions cluster** located in the Sichuan Basin, connected by ~**700km** of CO_2 pipelines
- The mega cluster total CO_2 emissions are ~200Mt (~75% power generation, ~10% Cement, ~10% Iron & Steel, ~4% chemicals and ~1% Others), with ~**180Mt** CO_2 potential to be captured at 90% capture rate

Identified Opportunities	Feasibility
Store CO_2 in nearby depleted hydrocarbon fields	◕ [1]
EOR storage in nearby hydrocarbon fields	◑ [2]
Store CO_2 in surroundings saline aquifer	◔ [3]
Leverage O&G local knowledge of sites characteristics for CO_2 storage	● [4]

Source: Chinese Academy of Science (CAC), Appraisal of CO_2 storage potential: Case Study in the Sichuan Basin (2020), IEA, Monitor Deloitte Analysis

07 Conclusions

Conclusions

- CCUS can be instrumental in compensating residual CO_2 emissions that are hard to abate in Energy-Intensive Industries, Power Generation and Refined Hydrocarbons. The overall picture of all types of CCUS projects in 2022 shows that we are off to a running start.
- We see three avenues of improvements to offset the No Business Value of CO_2 abatement: (A) decrease of cost through technology & financing, (B) enhance regulatory and political support and (C) expand access to markets.
- We are still on the path to reduce costs of CCUS. We expect to see benefits from further technology innovations, positive effects of a projects' scale up and efficiencies, and the entrance of major players into the CCUS landscape. Restructuring the cost of capital will offer additional opportunities for cost reduction thanks to the expected scaling up of CCUS projects.
- The most advanced CCUS industries are in countries where the private sector benefits from a tailored CCUS public support. Few recent policy revisions are encouraging more-effective Public-Private Partnerships (PPP), which provides strong foundations for the CCUS industry to gain momentum, while ensuring investment stability.
- Recently, we have noted several positive signals of confidence in the technology, and of collaboration between industry leaders, governments and investors. We believe that this will drive public acceptance of CO_2 storage, while industry leaders will prioritize offshore storage rather than onshore.
- CCUS expands in hubs to leverage CO_2 emission clusters and combined expertise. We propose that Public-Private Partnerships should focus on mega clusters as a solution to bridge the 0,6Gt CO_2 gap by 2030. We highlighted three mega clusters in North America, Poland and China, which could capture 2/3rd of the additional 0,6Gt capture capacity required by 2030.

Source: Monitor Deloitte Analysis

08 Deloitte and CCUS

Deloitte is positioned to lead on CCUS development around the world

The Deloitte CCUS service offering encompasses the entire value chain – from an emitter to a CO_2-disposal & utilization business, as well as important stakeholders, as service companies and regulators

Technology & Innovations
Scan of the technology & innovation landscape to understand readiness levels, opex & capex costs, risk of adaptations and development of fit-for-purpose technical specifications

Market Insights
Insights on the market potential on sectoral / emitter level relevant for CCUS-technology company as well as CO_2-disposal company to understand “supply / demand” and “window-of-opportunities”

Funding & Subsidies
Selection of project specific options with details on the funding / subsidy mechanisms, consideration of eligibility, as well as support in filling and application process

Policies & Regulations
Analysis of the local regulatory framework and an impact on the CCUS-related activities, including licenses, cross-boarder regulations, emissions reduction regulations etc.

Business Models
Full-scale financial model to get insights on financial attractiveness of various business models (i.e. operation / owner) as well as on impact of key parameters (i.e. CO_2-price)

CO_2-accounting & taxation and value creation options
Impact of CO_2-accounting and carbon-taxes on the business case, as well as recommendation of additional value creation options to boost returns of projects

We have supported the most important CCUS projects...

Technology & innovation | Policies & Regulations | Business models | Market insights | Technology & innovation | CO_2 accounting & taxation

Financial model and risk assessment for CCUS project

Deloitte performed analytical procedures on the financial model of Porthos, including revenue, opex, capex and decommissioning parts for the transport and storage components of the CCUS value chain. Deloitte also analyzed risk profiles to determine appropriate discount rates for project valuation and analysis of value distribution across the chain. The financial model is used to support decisions, commercial agreements, and financing applications.

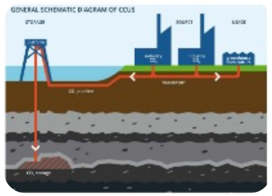
Technical and commercial feasibility study

Deloitte supported the Norwegian government's plans to develop a full-scale CCUS value chain in Norway by 2024. Deloitte advised Fortum Oslo Varme throughout the concept study, FEED and piloting of carbon capture from its waste-to-energy facility in Norway, with a focus on business model, procurement strategy, cost control, planning. Deloitte also carried out detailed modelling of uncertainties around capital and operating cost requirements and supported stakeholder negotiations.

Operational & technical due diligence for CCUS project

Carried out an in-depth operational due diligence on P18-A platform analyzing opex and capex costs, maintenance, production profiles and reserves, as well as decommissioning liabilities. The detailed map of key cost drivers, risks and opportunities is used for commercial negotiations, economic forecast scenarios and strategic decisions.

Grants & incentives advisory for CCUS projects



For two CCUS projects in Belgium and The Netherlands, Deloitte conducted an assessment of available grant and subsidy opportunities. After the feasibility has been demonstrated, Deloitte formulated the business plan (including the financial and implementation plans), for Innovation Fund and SDE++ applications, and submitted the required documentation to the relevant regulatory bodies.

… across multiple stakeholders and for multiple services

Technology & innovation | Policies & Regulations | Business models | Market insights | Technology & innovation | CO_2 accounting & taxation

Market model to assess commercial potential for CCUS

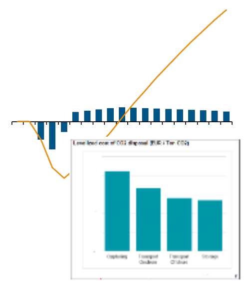
Assisted European O&G client with determining the value creation potential and window of commercial opportunity for CCUS in North-West Europe. This involved the development of an integrated source-to-sink market model which captures the key supply and demand drivers, forecasts logistically and commercially accessible CO_2 volumes, and models emitter choices, optimizing on a cost basis. The model supports strategic investment decisions.

Financial advisor to UK Government on CCUS Programme

Department for Business, Energy & Industrial Strategy

Deloitte advised the UK Government's Department of Business, Energy and Industrial Strategy (BEIS) on the £1 billion grant CCUS Commercialisation Programme of 2013-15, aimed at procuring up to two new-build power and CCUS projects. This involved the structuring and drafting of the tender documentation and evaluation of the bids received, providing input on the structuring of a contract for difference to support full chain CCUS projects, and assessing project financing aspects.

Life-of-asset economic model to screen CCUS project options



Supported a multinational O&G client with determining the key value drivers for CCUS projects and mapping the value-risk distribution and economic benefits across the CCUS value chain. Deloitte developed a life-of-asset economic model and carried out a bottom-up analysis of key cost drivers, potential revenue streams and tariff structures, and quantified impact of subsidies, grants, incentives, carbon pricing, and long-term liabilities on project economics across each segment of the CCUS value chain. The model output was used to screen investment opportunities and optimize decisions in respect to CCUS participation, operating models, and pricing formulae .

Advise on future-proof corporate structure for CCUS projects

ebn

In the context of potential (new) investments in carbon capture and storage and other new businesses in the Netherlands, EBN asked Deloitte to provide an integrated advice on a future-proof corporate structure that best supports these investments. Through interactive workshops with the client's senior management, we have identified and prioritised the possibilities and hurdles from a legal, commercial, financial, governance, tax and audit perspective.

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