CCUS for Paris Alignment

Supporting Carbon Neutrality in Heavy Industrials and Power

Report by:

HSBC Centre of Sustainable Finance

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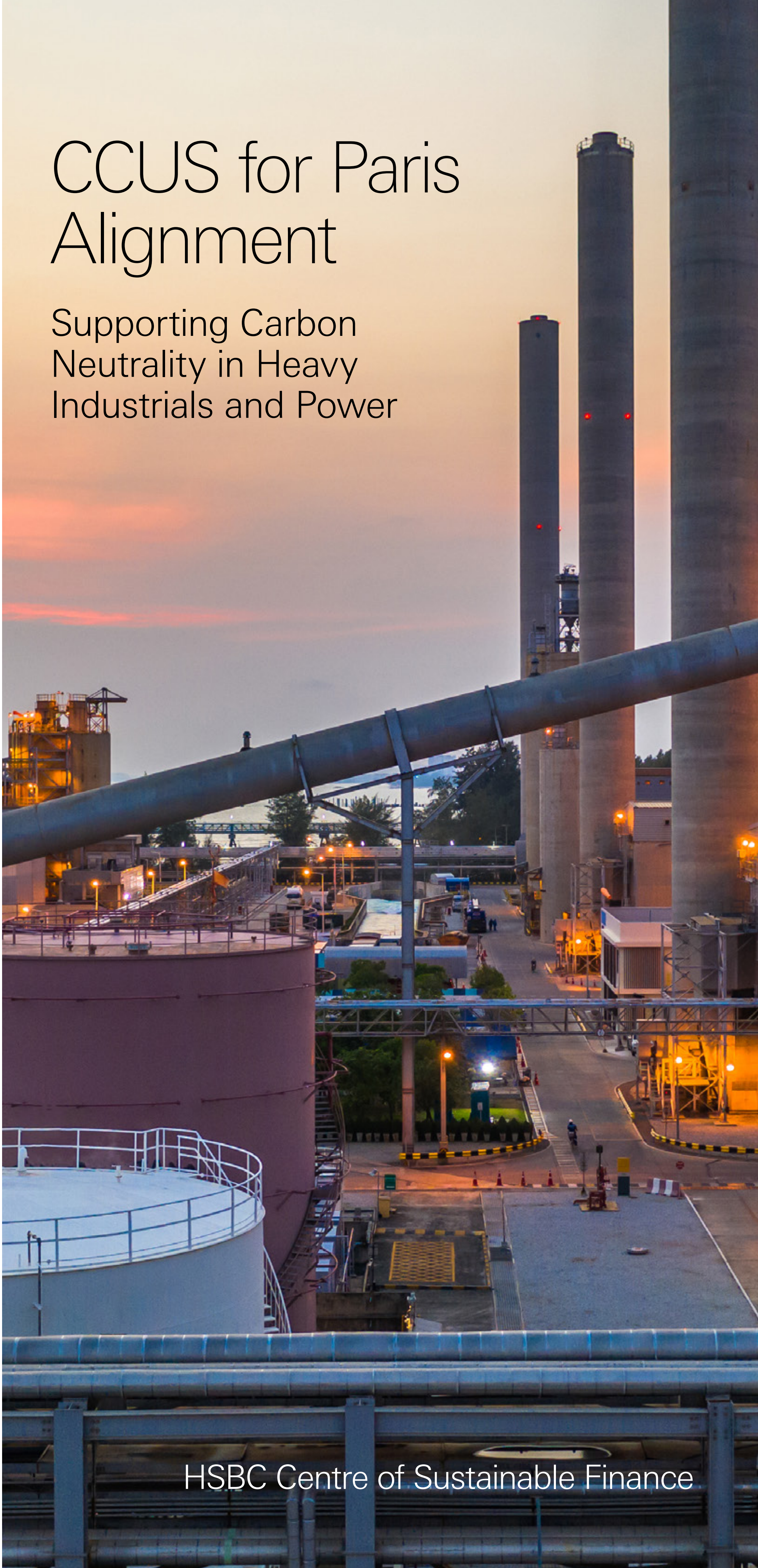

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Executive Summary

Carbon capture, use and storage (CCUS) refers to the integration of different technologies that together can sequestrate and store carbon dioxide safely and permanently. As emissions from industry and power continue to grow, CCUS technologies are increasingly a feature for businesses aiming to deliver net-zero outcomes. The International Energy Agency estimates that if no deep decarbonisation solution is provided, the related existing and planned infrastructure stock in power and industry are set to consume 95% of the carbon emissions allowances for limiting global warming to 1.5oC[1].

CCUS deployment for Paris goals will require investments of around USD9.7tn, according to the IEA[2]. The bulk will come from the financial sector but only one large scale CCUS facility has received commercial financing today. Uncertainties around whether CCUS can help solve climate and insufficient evidence of how the technologies can achieve commercial scale are the key barriers preventing flows of capital to CCUS.

This paper addresses the three questions below to showcase the practical opportunities available for the financial sector to support the Paris Agreement goals through CCUS.

1. **How do the CCUS technologies work?**
2. **When can the applications of CCUS support significant emissions reductions in alignment with Paris goals?**
3. **What is enabling the large scale deployment of CCUS?**

Key messages

- **Achieving economies of scale will increase the chances for CCUS to become a cost effective decarbonisation solution.** This means carbon being captured from large emitters and transported to sites where a significant volume of carbon can be stored or used. As storage capacity depends on natural conditions, proximity to adequate geological formations would be a precondition for carbon storage to be technically and economically feasible. For carbon use to make economic sense, high demand for CO_2 from clusters of manufacturing facilities would also be necessary.
- **The IEA estimate 115GtCO_2 to be addressed with CCUS between 2018 and 2060 for Paris goals (13% of all required carbon emissions), but the bulk will be through geological sequestration.** 93% of the emissions cuts will be through geological sequestration and 7% through carbon use. There is sufficient underground storage potential with the top 12 countries offering a sequestration opportunity of hundreds of billions of tCO_2. Most advance storage projects moving to commercial stage have received public support for appraisal and feasibility studies, which can spin several decades. For carbon use to support emissions reductions at scale, CO_2-derived products that sequestrate carbon for longer like construction materials, chemical, and fuels, should achieve commercial maturity rapidly.

[1] IEA. 2019. Transforming Industry through CCUS
[2] IEA. 2019. The Role of CO_2 Storage

- **Because of lower carbon capture costs, commercial scale has been achieved mostly in activities like gas processing, hydrogen production from natural gas, and fermentation of biomass (84% of the facilities).** These activities generate gases with high concentration of CO_2, which makes the process of separating CO_2 from other gases simpler and cheaper. In turn, cement and steel show the lowest CO_2 concentrations (<30%) and hence, the smaller number of carbon capture facilities in these sectors. **Projects entering the pipeline are testing technologies that aim to make carbon capturing cheaper in cement and steel.**
- **CCUS applications in heavy industrials, hydrogen production, and flexible power generation from natural gas and bioenergy are discussed in the paper as they help achieve deep decarbonisation even after considering life-cycle emissions.** Life-cycle emissions mean all associated emissions of the activity, from the manufacturing process to the use of the goods.
- **The EU Taxonomy provides concrete guidance for market players to assess when CCUS makes significant contribution to solve climate in alignment with Paris.** It uses carbon intensity thresholds for identifying when carbon capture helps an economic activity operate within an acceptable carbon performance standard. Other countries like the USA focus mostly on the potential for CCUS to achieve absolute carbon emissions reductions, without setting a specific carbon performance standard.
- **From the examples discussed in the paper, there are three key enablers of CCUS deployment at scale:** i) Concentration of large emitters in a production / industrial region; ii) Supportive policy and government grant funding; and iii) Proximity to existing transport and storage infrastructure or the opportunity to build new infrastructure in partnership. Large CCUS projects are increasingly shaping up as a network of large emitters that take advantage of their relatively close proximity to either trade CO_2 as a production material or share transport and storage infrastructure.

The paper is organised as follows: the introduction discusses the scientific evidence supporting CCUS deployment and the key barriers to achieve commercial scale. Part 1 explains the technologies across the CCUS chain (i.e. carbon capture, transportation, use and storage). Part 2 outlines the applications of CCUS to achieve significant carbon emissions cuts across sectors in alignment with the Paris Agreement. Examples of inter-industry partnerships that are helping address costs and risks associated with CCUS deployment at scale are discussed in Part 3.

Acknowledgements

The HSBC Centre of Sustainable Finance supports HSBC's ambition to facilitate low-carbon transition by providing thought leadership about transforming the real economy and strengthening the financial system response to climate change.

Building on internal subject matter expertise and our external network of experts, we generate and promote reports that support the climate ambitions of key stakeholders including industry, financial regulators, governments, and financial institutions.

The Centre would like to thank the work of **Indira Masullo** in the production of this piece, alongside insights from the Global Carbon Capture and Storage Institute.

Contents

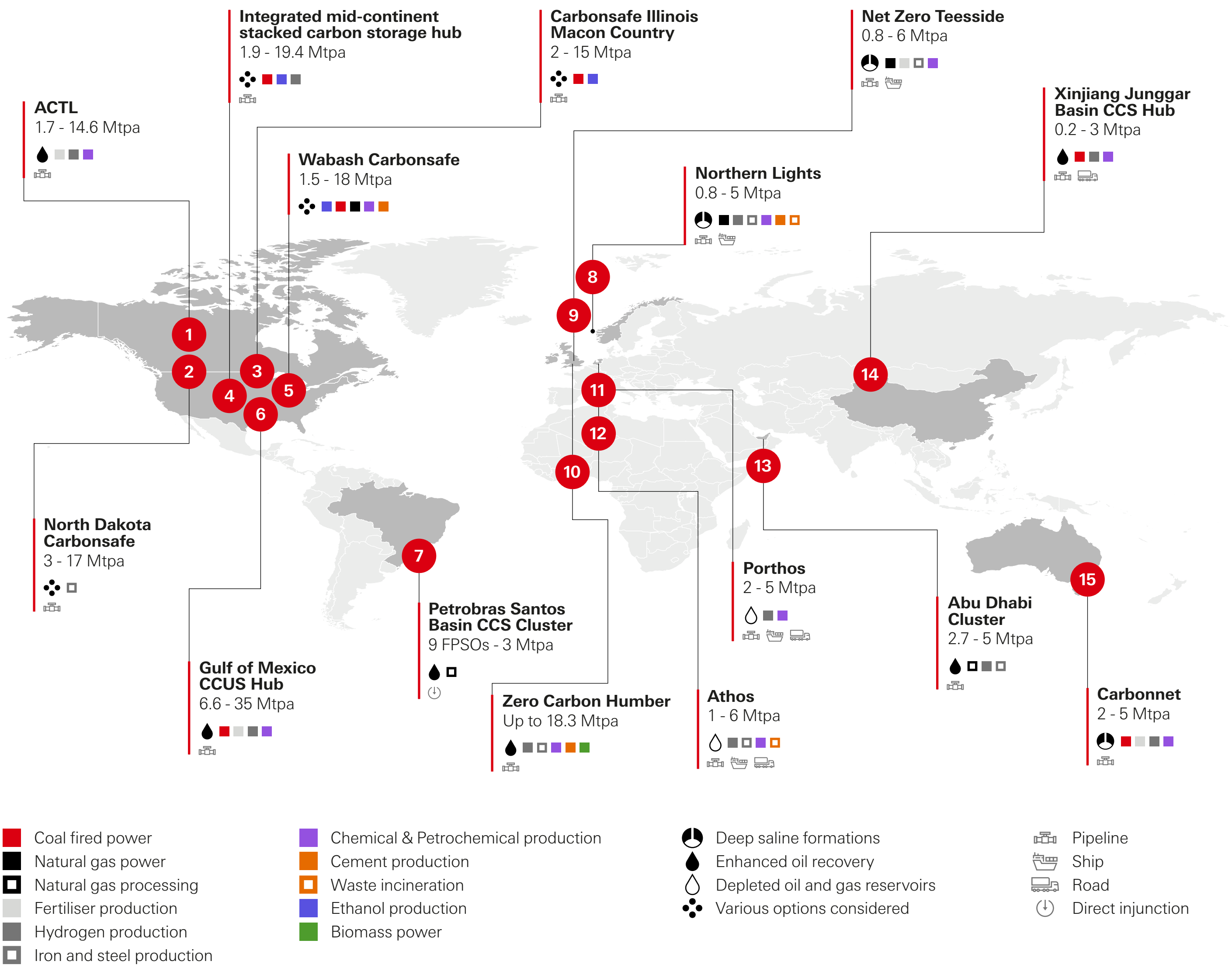
Introduction

Carbon capture, use and storage (CCUS) refers to the integration of different technologies that together can sequestrate and store carbon dioxide safely and permanently. The process starts with capturing carbon from sources of emissions such as power generation and industrial processes. It ends either by storing carbon underground or by using carbon as a feedstock to production processes.

Despite being around for over 40 years, CCUS technologies have had limited uptake with only 21 facilities achieving industrial scale globally today[3]. The barriers to uptake have been as follows:

- An unclear role in solving climate change. An important number of CCUS applications relate to fossil fuels and hence, they are perceived to prolong the use of carbon intensive activities rather than providing an absolute emission reduction outcome (see Figure 1).
- Relatively higher carbon abatement costs, which could range from USD15 to USD 120 per tCO_2, according to the International Energy Agency (IEA).
- Compared to other decarbonisation solutions, CCUS often implies higher project, technology, and counterparty risks. This is owed to the number of players involved in CCUS projects and the economies of scale that are required to be met for CCUS to make economic sense[4].

Figure 1. The Relevance of CCUS to Solve Climate is Often Contested as the Majority of the Existing CCUS Facilities Relate to Fossil Fuels



Source: Global CCS Institute

[3] Global CCS Institute. CO_2RE – CCS Facilities Data
[4] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions and IEA. Topics: Carbon Capture and Storage

However, since the 2015 Paris Agreement, the landmark accord for strengthening the global climate action, CCUS has progressively emerged as an important solution to support the significant carbon emissions reductions required to limit temperature rises.

The Paris accord's ambition is to hold "global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change."[5]

In its 2018 Special Report, the IPCC, the scientific body of the United Nations, points to the urgency to push for 1.5°C threshold as it would significantly reduce the negative impacts of climate change, relative to 2°C. The IPCC work suggests an emission reduction across all sectors of the economy by 45% from 2010 levels in the next decade and achieve zero emission by 2050 to improve the chances of limiting global warming to 1.5°C. Yet, this would require an accelerated and unprecedented pace in carbon emissions reductions[6].

CCUS can help deliver on these aims in two ways. First, it is particularly useful for industrial sectors where emissions have historically been unchecked. CCUS can nearly eliminate process related emissions which come from chemical and / or physical reactions like those in the production of cement, steel and chemicals. Emissions from these processes can't be avoided by switching to a carbon neutral fuel. CCUS can also help address emissions from burning fossil fuels to power industrial activities, when the switch to renewables is yet to achieved commercial viability.

Second, CCUS technologies can decarbonise power generation from natural gas, which is often the immediate source of flexible electricity in some geographies[7].

The IEA estimate that for the Paris emission reduction goals to be met, CCUS capacity should increase to 2000 large scale facilities in the next 40 years[8], implying a combined investment requirement of USD9.7tn in the power, industrial, and fuel transformation sectors[9]. So far, only one large scale CCUS facility has attracted commercial capital.

This paper looks at how CCUS technologies can support emissions reductions in alignment with the Paris Agreement and how these technologies are achieving economies of scale. The purpose is to showcase the practical opportunities available to investors and lenders.

Paris alignment is understood here as activities that contribute towards a **45% reduction in CO_2 emissions by 2030 from 2010 levels and net-zero emissions by 2050**, consistent with the IPCC 1.5°C Special Report. This means that any activity to cut carbon emissions should demonstrate consistency with medium- and long-term climate goals[10].

Part 1 looks at the chain of CCUS technologies, meaning carbon capturing, transport, use and storage.

[5] 2015 Paris Agreement. Article 2.
[6] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report
[7] EU Technical Expert Group on Sustainable Finance. 2020. Technical Report. Taxonomy: Final Report of the Expert Group on Sustainable Finance. IEA. 2020. CCUS in Power. IEA. 2019. Transforming Industry through CCUS.
[8] IEA Website. Topics: Carbon Capture and Storage
[9] IEA. 2019. The Role of CO_2 Storage
[10] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report. And EU Technical Expert Group on Sustainable Finance. 2020. Technical Report. Taxonomy: Final Report of the Expert Group on Sustainable Finance

Part 1 – The CCUS Technology Chain

Carbon capture, use and storage (CCUS) refers to the integration of different technologies that together can sequestrate and store carbon dioxide safely and permanently. The chain starts with capturing carbon from sources of emissions such as power generation and production of cement, steel, and chemicals. It ends either by storing carbon underground or by using carbon as a feedstock to production processes for fertilisers, construction materials and lower-carbon fuels.

Achieving economies of scale will increase the chances for CCUS to become a cost effective decarbonisation solution[11]. This means carbon being captured from large emitters and transported to sites where a significant volume of carbon can be stored or used. As storage capacity depends on natural conditions, proximity to adequate geological formations would be a precondition for carbon storage to be technically and economically feasible (top sites in Figure 7 below)[12]. For carbon use to make economic sense, high demand for CO_2 from clusters of manufacturing facilities would also be necessary (see example in Box 3 below).

The examples discussed across the paper show that the deployment of CCUS at scale would require a significant amount of collaboration among actors from different industries and in some cases, different jurisdictions. Large CCUS projects are increasingly shaping up as a network of large emitters that take advantage of their relatively close proximity to either trade CO_2 as a production material or share transport and storage infrastructure to transport and store carbon.

However, after over 40 years using the technologies, only 21 facilities have achieved industrial scale, totalling around 39MtCO_2 a year in capturing and storing capacity. An additional 59MtCO_2 capturing capacity is either in construction, advanced deployment or early development stage[13]. The entire pipeline equates to 98MtCO_2 or approximately what Chile emits in a year[14]. Capture capacity is required to increase to 0.8GtCO_2/year by 2030 and 2.8GtCO_2/year by 2050 to increase the likelihood of limiting global warming to well below 2°C[15]. This would mean 8x the current pipeline by 2030 and 28x by 2050.

To achieve this volume, 70-100 new capture facilities, 5,200-7,200 km of new or re-purposed pipeline infrastructure, and 10-30 storage facilities would be required to come online every year, according to the Global CCS Institute[16]. We look at the practical application of this infrastructure in chapter two, but first we outline the chain of CCUS technologies, meaning carbon capturing, transport, use and storage.

Figure 2. Overview of the Full CCUS Chain and Expected Annual Build Rate to Meet Paris Goals[17]

1 Capture

Carbon is captured from sources of emissions such as power generation and production of cement, steel, and chemicals.

Annual build rate to 2050
Capture facilities: 70-100

2 Transport

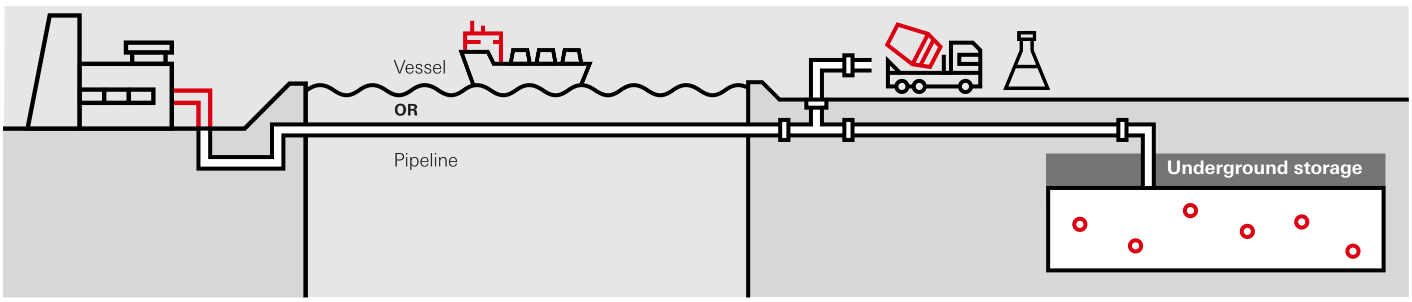
Carbon can be transported through pipelines and / or ships from the industrial site where it has been captured to a storage site. Alternatively, carbon can be transported to an industrial facility for its use as a feedstock.

Annual build rate to 2050
Pipelines: 5,200 - 7,200 KM

3 Use or Storage

Carbon can be injected underground for its permanent storage or used in the production of construction materials, chemicals, and fuels, among other products.

Annual build rate to 2050
Storage sites: 10 - 30



[11] Global CCS Institute. Scaling Up the CCS Market to Deliver Net-Zero Emissions. 2020.
[12] IEA. Five Keys to Unlock CCS Investment
[13] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[14] Climate Action Tracker. Country Summary: Chile
[15] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[16] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[17] Sources: 2019 Sustainability Report of Shell and Equinor, and Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions

Capturing carbon

Types of Carbon Capturing Technologies

Power generation and the production of cement, steel, and chemicals emit carbon dioxide along with several other gases. Membranes and solvents are the most advance technologies to separate and capture CO_2 from the other emissions. When membranes and solvents are used to separate CO_2 after combustion has taken place, the method is called post-combustion (see example in Box 1 below). It is called pre-combustion if separation occurs before the fuel is burned (see H2H Saltend example in Box 2 below).

An additional carbon capture technology, oxyfuel, involves the use of oxygen rather than air in the combustion process in sealed boilers or gas turbines, which helps separate the CO_2 stream from the other gases. Holcim is considering oxyfuel to produce low-carbon cement, as illustrated in Box 3 below. Fuel cells are in pilot stage to capture carbon today, as shown in the Box 4 below. Fuel cells perform a combustion-like reaction to generate electricity while keeping the CO_2 stream separate from the fuel.

Post-combustion typically requires less alterations and physical space for the added equipment than pre-combustion and oxyfuel. Therefore, post-combustion can better help retrofit existing facilities[18]. The table below outlines the typical application of each across industries.

Table 1. Four Types of Carbon Capturing Technologies

Method	Technology	Description	Outputs	Typical applications[19]
Pre-combustion	Solvents and membranes	Conversion of a fossil fuel into hydrogen and CO_2 before combustion process	CO_2 and Hydrogen	Production of hydrogen
Post-combustion	Solvents and membranes	CO_2 removal from the flue gases resulting from fossil fuels combustion	CO_2 and Nitrogen	Power and industrials
Oxyfuel	Boilers and gas turbines	CO_2 released from burning fossil fuels with nearly pure oxygen	CO_2 and Steam	Power
Fuel cells	Fuel cells	Combustion-like reaction that generates electricity while keeping the CO_2 stream separate from the fuel	CO_2 and electricity	Pilots conducted in power and industrials

Source: HSBC and Global CCS Institute

[18] BEIS. 2018. Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology. Literature Review
[19] Consultation with experts of the Global CCS Institute. August 2020

Box 1
Capturing CO_2 from Bioenergy Power Generation through Post-Combustion[20]

- The company C-Capture is piloting its solvent materials for carbon capturing in Drax's bionenergy power generation plant in North Yorkshire. The solvents capture CO_2 through post-combustion.
- The pilot aims to improve process efficiency to reduce carbon capturing costs to achieve commercial scale. By adopting carbon capturing technologies, Drax aim to become the first negative emissions power station in the 2020s.
- The UK's CCUS Innovation Programme of the Business, Energy and Industrial Strategy (BEIS) has provided grant support for process design development.

Box 2
Pre-combustion CO_2 Capture in Hydrogen Production - Humber Saltend (H2H Saltend)[21]

- Equinor is leading the development of H2H Saltend, the largest plant in the UK to convert natural gas to hydrogen with zero emissions.
- The plant is located in the Humber region, the largest industrial source of carbon emissions in the country. The Humber region is close to the Endurance aquifer, a well understood geological formation that offers significant potential to store carbon. Both the concentration of large emitters in the same region as well as the proximity to a large storage site could create important opportunities to minimise costs and delays in deployment[22].
- It will use pre-combustion carbon capture technologies to address emissions in the conversion of natural gas into hydrogen.
- Industrial players in the Humber region will have access to important hydrogen resources to achieve deep decarbonisation. The largest emitters in the region plan to become carbon neutral by 2040.

Box 3
Lower-carbon Cement Production in Lägerdorf Plant through Oxyfuel[23]

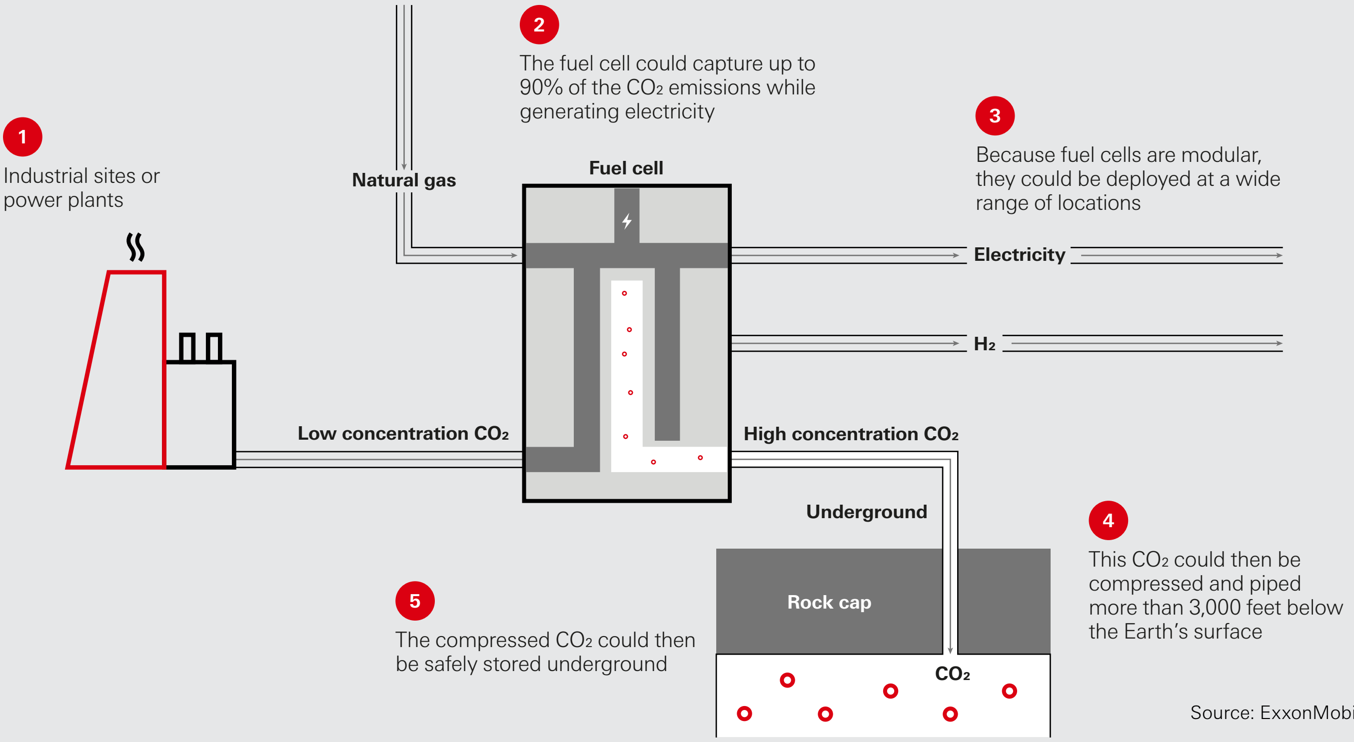
- Westküste 100 is a cross-industry partnership to produce green hydrogen, sustainable fuels and construction materials in Schleswig-Holstein, Germany. Holcim, the cement producer, is one of the partners along with several energy and heavy industrial companies.
- Oxygen arising from the production of green hydrogen in the industrial cluster will be used by Holcim to capture carbon in cement manufacturing through oxyfuel. Green hydrogen is produced through electrolysis, a process where electricity breaks the molecule of water into hydrogen and oxygen.
- With oxyfuel, the combustion process for cement manufacturing will burn the fuel using pure oxygen instead of air, which will help separate and capture the associated CO_2.
- The carbon captured will be used by a different partner in the industrial hub to produce methanol. This project is still in feasibility stage and could potentially save up approx. $1MtCO_2/y$.

Box 4
Capturing Carbon through Fuel Cells[24]

- ExxonMobil and FuelCell Energy have partnered to test fuel cells carbon capture technologies to reduce emissions in power and industrial facilities.
- The flue gas stream of gas-fired power plants is fed into the fuel cells, which separate CO_2 while producing electricity (see Figure 3).
- The process has significantly higher efficiency than other carbon capture technologies and could also boost production output.
- The companies are currently testing ways to improve integration of fuel cells with existing facilities and developing strategies to facilitate commercial deployment.

[20] C-Capture Website (https://www.c-capture.co.uk/); and BEIS. 2020. CCUS Innovation Programme: Selected Projects
[21] Equinor. 2020. News: Plan for world-leading clean hydrogen plant in the UK
[22] Equinor. 2020. H2H Saltend. The First Step to a Zero Carbon Humber
[23] Westkueste100. Project Website: https://www.westkueste100.de/en/
[24] ExxonMobil. 2020 Energy & Carbon Summary

Figure 3. Fuel Cell Technology for Carbon Capture



Source: ExxonMobil

Cost Considerations

An important factor driving capture costs is the concentration of CO_2 in the gases being emitted from power and industrial processes. Lower concentrations of CO_2 require more complex processes to separate carbon dioxide from the other gases, which typically result in higher costs. For example, steel and cement show the lowest concentration of CO_2 (<30%) and the highest capture costs (>USD$60/t$CO_2$) relatively to bioethanol (around 98% CO_2 concentration and max. USD$35/t$CO_2$). The table below outlines CO_2 concentration and carbon capture costs across different sources.

Table 2. CO2 Concentration and Carbon Capture Cost per Type of Activity

CO2 source	CO2 concentration (%)	Capture cost (USD$ / tCO_2)
Bioethanol	98-100	25-35
Ethylene oxide	98-100	25-35
Syngas (hydrogen and CO)	30-100	15—60
Ammonia	98-100	25-35
Iron & Steel	21-27	60-100
Cement	15-30	60-120

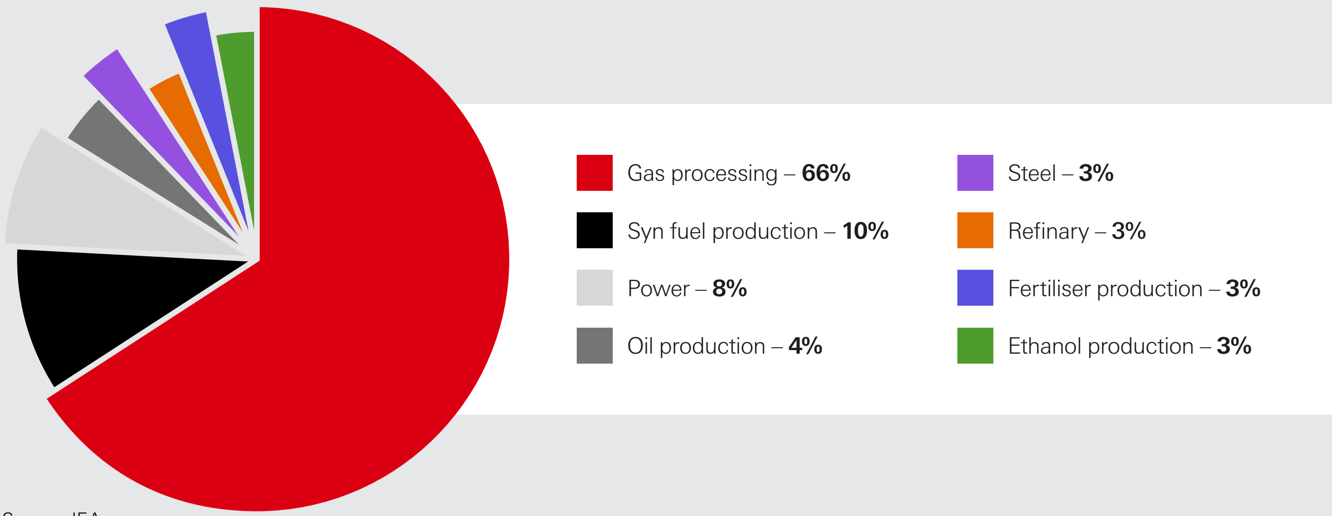
Source: IEA

Commercial scale of carbon capturing has been achieved mostly in activities that generate gases with high concentration of CO_2. This is because of the relatively lower costs of separating CO_2 from the other gases. The activities include gas processing, synfuel production (i.e. hydrogen production from fossil fuels), and ethanol involving fermentation of biomass (see Figure 4 below), which together account for 84% of capturing capacity, according to the IEA[25].

Moving forward, the expansion of capture capacity of approx. 70-100 facilities every year that the Global CCS Institute estimate for Paris goals, will address economy wide emissions. Therefore, achieving costs reductions in capturing carbon from activities like steel and cement, will be instrumental to facilitate the uptake of the technology. Major CCUS hubs are already underway in Europe to make more cost effective carbon capturing across different industries. Examples include the Porthos Carbon Capture and Storage project in the Netherlands (in advanced development) and the Net Zero Teesside in the United Kingdom (in early stage of development). These plan to capture carbon from activities with both low and high- carbon concentration.

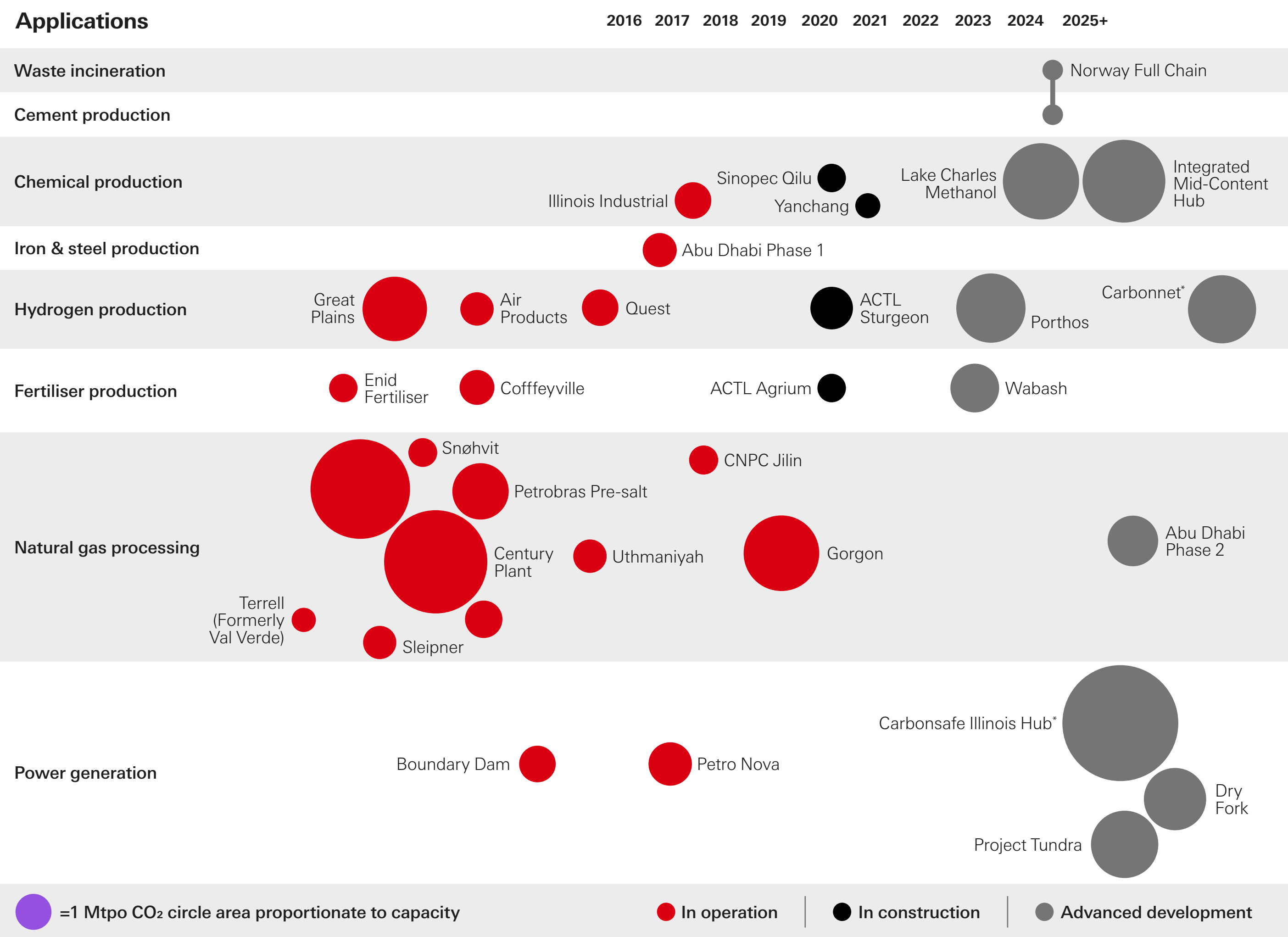
[25] IEA. 2019. Transforming Industry through CCUS.

Figure 4. 84% of Carbon Capture Projects Relate to Activities that Generate Gases with High Concentration of CO_2



Source: IEA

Figure 5. Large-Scale CCUS Facilities in Operation, Construction, and Advanced Development



Source: Global CCS Institute

Transporting carbon

Carbon dioxide can be transported through pipelines, ships or trucks. Volume and distance between the sources and storage site or carbon usage facility are the main factors driving the choice for transport method. While pipelines and ships are typically the most adequate option for large volumes of carbon dioxide, trucks are often used to transport smaller volumes. Short distances are often covered by trucks. Projects proposed in Korea and Norway are considering transporting carbon through ships and pipelines due to the long distance between the capture and storage locations[26].

Pipelines are the dominant method and have shown excellent safety and reliability performance. The current 21 large scale CCUS projects transport carbon through a network of pipelines exceeding 6,500km globally[27]. To meet Paris goals, 200,000km of pipeline capacity by 2050 could be required to support CCS facilities, according to the Global CCS Institute. This implies around 5,200-7,200km between new and repurposed pipeline capacity coming in operation every year till 2050. Repurposing oil and gas pipelines for transporting CO2 is possible where technical suitability and integrity requirements are satisfied. This would allow to save emissions from building new infrastructure, which can be a concern for larger pipeline expansion plans (e.g. over 500km).

In recent years, an increasing number of CCUS projects in the pipeline achieve economies of scale by having several high carbon emitters like steel, cement, and energy companies share a network of pipelines to transport CO_2. This setting aims to lower costs and commercial risks of deployment. It also aims to benefit the development cycle of carbon capturing projects that come along later as they would find a rapid connection to storage locations or buyers of carbon for feedstock[28]. Part 3 further discusses examples of this arrangement.

Box 5. Acorn CCUS Project: Repurposing Gas Pipelines for Transporting CO_2 in the UK[29]

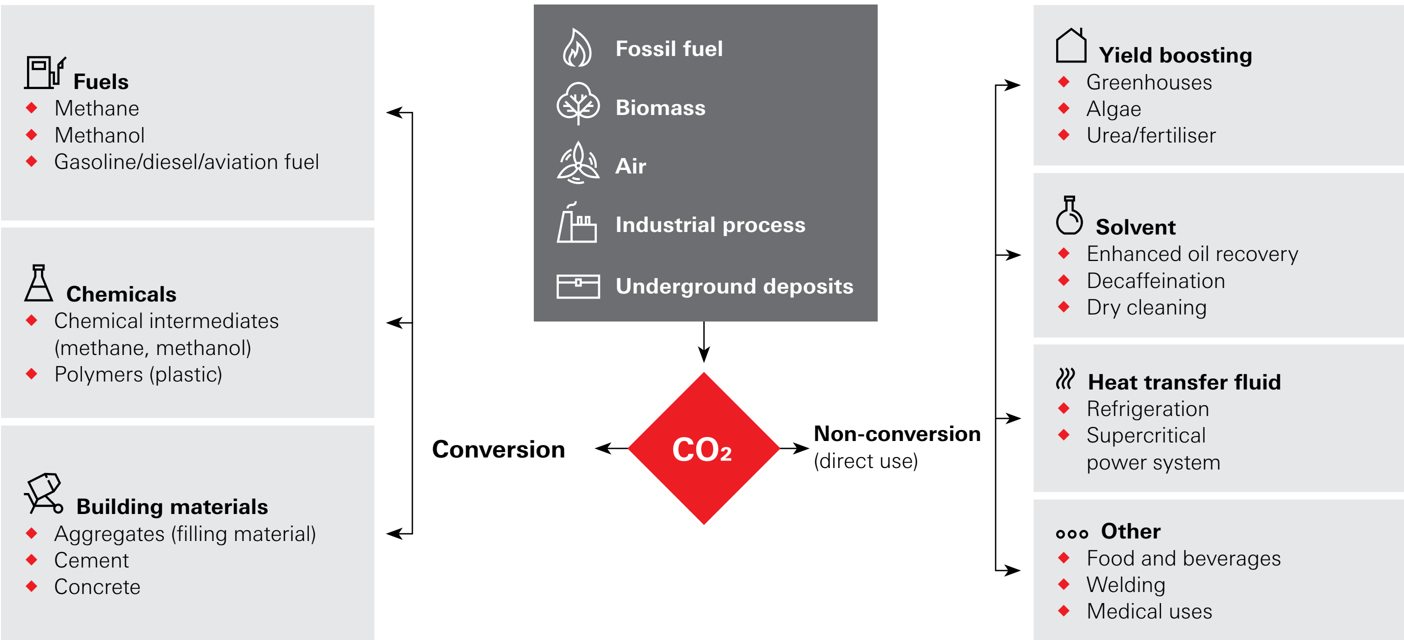
- Acorn CCUS project entails the repurposing of existing offshore gas pipelines connecting large emitters in Scotland to the North Sea Basin, where there is the largest carbon storage potential in the region.
- The aim is to make the best use of existing infrastructure in the UK and initiate carbon capture at a lower cost. Repurposing pipelines is likely to yield more than £750 million in cost savings[30].
- Pipelines will serve other carbon capturing projects including Acorn Hydrogen Production[31].
- UK government support for engineering studies is in progress through the CCUS Innovation Programme of the Business, Energy and Industrial Strategy (BEIS). A final investment decision is expected in 2021.

[26] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[27] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[28] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[29] BEIS. 2020. CCUS Innovation Programme: Selected Projects
[30] The Acorn CCS Project. Website. https://theacornproject.uk/
[31] The Acorn CCS Project. Website. https://theacornproject.uk/about/#hydrogen

Carbon use

Carbon can also be used directly as a feedstock in a wide range of production processes, such as the production of fertilisers, welding metals, and cooling of food and beverages. Other industrial processes involve the conversion of carbon dioxide from its pure form, including the production of construction materials, fuels, and chemicals.

Figure 6. – Pathways for CO_2 Use and Range of CO_2-derived products[32]



Source: IEA

The direct use of carbon has reached commercial scale and represents approximately 150MtCO_2/year, roughly 3x the size of annual emissions in Switzerland[33]. However, they typically only allow to retain carbon for less than a year. In turn, CO_2-derived products involving the conversion of carbon are the most relevant for addressing climate change as they can store carbon for longer. For example, fuels can retain carbon for about one year, chemicals for up to 10 years, and building materials for millions of years[34]. Nonetheless, they have not achieved commercial maturity yet.

For carbon usage to support emissions reductions at scale, CO_2-derived products that sequestrate carbon for longer should achieve commercial maturity rapidly. For example, new regulation favouring lower-carbon construction materials would be needed to create adequate demand for these products.

The table below elaborates on the barriers to commercial viability as well as the potential enablers. Relatively to conventional products, CO_2-derived construction materials could be less energy intensive and could have superior performance. In turn, CO_2-derived chemicals and fuels face higher production costs compared to incumbent products. Fuels are still being tested against industry standards.

[32] Carbon sources include fossil fuels, biomass and direct air capture. A zero emissions energy system would require that carbon dioxide comes from these last two sources.
[33] Climate Action Tracker. Country Summary: Switzerland
[34] IEA. 2019. Putting CO_2 to Use. Creating Value from Emissions

Table 3. Opportunities with Carbon Utilisation

CO_2 pathway	Selected CO_2-derived products[35]		Product maturity; market enablers / barriers
Direct use	Urea – fertilizers	Carbon is combined with ammonia in the production of urea	Commercial scale achieved
	Beverages & Food	Carbon used to cool food and beverages (e.g. dry ice)	
	Welding	High purity carbon dioxide is used in welding	
	Crop yield boosting	Often involving the application of CO_2 with low-temperature heat in industrial greenhouses, which can increase yields by 25-30% E.g. algae production and crop cultivation in greenhouses	Pilot stage. The market is limited in nature Increased revenues because of higher crop yields
Conversion	Chemicals	Replacement of fossil fuels with CO_2 as a raw material for the production of chemicals E.g. fibres, synthetic rubber, aromatics, and polymers for the production of plastics, foams and resins	Pilot stage Production costs higher than counter-parts, being hydrogen and electricity the largest costs Cost reductions possible in markets with lower electricity costs and vast CO_2 sources. E.g. North Africa, Chile and Iceland for fuels Carbon-based fuels still being tested against industry standards
	Fuels	Combination of CO_2 and hydrogen to produce a fuel that is easier to handle and use than pure hydrogen. E.g. methanol and methane Most relevant where power from electricity or hydrogen is extremely challenging, like in aviation	
	Construction materials	CO_2 curing: CO_2 replaces water in concrete production CO_2 reacting with minerals or waste streams, such as iron slag, to form carbonates for building materials (e.g. cement and concrete)	Pilot stage Production typically show lower energy requirement relatively to other CO_2-derived products Concrete: superior performance and lower cost than conventional products New regulation can be introduced to accelerate the uptakes

Source: HSBC and Global CCS Institute

In absence of commercial barriers and infrastructure constrains, production of carbon-derived fuels can reach more than 5GtCO_2 annually. This compares with 1-5GtCO_2 a year for either chemicals or concrete, according to the IEA. However, projections by the IEA suggest that market and physical obstacles would limit the contribution of carbon-derived products to the order of the million tonnes a year[36]. Carbon use accounts for 7% of the 115GtCO_2 reduced through CCUS between 2018 and 2060 for Paris goals in IEA estimates. The rest (93%) will be stored underground[37]. Geological storage is discussed next.

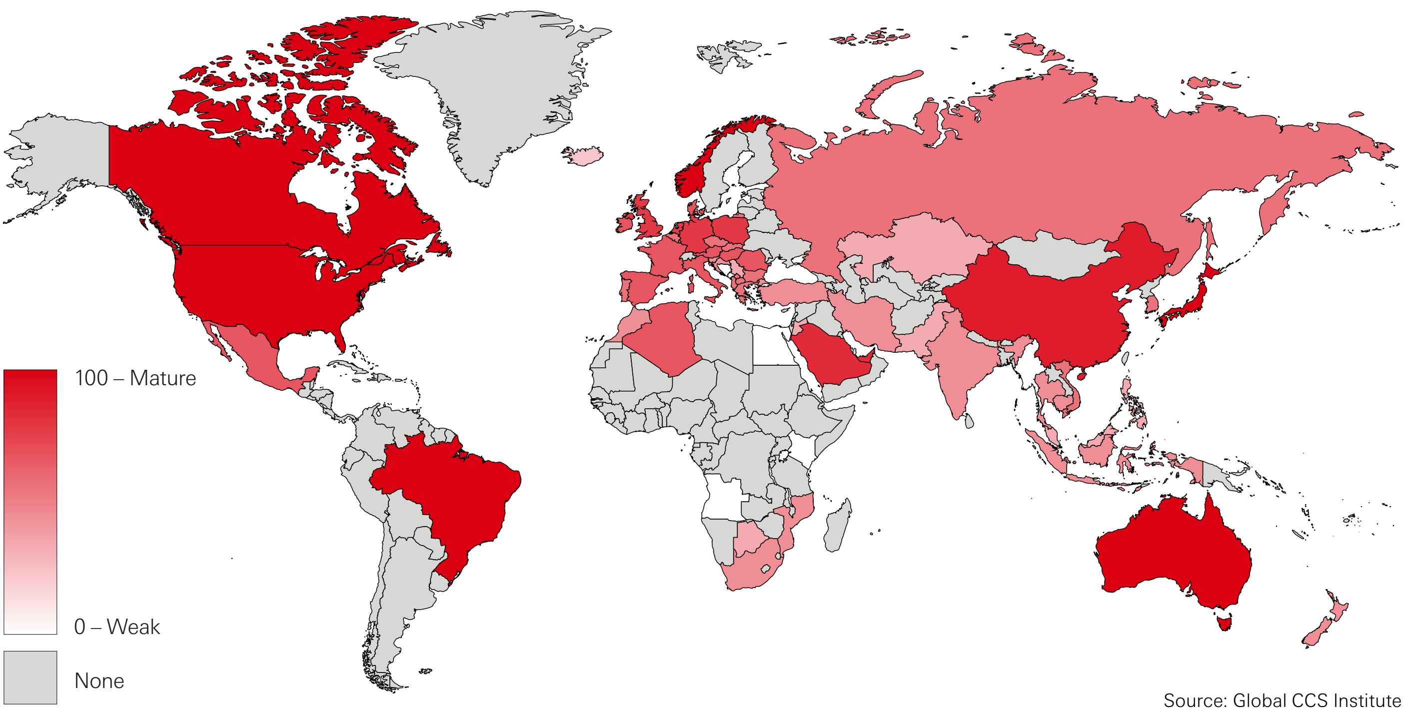
[35] Others matured CO_2-derived products include: cooling, fire suppression.
[36] IEA. 2019. Putting CO_2 to Use. Creating Value from Emissions
[37] IEA. 2019. The Role of CO_2 Storage

Carbon storage

Carbon dioxide can be safely stored in porous geological formations several kilometres underground. Extreme pressure and temperature conditions under the earth's surface retain carbon dioxide in liquid form, becoming less mobile over time as it mineralises with the geological formations. The IPCC estimate that 99% of carbon dioxide stored underground is likely to be retained geologically over 1000 years, and the risk of leakages decreases with the pass of time[38]. Carbon storage addresses 12% of the required emissions reductions between 2018 and 2060 for Paris goals in IEA estimates (107GtCO_2)[39]. This would entail the development of between 10-30 new storage facilities a year by 2050, according to the Global CCS Institute[40].

Storage capacity greatly depends on natural conditions. The Global CCS Institute has developed a scoring system to measure the potential for developing new storage capacity across 80 countries. The scores are based on (i) the natural geological storage potential; (ii) maturity and confidence of scientific data; and (iii) past tracked record with CO_2 storage. The heat map below summarises the Institute's latest analysis of storage potential. The top 12 countries together can develop hundreds of billions of tonnes of CO_2 in storing capacity.

Figure 7. 2018 Storage Indicator Heat Map[41]



Source: Global CCS Institute

[38] IPCC. 2005. Carbon Dioxide Capture and Storage. Special Report
[39] IEA. 2019. The Role of CO_2 Storage
[40] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[41] Highest scoring 12 nations: Norway, Canada, United States, China, Australia, Brazil, United Arab Emirates, Saudi Arabia, United Kingdom, Netherlands, Germany, and Japan

Norway, USA and the UK have the most advanced portfolio of commercially viable storage facilities. These often benefit from some sort of stable government support to cover for appraisal and feasibility studies, which can spin several decades[42]. For example, suitability studies funded by the UK government and published in 2015 and 2016 built important knowledge of the CO_2 storage sites for the Acorn CCS project. Acorn CCS project will capture CO_2 from natural gas conversion into hydrogen and storage it permanently in the North Sea. Acorn's storage site is the first to be awarded the CO_2 appraisal and storage license by the UK Oil and Gas Authority[43]. Government support will continue to be fundamental to further develop new storing capacity[44].

Carbon can also be stored in empty oil and gas fields, in which case appraisal costs are typically lower because there is geological data available for the site. An example is the Porthos CCS project in the Netherlands, which could store 2 to 2.5 million tonnes of CO_2 per year in an empty gas field 3km beneath the North Sea seabed[45]. Furthermore, carbon has been injected and stored in depleting oil and gas fields for boosting production output for over 30 years in a process called Enhanced Oil Recovery (EOR). EOR stores approx. 70-80 Mt CO_2 a year today[46], which is equivalent to Kenya's annual carbon emissions[47].

The components of the CCUS technology chain, meaning carbon capture, transport, use and storage, need to be integrated fully. Achieving economies of scale will increase the chances for CCUS to become a cost effective decarbonisation solution. This means carbon being captured from large emitters and transported to sites where a significant volume of carbon can be stored or used.

Part 2 looks at the CCUS applications across sectors in alignment with the Paris Agreement.

[42] Global CCS Institute. 2018 Review. CCS Storage Indicator.
[43] Pale Blu Dot. Acorn CCS Project. Website. https://pale-blu.com/acorn/ and UK Government. 2016. Carbon Capture and Storage knowledge sharing
[44] Global CCS Institute. 2018 Review. CCS Storage Indicator.
[45] Rotterdam CCUS. Website. https://www.rotterdamccus.nl/en/
[46] IEA. 2019. Putting CO_2 to Use. Creating Value from Emissions
[47] Climate Action Tracker. Country Summary. Kenya

Part 2 - Paris Alignment of High-Energy Sectors through CCUS Applications

Paris Alignment Considerations

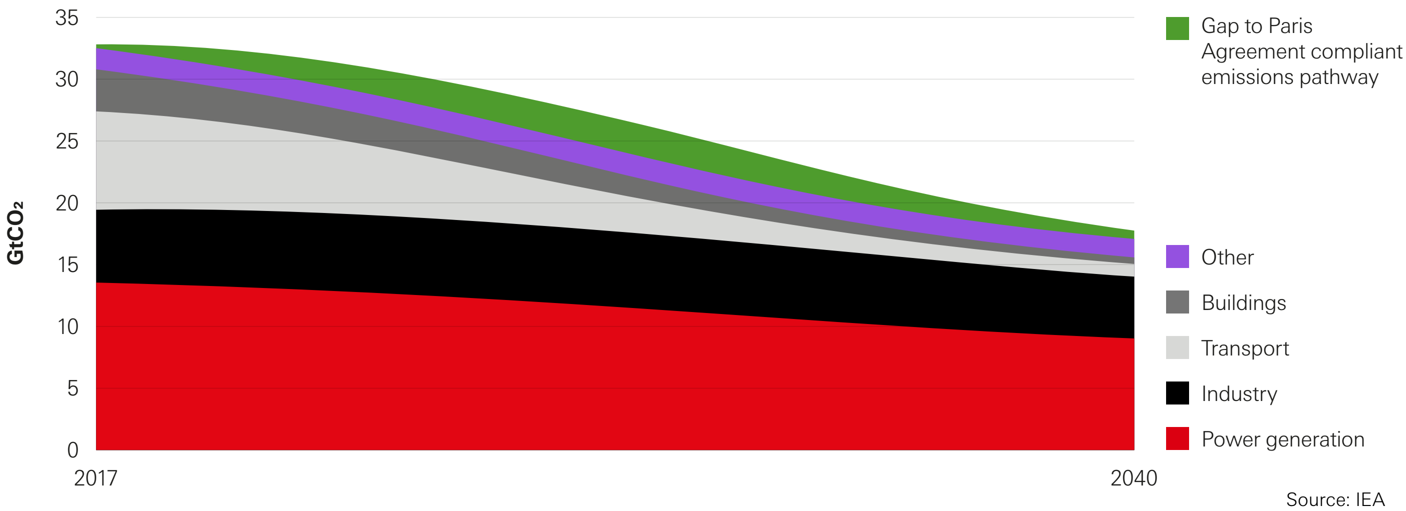
An important number of CCUS applications relate to fossil fuels and hence, they are perceived to prolong the use of carbon intensive activities rather than providing an absolute emission reduction outcome. This is because of the lower costs to capture CO_2 from burning fossil fuels[48] and the use of carbon to increase output in depleting oil & gas fields through EOR[49], which accounts for nearly three-quarters of CCS projects revenues[50].

However, evidence presented by IEA suggests that CCUS is in the mix of technologies that can be used to limit global warming to 1.5ºC in alignment with Paris. The IEA estimate that carbon capture technologies can address around 115GtCO_2 between 2018 and 2060, which is 13% of all emissions required to meet Paris goals in the period. Carbon capture would only come after energy efficiency and renewables, which account for 39% and 36% of the mitigation potential, respectively[51].

The IEA point to the applications of CCUS to overcome challenges related to carbon lock-in of existing infrastructure in power and industrials. Carbon lock-in relates to the sustained support to carbon intensive activities over lower-carbon alternatives owing to a blend of technical, economic, and institutional factors, which would restrict the transition to a net zero carbon future[52].

IEA projections of carbon emissions of current and planned infrastructure across sectors between 2017 and 2040 suggest that power and industry face the highest lock-in risk. They would absorb nearly 95% of the cumulative CO_2 emissions allowances for Paris goals for the period (see Figure 8 below). This means that significant changes to the infrastructure stock in these industries are needed for their alignment with Paris. As explained in this section, CCUS stands as a viable solution to address emissions in these industries[53].

Figure 8. Existing and Planned Power and Industrial Infrastructure Already Locking in 95% of CO_2 Emissions Allowable for a Future Aligned with Paris



Source: IEA

[48] As explained in the previous chapter, gases from burning fossil fuels mostly contain CO_2 with a negligible portion of other components, requiring simpler and cheaper carbon capture processes.
[49] Global CCS Institute. 2019. Carbon Capture and Storage: Global Status Report 2019. And BEIS.2018 Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology. Literature review
[50] IEA. 2018. Unlock CCS Investment.
[51] IEA. 2019. The Role of CO_2 Storage
[52] EU Technical Expert Group on Sustainable Finance. 2020. Technical Report. Taxonomy: Final Report of the Expert Group on Sustainable Finance.
[53] IEA. 2019. Transforming Industry through CCUS

An increasing number of governments including Norway, The United Kingdom, USA, Canada, China, Japan, the Netherlands, and Denmark have recognised the potential for CCUS technologies to address carbon emissions. These countries have, or are in the process of establishing supportive policy to facilitate its deployment. In these countries, the emphasis is on the potential for CCUS to cut emissions in absolute terms without further deliberation around whether CCUS contributes to carbon neutrality in alignment with Paris goals.

For example, section 45Q of the USA Federal Tax Code grants tax credits to projects that permanently store carbon either through EOR or geological sequestration. The carbon sources could include economic activities involving coal, oil, industrial processes, etc. The tax credit support dates from 2008 and was increased in 2018 to USD$35/t$CO_2$ for EOR and USD$50/t$CO_2$ for geological sequestration. To be eligible, facilities should be under construction no later than 1 January 2024. The tax credits provide a stable and predictable value to the carbon being stored, aiming to reduce the costs associated with capturing and storing CO_2. Through this incentive, the USA federal government recognises the contribution these technologies have to address carbon emissions.

The European Commission in early 2020 provided guidance around the contribution of CCUS to carbon neutrality. This is as part of the work by the Technical Working Group (TEG), the advisory group for Sustainable Finance of the European Commission, for developing a taxonomy of sustainable activities that can deliver carbon neutrality across key sectors, a.k.a. EU taxonomy. The EU Taxonomy aims to accelerate the pace at which financial institutions and corporates embrace sustainable activities by requiring disclosure of where they stand in terms of transitioning to a carbon neutral, resilient, and resource-efficient economy. Disclosure for climate change mitigation and adaptation are scheduled to start from 2022 onwards. Areas for future disclosure include water, circular economy, pollution control and prevention, and biodiversity.

The EU Taxonomy sets technical criteria per each component of the CCUS technology chain as shown in Table 4.

Table 4. EU Taxonomy Mitigation Criteria for CCUS

CCUS Chain Component	Technical criteria
Carbon Capture	Carbon capture technologies enable an economic activity like power generation and the production of hydrogen, steel, cement, and chemicals to operate within the allowed carbon intensity threshold. Thresholds vary depending on the industry (see Table 5 below).
Carbon Transport	CO_2 leakage of carbon transport methods are limited to <0.5%.
Carbon Storage	Carbon sequestration sites comply with internationally recognised standards (i.e. ISO 27914:2017).

Source: EU Taxonomy – Technical Annex

[54] Global CCS Institute. 2019. Carbon Capture and Storage: Global Status Report 2019.

For carbon capture to comply with the EU Taxonomy, its application should enable an economic activity to perform within a determined carbon intensity threshold (see Table 5 below). The thresholds help to assess whether the economic activity is making a substantial contribution to climate change mitigation in accordance with a carbon neutral outcome by 2050. The thresholds match the 10% best performers within an industry and are adjusted downwards every five years. These thresholds are also used in the EU Emissions Trading System (ETS), the largest carbon market in the world[55].

For example, a French producer of primary steel[56] operating at 1.48 tCO_2/t of output, which is near the country's average for steel manufacturing[57], is outside the carbon intensity threshold of <1.328 tCO_2e/t of steel set by the EU Taxonomy and hence, it would not be able to claim compliance. The steel maker might take a loan to finance the installation of carbon capture and other mitigation technologies to improve its carbon performance. Once it performs within the threshold, it will be able to claim compliance with the EU climate mitigation criteria. The steel maker's lender could also claim compliance for the respective portion of the balance sheet the loan represents.

Table 5. CCUS Can Help High Energy Sectors Achieve Compliance with EU Taxonomy Carbon Intensity Thresholds Sectors[58]

Sector	EU Taxonomy Threshold[59]
Steel	Primary steel: depending on the technology, threshold ranges between 0.283-1.328 tCO_2e/t of steel Secondary steel: no threshold for electric arc furnace (EAF) where a min. of 90% output is from scrap
Cement	Cement production: <0.498 tCO_2e/t of cement Clinker production: <0.766 tCO_2e/t of clinker
Organic[60] and Inorganic chemicals[61]	Carbon black: 1.954 tCO_2e/t Soda ash: 0.843 tCO_2e/t Chlorine: carbon intensity of power is <100gCO_2e/kWh. Carbon intensity of chlorine production <2.45 MWh/t of chlorine High Volume Chemicals: 0.702 tCO_2e/t Aromatics: 0.0295 tCO_2e/t216 Vinyl chloride: 0.204 tCO_2e/t Styrene: 0.527 tCO_2e/t Ethylene oxide/ethylene glycols: 0.512 tCO_2e/t
Chemicals - Fertilisers	Nitric acid: 0.302 tCO_2e/t Ammonia: scope 1 emissions <1tCO_2/t ; and scope 1-2 emissions <1.3tCO_2/t
Power - Natural gas and bioenergy (i.e. biomass, biogas and biofuels)[62]	<100gCO_2e/kWh, declining to 0gCO_2e/kWh by 2050

Source: EU Taxonomy – Technical Annex

[55] The ETS operates according to the cap and trade principle. Carbon emissions of facilities in key sectors are capped at certain level, which decreases every year. Players exceeding the cap should buy credits in the carbon market to avoid pecuniary penalties.
[56] Explanation of primary and secondary steel production in Steel sub-section below.
[57] CE Delft. 2018. Carbon Intensities of Energy-intensive Industries. A Top-down Country Comparison
[58] This report presents a summary of carbon intensity thresholds set in the EU Taxonomy. For the full list of technical criteria for Paris alignment consult the Taxonomy Report: Technical Annex. 2020. EU Technical Expert Group on Sustainable Finance
[59] The EU Taxonomy relies on the thresholds set for the EU Emissions Trading Scheme (ETS). The thresholds reflect the average performance of the 10% most efficient installations in a sector in Europe. Thresholds will be reduced every 5 years in line with a net-zero CO_2e in 2050 trajectory. Along with meeting climate mitigation technical criteria, activities should also demonstrate they avoid significant harm to other environmental objectives and observe social safeguards (e.g. climate adaptation, depletion of water resources, air pollution control, human rights, etc.).
[60] Uses of these chemicals include the production of polyester fibres, packaging, resins, antifreezes, and glue, among many others.
[61] Attributes of inorganic chemicals include catalysis, reactive chemistry, and conductivity. They are widely used to produce semiconductors, fuels, coating, pigmentation, and medicine, among others.
[62] The EU Taxonomy highlights the following tools / frameworks to show compliance ISO 14067 and GHG Protocol Lifecycle Standard Complaint Product Carbon Footprint

The EU taxonomy excludes CCUS applications that undermine climate change mitigation objectives when considering life-cycle emissions. A life-cycle emissions assessment looks at the emissions associated with the full value chain of an economic activity, including upstream and downstream. For example, the assessment would consider the emissions from producing cement as well as the emissions associated with the inputs to this industrial process (upstream) and the use of cement in construction (downstream). It would also consider the carbon intensity of transporting and storing CO_2 associated with cement production.

When accounting life-cycle emissions, the EU Taxonomy highlights the use of CCUS technologies in heavy industrials in which switching to renewables alone does not facilitate a deep decarbonisation. In power, carbon capture would allow generation sources that guarantee flexible, year-round electricity, like natural gas, to be fully decarbonised. In turn, EOR and CCUS applications involving coal would not meet the thresholds and are then incompatible with sustainable activities in the context of the EU taxonomy.

While the EU taxonomy stands as the most advance effort to assess the contribution of an economic activity to carbon neutrality, it is still too early to convey how effective it will be both within the EU and beyond. Other regions might build on it or develop a different approach.

Table 6. EU Taxonomy Climate Mitigation Criteria for Hydrogen Production

Production process	EU Taxonomy Threshold
Fossil fuel reforming	Hydrogen production: <5.8tCO_2e/t of hydrogen Power: <100gCO_2e/kWh
Electrolysis	Power: <58MWh/t of hydrogen

Source: EU Taxonomy – Technical Annex

Box 6.
EU Taxonomy Sets Carbon Intensity Thresholds for Hydrogen Production

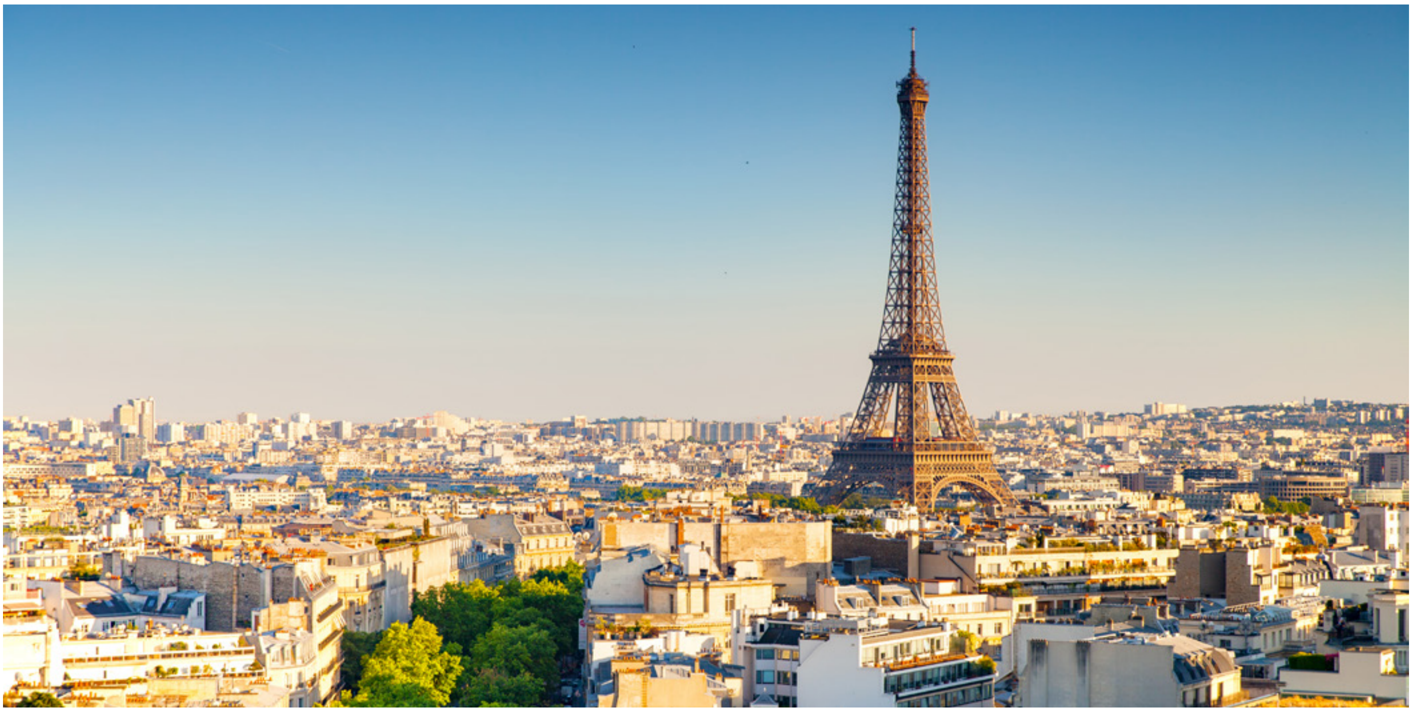
In IPCC and IEA scenarios, hydrogen is expected to have an important role in decarbonising the energy system. Like natural gas, hydrogen can be used to heat homes, power industrial processes, and produce flexible electricity. Unlike natural gas, hydrogen does not emit carbon when burned.

However, hydrogen can have a large carbon footprint when considering life-cycle emissions. 96% of global hydrogen production at industrial scale currently involves reforming natural gas (48%), liquid hydrocarbon (30%), and coal (18%), largely with unabated carbon emissions. If produced through electrolysis, a process where electricity breaks the molecule of water into hydrogen and oxygen, hydrogen can have high indirect emissions when the production process is powered with high carbon electricity. Electrolysis accounts for 0.1% of hydrogen production.

Carbon capture technologies can facilitate the alignment of hydrogen production with a carbon neutral outcome. For example, carbon capture can help meet the carbon intensity thresholds set by the EU taxonomy, which considers the life-cycle emissions of hydrogen production to assess its contribution to carbon neutrality. See EU Taxonomy thresholds for hydrogen in Table 6.

Hydrogen production from fossil fuels is currently at USD$1/kg of hydrogen in the USA vs. USD$1.7/kg of hydrogen in Europe. The abatement cost would add around USD$0.5/kg of hydrogen, according to the IEA. The additional cost of mitigating emissions in power generation for electrolysis would greatly vary across geography. The average cost of hydrogen through electrolysis without abatement measures is USD$3-7.5/kg of hydrogen[63].

[63] IEA. 2019. The Future of Hydrogen



Box 7. Considerations for Paris Alignment of CO_2-derived Products

The use of carbon to produce fuels, chemicals, and construction materials are the most relevant in the context of climate change because they can store CO_2 for longer. For example, fuels can retain carbon for about one year, chemicals for up to 10 years, and building materials for millions of years. Table 7 below provides additional considerations that the IEA set out for Paris alignment of these products[64].

CCUS Applications for Paris Goals

The following pages outlines how CCUS technologies can help achieve carbon neutrality in steel, cement, chemicals and power (natural gas and bioenergy). The paper focuses on these industries for three main reasons:

- They represent significant sources of emissions with the highest lock in risk (see carbon emissions for each industry in Table 8 below and lock in risk in Figure 8 above).
- CCUS applications offer significant carbon mitigation potential for both process and energy related emissions.
- Demand for products in these industries will grow but additional carbon mitigation actions are required to ensure their alignment with a carbon neutral outcome by 2050.

Table 7. IEA Guidance on Paris Alignment of CO_2-derived Products

Consideration	Description	Examples of Paris Alignment
Transitioning to less carbon intensive sources	Fossil fuels are the most prominent source of carbon for the production of CO_2-derived products. In the long-run, bioenergy and direct air capture are expected to be the majors sources to achieve a net zero emissions outcome across the energy system.	Production of construction materials from waste would be aligned with Paris if more carbon is being sequestrated in the products than emitted during the manufacturing process. Carbon9 is a company advancing this technology.
Facilitating the adoption of products with smaller carbon footprint	Carbon-derived products displace products with higher life-cycle emissions. This is considering direct (e.g. manufacturing related emissions) and indirect emissions (e.g. emissions from the electricity use in manufacturing).	CO_2-derived methanol and methane powered with low-carbon electricity, could reduce emissions by up to 74%-93% and 54%-87%, respectively relatively to conventional production routes.
Achieving industrial scale	CO_2-dervied products that are the most relevant to solve climate have not achieved industrial scale. This can change with favourable regulation and growing demand for CO_2-derived products.	Construction codes adopting performance-based standards can support the uptake CO_2-derived construction materials at scale.

Source: IEA

[64] IEA. 2019. Putting CO_2 to Use. Creating Value from Emissions

Table 8. CCUS Is Instrumental to Achieve Net Zero Emissions of Heavy Industries and Flexible Power Generation in Alignment with Paris

Industry	% of CO_2 global energy emissions[65]	Decarbonisation potential via CCUS[51]	CCUS Applications for Paris goals
Steel	7%	60-90% reduction in total emissions	Expected demand increases to support economic growth Meeting increased demand in the near and mid-term (not earlier than 2050) comes from primary steel, which is more carbon intensive CCUS can address both process and heat emissions in primary steel production
Cement	7%	90% of process and heat emissions	Rapid urbanisation is driving demand for cement Deep decarbonisation not possible through fuel shift only as process emissions account for over 50% of total. CCUS can address both process and heat emissions
Chemicals	3-4%	38% of total emissions	Demand for chemicals expected to grow by 40% by 2060 Higher CO_2 volume is more economic to apply carbon capture technologies
Power – natural gas and bioenergy	39%[66]	90-99% reduction in total emissions	Natural gas and bioenergy are likely to be needed for electrifying the economy in view of lower than expected penetration rates of renewables (<70% of the energy mix by 2050- IPCC) CCUS required for achieving carbon neutrality

Source: HSBC

Steel

Steel is widely used in infrastructure, construction, and manufacturing. Demand for steel has more than doubled in the last 30 years, mainly driven by economic growth and improved provision of infrastructure services in both developed and emerging countries. By 2050, global steel demand could grow from the current level of nearly 1.7bn tonnes to over 2.1bn tonnes[67]. Relative to other construction and manufacturing materials such as cement, plastics, and aluminium, steel is the only one that can be fully recycled and hence increased demand for steel can be favoured from the circular economy point of view[68].

However, Paris alignment of demand increases would be challenging as carbon is widely used to meet the substantial energy requirements in steelmaking. Indeed, steel production accounts for 7-9% of global carbon emissions and without any additional actions, demand growth will drive the industry's emissions up[69].

There are two types of steel production: i) primary steel production represents roughly 80% of total supply and mostly uses carbon in the form of coal or charcoal to process iron ore and; and ii) secondary steel production, which uses gas, biogas, or electricity to produce steel from end-of-life scrap[70]. Primary steel production is more energy intensive, being responsible for 70% of the sector's emissions, according to Energy Transitions Commission. For example, the main route for secondary steel uses Electric Arc Furnaces (EAF), which carbon intensity is 0.4tCO_2 per tonne of steel. This compares with the carbon intensity of 2.3tCO_2 per tonne of steel in Basic Oxygen Furnace (BOF), the main production process for primary steel (see Figure 9 below).

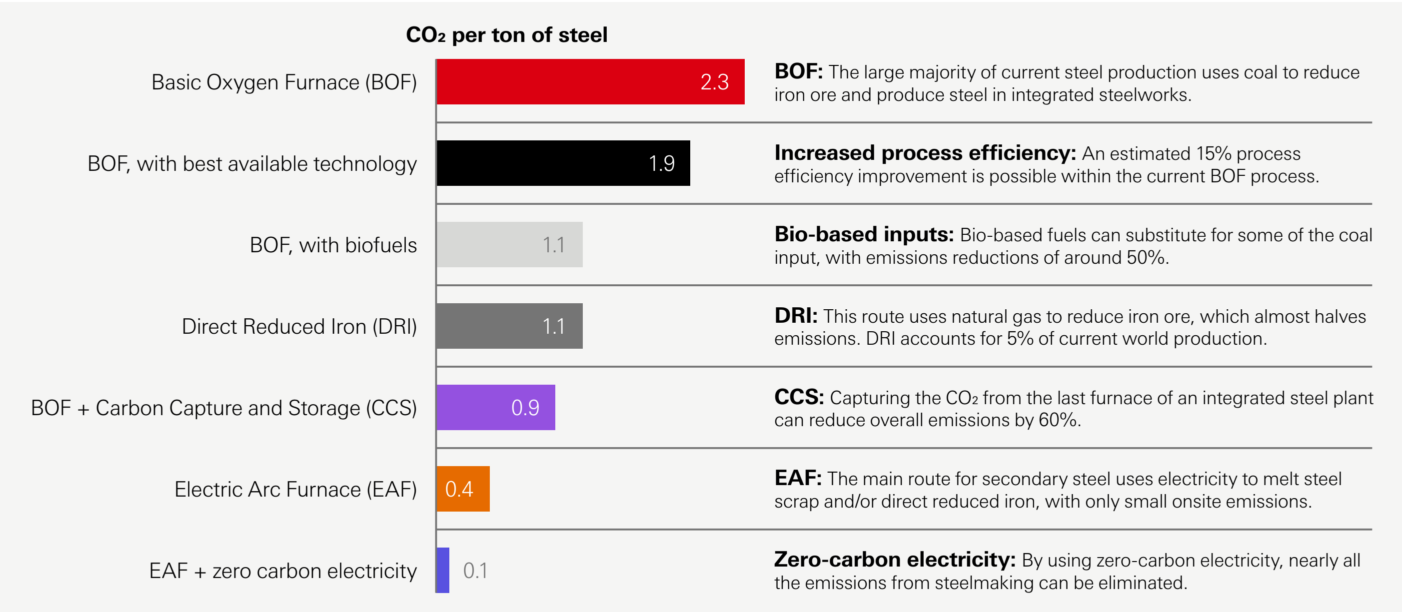
However, secondary steel today can only meet approx. 30% of total steel demand[71]. IEA scenarios suggest that in the long-term secondary steel could meet most demand, growing by 40% between 2015 and 2050. The question is how to address emissions from primary steelmaking in the near and mid-term.

The figure below from Material Economics, a well-known sustainability consultancy firm, depicts the carbon intensity of the different steel production processes and the relevant technology options to address carbon emissions. Carbon capture in conventional BOF or BOF with hydrogen as feedstock can help deliver a reduction in emissions of 60% and 90%, respectively.

Carbon capture would increase costs by around USD$66 per tonne saved, according to the ETC. These technology options are currently in pilot stages[72] and commercial projects are being increasingly being proposed in Europe (GCCSI). Technologies to increase the purity of CO_2 in conventional BOF are currently being tested, as pilots suggest that higher purity can decrease the cost of CO_2 avoided when using CCS[73].

[65] Energy Transitions Commissions. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century
[66] IEA. 2019. Transforming Industry through CCUS
[67] Energy Transitions Commission. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century. Sectoral Focus: Steel
[68] Circularity is broadly understood as the reconfiguration of production processes to minimise waste by increasing materials reutilisation and recycling or using by-products / waste to create new products.
[69] Energy Transitions Commission. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century. Sectoral Focus: Steel
[70] Centre of Sustainable Finance. 2019. Steel for the Future. The transition to responsible, zero carbon steel making
[71] Centre of Sustainable Finance. 2019. Steel for the Future. The transition to responsible, zero carbon steel making
[72] Energy Transitions Commission. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century. Sectoral Focus: Steel
[73] IEA. 2019. Transforming Industry through CCUS

Figure 9. CO_2 Intensity of Steel Production



Source: Material Economics

Cement

According to the Energy Transitions Commission (ETC), rapid urbanisation is likely to increase the demand for cement from the current level of 4.2bn tonnes/year to 4.7bn tonnes/year in 2050. This could relate to a surge in emissions from 2.2 $GtCO_2$/year today to 2.3$GtCO_2$/year by 2050 under "Business as Usual" production techniques. Up to a third of the emissions can be addressed by shifting to lower-carbon fuels like hydrogen, biomass and carbon neutral electricity. But the bulk of the sector's carbon footprint (over 50%) relates to process emissions, in which carbon is released from chemical and / or physical reactions and hence, they can't be avoided by using a different fuel. For this, carbon capturing technologies stand as the only technically feasible solution to achieve a carbon neutral outcome.

Carbon capture technologies can be adapted to existing kilns to help reduce as much as 90% of the process and heat emissions in cement, which together account for the bulk of the emissions (i.e. approx. 50% and 34% of total emissions, respectively). When combined with lower-carbon fuels like hydrogen, biomass or carbon neutral electricity, CCUS can achieve deeper decarbonisation rates[74].

Nonetheless, the implied additional cost of CCUS could amount to USD$110/$tCO_2$ captured, which compares to USD$14/$tCO_2$ in hydrogen production through methane reforming[75]. The higher costs mostly relate to the lower concentration of CO_2 in cement exhaust gas streams, as explained in part 1. Cost reductions can be achieved through economies of scale, use of oxygen instead of air in cement production (oxyfuel method), and new technologies that enhance CO_2 purity in a cost effective manner[76].

As of transport and storage costs, these would depend on the location of the facility. Cement producers can lower these costs by using the carbon captured from their operations to produce carbon-derived construction materials that often show higher efficiency relatively to traditional ones (see Carbon usage section in Part 1). They could also share transport and storage infrastructure with other high energy companies that are relying on carbon capture technologies to address their emissions, like in the Acorn CCUS project in the box above.

[74] Energy Transitions Commission. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century. Sectoral Focus: Cement
[75] Energy Transitions Commission. 2019. Mission Possible: Reaching Net-Zero Carbon Emissions from Herder-to-Abate Sectors by Mid-Century. Sectoral Focus: Cement
[76] Global CCS Institute. 2017. Global Costs of Carbon Capture and Storage

Table 9. The Technological Maturity Differs per Decarbonisation Option

	Conventional option	Applied at industrial-scale sites	Technology to be applied in pilot sites	Research phase
Fuel	◆ Coal ◆ Petcoke ◆ Natural gas	◆ Biomass ◆ Biogas		◆ Kiln electrification ◆ Hydrogen-based heat generation
Feedstock	◆ Limestone	◆ Blending of clinker with slag / fly ash ◆ Dehydration of bioethanol ◆ Bio-diesel	◆ Blending of clinker with other minerals	◆ Replacement of limestone feedstock ◆ Bio-based monomers
CCS			◆ Conventional process with CSS on both process and fuel emissions ◆ Adjusted process with CSS on a pure flow of process emissions ◆ Conventional process with CCS on oxyfuel combustion emissions	

Key

Complete decarbonization of heat and process	Complete decarbonization of heat or process	Partial decarbonization of process only

Source: McKinsey & Company (2018)

Chemicals
This sector encompasses a great variety products including ammonia, ethylene, propylene and aromatics, which collective demand is set to by 40% by 2060. The sector's emissions are around 1GtCO_2/y today, which is equivalent to Brazil annual emissions (excluding forestry)[77]. Without additional checks, emissions form chemicals are set to grow in parallel with demand[78]. Ammonia, the most prominent source of emissions in the sector (30%), is used in the production of methanol, urea and other fertilisers products.

Carbon capture in chemicals offer the greatest potential by volume and costs relative to cement and steel. This is because of the fact that chemicals processes typically produce CO_2 streams of higher purity compared with cement and steel. As seen in Part 1, higher purity results in lower costs of capturing CO_2.

In IEA scenarios for Paris alignment, the carbon footprint of chemicals is reduced by 60% by 2060 from 2017 levels, reaching 0.6GtCO_2/y. CCUS could facilitate 38% of the emissions cuts, a cumulative of 14GtCO_2 by 2060. This is higher than 5GtCO_2 and 10GtCO_2 by 2060 for cement and steel, respectively. For this, the IEA forecast CCUS capacity in chemicals growing from 130MtCO_2/year today to approx. 500Mt CO_2 by 2060, with the bulk of the growth going to carbon storage (256MtCO_2). The production of urea and methanol accounts for 100MtCO_2 of carbon capture capacity today[79].

[77] Climate Action Tracker. Country Summary: Brazil
[78] IEA. 2019. CCUS for Transforming the Industry
[79] IEA. 2019. CCUS for Transforming the Industry

Power

In IEA decarbonisation scenarios, CCUS applications in power is expected to go from the current capacity of 2.4 $MtCO_2$/year to around 310 $MtCO_2$/year by 2030[80]. Natural gas, bioenergy, waste, and coal are among the power generation sources included in these scenarios. This paper focuses on lower-carbon energy sources as increased scientific evidence suggests that delivering on Paris goals would demand phasing out coal (IPCC).

The pipeline of CCUS projects in power today include seven gas-fired power plants, two biomass and waste power generation facilities, and one gas-to-hydrogen conversion facility. Carbon capture technologies can address between 90-99% of the emissions in power generation at a cost ranging from USD$15/$tCO_2$ and USD$60/$tCO_2$. The lower cost relatively to industrials is due to the higher purity of CO_2 in the effluxes, as explained in part 1. Achieving a higher rate of carbon capturing would be a decision driven by marginal costs rather than technical constrains. For example, IEA found a 10% capture cost difference when using more efficient technologies in the post-combustion method to increase capture rates from 90% to 99% in gas-based power generation (i.e. chemical absorption technologies)[81].

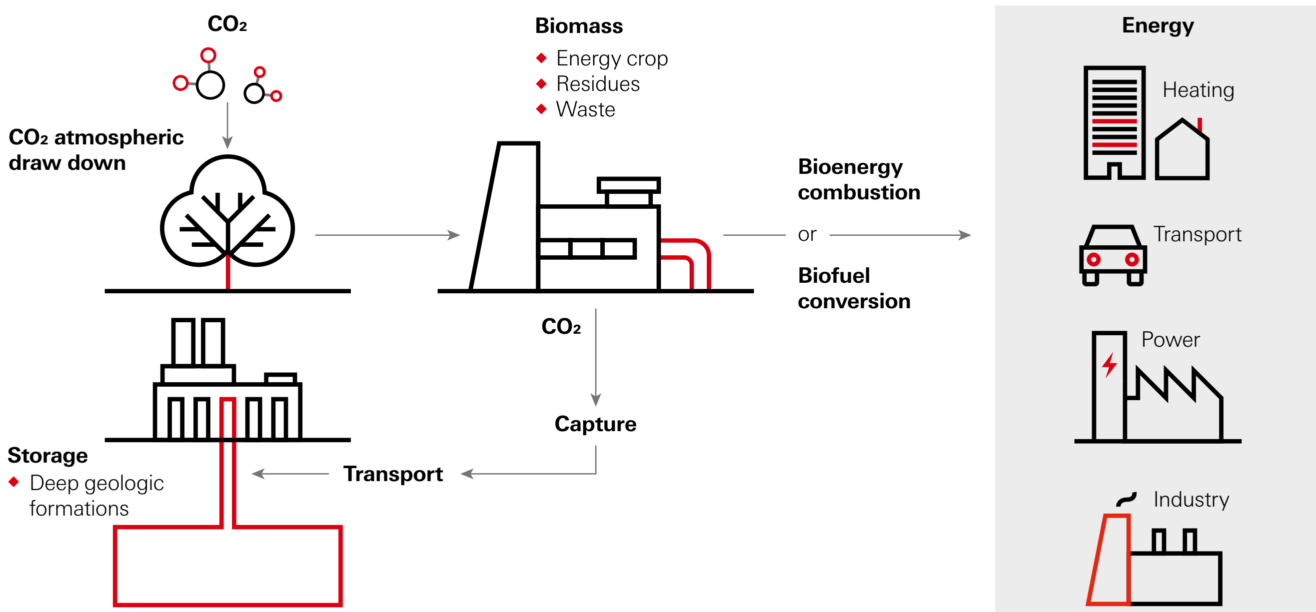
Box 8.
Negative-emissions through Bioenergy with Carbon Capture and Storage (BECCS)

Bioenergy with Carbon Capture and Storage (BECCS) refers to the use of biomass like energy crop, food waste, wood and paper in power generation (bioenergy combustion) or fuel production (biofuel conversion). BECCS is underpinned in the concept of negative-emissions solutions where carbon is captured through biomass production and then, through carbon capture technologies applied to either bioenergy combustion and biofuel production (see Figure 10).

There are currently four small scale and one industrial scale[82] BECCS facilities, totalling 1.5$MtCO_2$/year of capture capacity[83]. In 2019, a BECCS pilot project in the UK by the energy company Drax started to produce power entirely from biomass feedstock (1tCO_2/day of capture capacity). If successful at achieving industrial scale, Drax's project could store a larger amount of CO_2 than the one being emitted in biomass production, transport, conversion and combustion[84].

Carbon capture costs associated with BECCS vary depending on the source of biomass and whether biomass is used for combustion or fuel production. While the production of bioethanol is the lower cost route, its availability is limited compared to crops, as shown in the graphic below. Most scenarios considered by the IPCC and IEA expect a higher contribution of BECCS to limit global warming to 1.5C (IEA Bioenergy).

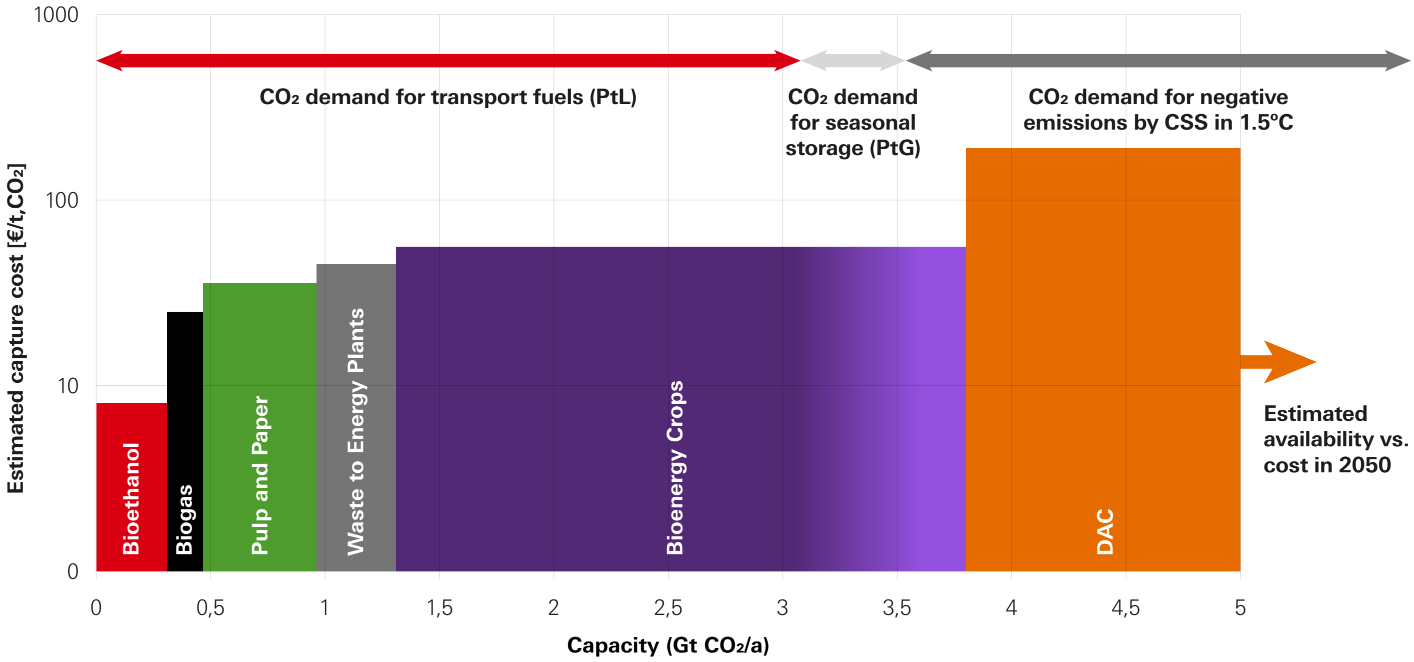
Figure 10. Bioenergy and Carbon Capture and Storage (BECCS) Schematic



[80] IEA. 2020. CCUS in Power
[81] IEA. 2020. CCUS in Power

Source: IEA Bioenergy

Figure 11. Global Renewable CO_2 Availability from Different Sources



Sources: IEA Bioenergy

> To assess the contribution of CCUS to carbon neutrality in alignment with Paris, it is fundamental to consider life-cycle emissions. CCUS applications can help achieve deep decarbonisation for heavy industrials, hydrogen production, and flexible power generation from natural gas and bioenergy even after considering life-cycle emissions.

The next section looks at the enablers for the deployment of CCUS at scale.

[82] The industrial scale BECCS facility is located in Illinois and captures up to 1 Mtpa of CO_2. The facility produces ethanol from corn. CO_2 from the fermentation process is captured and stored in a dedicated geological storage site in the same location.
[83] Global CCS Institute. 2019. Bioenergy and Carbon Capture and Storage. Perspective
[84] IEA. 2020. CCUS in Power

Part 3 - Enabling CCUS Deployment at Scale through Inter-Industry Collaboration

Compared to other decarbonisation solutions, CCUS often implies higher project, technology, and counterparty risks. This is because of the number of players involved in CCUS projects and the economies of scale that are required to be met for CCUS to make economic sense[85]. The table below discusses examples of how these risks could arise in CCUS projects.

Inter-industry partnerships are increasingly emerging to manage the risks associated with CCUS projects. They involve the development of carbon transportation and storage infrastructure for common use as well as pilots for new carbon capture technologies.

Table 10. Key Risks in CCUS Projects

Risk type	Definition	CCUS context
Project risk	Risks that are specific to the project given its complexity, which generally translate into long lead-in times (i.e. time for a project to move from concept stage to operation), and low survival rates (i.e. number of projects in the pipeline vs. those being cancelled)	Project complexity: CCUS projects often spin over several components including pipeline networks, carbon capture facilities and storage sites. The higher the number of project components the more complex the project is and hence, the higher the project risks. Lead-in times: Planning and construction of CCUS projects can be as long as a decade. The Global CCS Institute estimate an average lead time of 6-8 years for CCUS projects[86]. This compares with the lead-in times of 5-10 years for onshore wind farms[87]. Survival rates: 45 out of 122 CCUS projects (37%) between 2010-2019 remained in the pipeline. This compares with 54% of onshore wind farms in the UK[88].
Technology risk	Risks arising from technology failure or underperformance	Carbon storage: further studies are required to increase understanding of geological formations for converting theoretical capacity to bankable storage. The use of empty oil fields often helps address this risk as the relevant geological data is already known[89]. Carbon capture in low-purity gases: technologies to reduce the costs of capturing carbon from gases with lower concentration of CO_2 are still being tested. See example in Box 1 above.
Counterparty risk	Potential losses arising from counter-party's default or project delays because of counter-party's disengagement to the project	CCUS projects often involve several counterparties operating in different industries. They all rely on each other for the CCUS chain to come operational. Each counterparty would have relevant technical knowledge and competencies to lead a component of the CCUS chain; a.k.a the counterparties that lead transportation and storage are often different from the ones deploying carbon capture technologies.

Source: HSBC

[85] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions and IEA. Topics: Carbon Capture and Storage
[86] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[87] IWEA. 2019. Life-cycle of an Onshore Wind Farm
[88] Global CCS Institute. 2020. Scaling Up the CCS Market to Deliver Net-Zero Emissions
[89] IEA. Five Keys to Unlock CCS Investment

From the partnerships for CCUS in Europe (see summary Figure 12), the three factors below are enabling the deployment at scale. We focus on CCUS projects in Europe as they are often being framed in the context of carbon neutrality. This does not mean that the enabling factors are exclusive to Europe.

1. Proximity to existing transport and storage infrastructure or the opportunity to build new infrastructure in partnership

Large scale CCUS projects and their various emission sources are typically located close to known geological storage sites. In some cases these will be empty oil and gas reservoirs where it may be possible to repurpose old oil and gas infrastructure, thereby reducing investment costs. The Porthos CCS project is an example (see Figure 12 below)[90].

In absence of existing infrastructure, proponents have initiated partnerships to assess the economic feasibility of new infrastructure. Through the partnerships, proponents share the costs and risks related to the early planning and development. The Zero Carbon Humber is an example of a partnership for developing shared infrastructure (see Figure 12 below).

2. Concentration of large emitters in a production / industrial region, combining a diverse set of technical capabilities

Among the project proponents there are often large emitters that have set up ambitious decarbonisation targets in alignment with governments' climate ambition. Capturing a high volume of carbon emissions would allow for achieving economies of scale across the CCUS chain.

For example, relevant projects in the UK include the Zero Carbon Humber, South Wales, and Teesside, which together account for 6% of the country's carbon emissions (i.e. 23.7MtCO_2/y)[91]. Project proponents in these industrial clusters are collaborating to implement CCUS technologies to achieve carbon neutrality in alignment with the government's climate change agenda.

Furthermore, project proponents usually spin over a great variety of industries including energy companies, utilities, gas network operators, heavy industrials, ports, and technology providers, among others (see Figure 12 below). Each brings a different stock of technical expertise and knowledge, which allows them to lead the component of the CCUS chain that better fits their toolset.

For example, the technology innovator C-Capture, which is working with Drax in the Zero Carbon Humber project, focuses on testing new technology that can reduce carbon capture costs. Utilities and network operators often lead the development of transport networks. In turn, oil and gas companies often concentrate in pipeline networks and carbon storage as they have a good understanding of the pipeline technologies and the geology of potential storage sites.

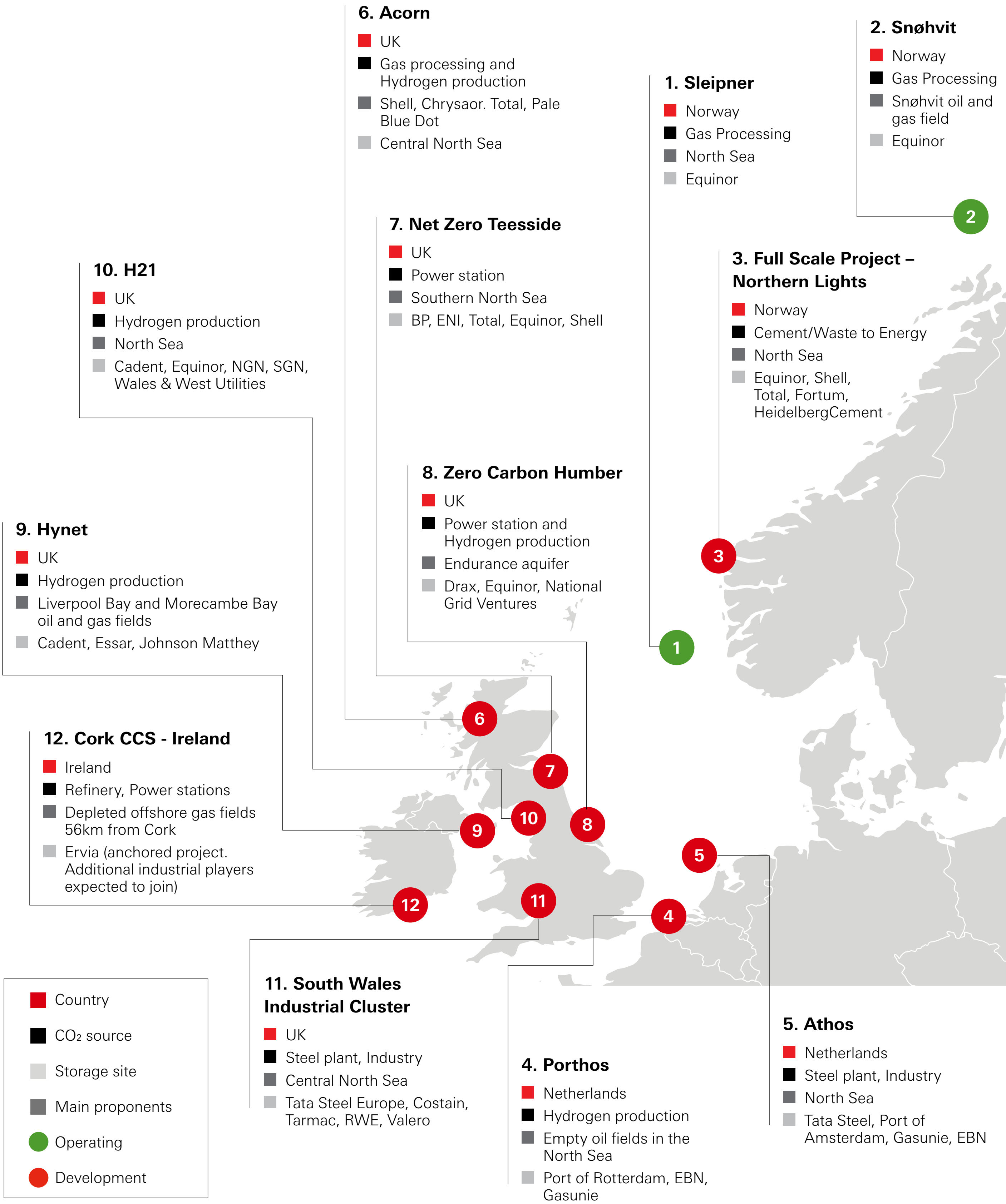
3. Supportive policy and government funding

Governments' ambition to achieve carbon neutrality coupled with consistent regulation to reduce emissions over time, can enable the deployment of CCUS at scale in Europe. The EU Emissions Trading System, which operates by the cap-and-trade principle, aims to set robust carbon emissions limits to facilitate a zero emissions outcome across all sectors by 2050. The EU considers CCUS technologies as relevant to comply with these limits (see Boxes 4 and 5 above).

Furthermore, grant support for mapping and assessing CO_2 storage potential and supporting CCUS commercial development has also played fundamental. For example, the UK's Business, Energy and Industrial Strategy (BEIS) since 2018 provides grant funding to CCUS projects within the GPB100m envelop for energy innovation. Funding could be used for research and development of any component of the CCUS chain. Several of the UK projects listed in the table below are beneficiaries of this grant funding scheme[92].

[90] IEA. Five Keys to Unlock CCS Investment
[91] Equinor. 2020. H2H Saltend. The First Step to a Zero Carbon Humber
[92] BEIS. 2020. CCUS Innovation Programme: Selected Projects

Figure 12. Proposed CCUS Industrial Projects in Europe Aim to Achieve Economies of Scale by Combining Several Large Emitters and Sharing Infrastructure[93]



[93] Global CCS Institute. CO_2RE – CCS Facilities Data; and project Websites: https://theacornproject.uk/about/#hydrogen; https://www.netzeroteesside.co.uk/project/; https://ukccsrc.ac.uk/sites/default/files/documents/event/gearoid-fitzgerald-min.pdf; https://www.h21.green/; https://www.portofrotterdam.com/en/news-and-press-releases/ccs-project-porthos-a-step-closer; https://www.ccusnetwork.eu/network-members/athos-consortium; https://ccsnorway.com/full-scale-capture-transport-and-storage/

Conclusions

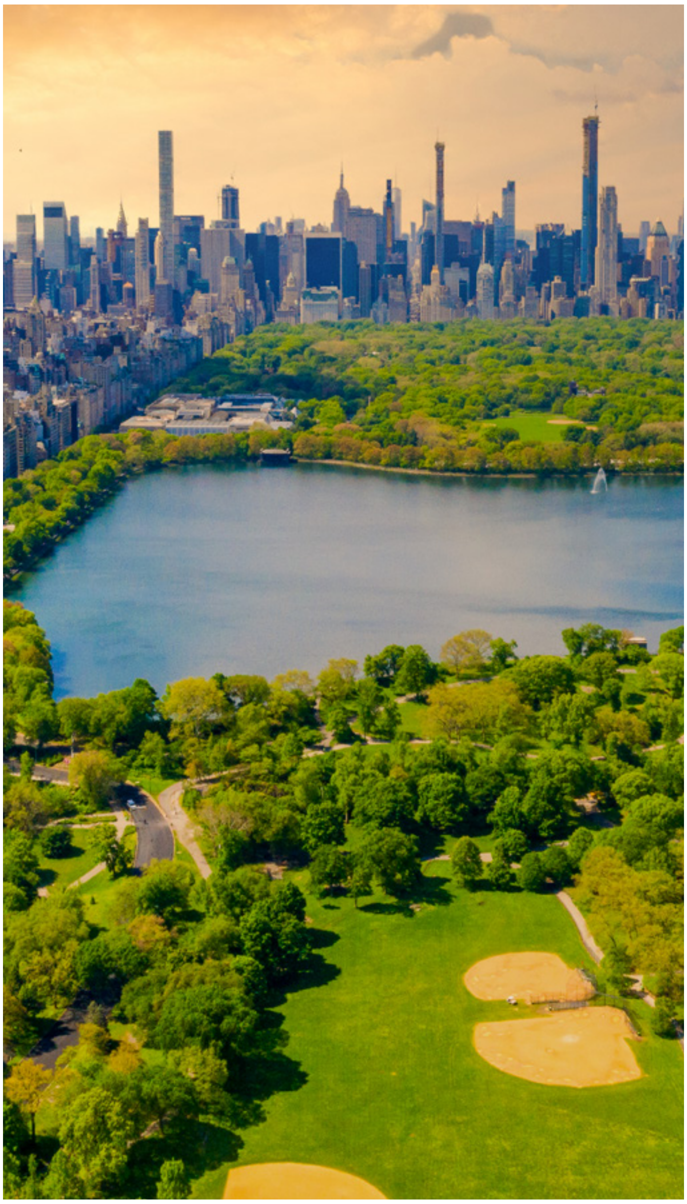
Accelerating Paris Alignment with CCUS in a Post Covid-19 World

There is growing consensus that CCUS applications can facilitate significant carbon emissions reductions in high energy industries like cement, steel, and chemicals, as well as in the supply of flexible electricity from sources like bioenergy, natural gas, and hydrogen. Without substantial climate mitigation measures, these industries pose the greatest carbon lock-in risk as the associated infrastructure (planned and existing) can absorb nearly 95% of the emissions allowances for achieving Paris goals. The IEA and ETC outline clear pathways to achieve deep decarbonisation in these industries; all of which rely on CCUS applications.

The uptake of CCUS at scale would require effective inter-industry collaboration and stable government support. Strategic partnerships involving industrial players are emerging to ensure safe, fast-tracked, and cost-effective implementation of the different components of the CCUS technology chain.

To assess the contribution of CCUS to carbon neutrality, it is fundamental to consider life-cycle emissions. CCUS applications in heavy industrials, hydrogen production, and flexible power generation from natural gas and bioenergy can help achieve deep decarbonisation even after considering life-cycle emissions. The EU taxonomy provides concrete guidance for market players in this regard.

2050 is cited as the target year to achieve carbon neutrality across all economic sectors and it is only one investment cycle away. With Covid-19 putting extra pressure on governments and corporates to activate the economy, strategic thinking about what decarbonisation solutions are financed and how they are implemented has reached the highest levels of urgency. Market players should focus on solutions that accelerate Paris alignment. In this context, the “climate” case for some CCUS is becoming stronger.



About the Centre of Sustainable Finance

"For more than a decade, HSBC has been at the forefront of the sustainable finance market. In November 2017, HSBC made five sustainable finance pledges. We committed to provide USD100 billion of sustainable financing and investment by 2025, source 100 per cent of electricity from renewable sources by 2030, reduce our exposure to thermal coal and actively manage the transition path for other high carbon sectors, adopt the recommendations of the task force on climate related financial disclosures to improve transparency, as well as leading and shaping the debate around sustainable finance and investment.

Taken together, these commitments reflect the scale of the challenge of delivering the Paris Agreement and UN Sustainable Development Goals. They also demonstrate the heights of our ambition to be a leading global partner to the public and private sectors in the transition to a low-carbon economy."

Daniel Klier, Global Head of Sustainable Finance

"Each and every one of us has a stake in developing a sustainable economic system. It is the combined responsibility of all players in society to respond to climate change, rapid technological innovation and continuing globalisation to secure a prosperous future. Yet addressing these changing forces is by no means straightforward. More work is needed to provide the financial system with the right toolkit to solve sustainability challenges.

Working with internal and external partners, this central think tank is uniquely positioned to lead and shape the debate. We will promote the sustainable finance agenda using our global network which covers the world's largest and fastest growing trade corridors and economic zones. We can provide the connections needed to foster sustainable growth across borders and geographies. We aim to mobilise the capital flows needed to address the world's major sustainability challenges."

Zoë Knight, Group Head, HSBC Centre of Sustainable Finance

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