Carbon Capture, Use and Storage

March - 2021

The Al-Attiyah Foundation

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INTRODUCTION

CARBON CAPTURE, USE AND STORAGE

CCUS refers to a range of technologies for capturing carbon dioxide (CO_2) from human-made sources including oil, gas and coal-fired power generation and industry, and using it to create useful products or storing it safely underground indefinitely.

How has carbon capture, use and storage (CCUS) advanced recently? What are important new projects, technologies and trends? What role will it play in tackling climate change, and in which regions? How does it compare to other low-carbon alternatives? What policies are required for it to progress?

Energy Industry Report

This research paper is part of a 12-month series published by The Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent energy topic that is of interest to The Foundation's members and partners. The 12 technical papers are distributed in hard copy to members, partners, and universities, as well as made available online to all Foundation members.

EXECUTIVE SUMMARY

- About 40 million tonnes (Mt) of CO_2 per year is currently captured; IPCC, IEA and BP scenarios suggest this would have to scale up to 1-15.8 billion tonnes (Gt) annually by 2050, mostly likely around 5-7 Gt.
- The emphasis of CCUS plans has shifted over the past decade from power generation to industry; and from single projects to clusters.
- CCUS is the leading candidate to decarbonise some key industries, such as petrochemicals, iron and steel, cement, 'blue' hydrogen, fertiliser manufacturing and others.
- CCUS costs are reasonable compared to those of other low-carbon options, and the main technologies for capture, transport and storage are technologically mature. Improvements and cost reductions are likely, and significant breakthrough technologies are possible, with work currently underway.
- Policy support has greatly improved in recent years through net-zero carbon commitments, government funding for specific projects, the rising price of European CO_2 emissions permits, and the US's 45Q tax credit.
- Europe and the US are most active, with projects also in Australia, Canada, China and the GCC. CCUS progress elsewhere in the Middle East, India, Russia, Africa and Latin America has been very limited so far.

IMPLICATIONS FOR MAJOR OIL AND GAS PRODUCERS

- Government financial and policy support for CCUS has advanced to the stage that several major projects are under development.
- CCUS is an essential tool for oil and gas companies to decarbonise and to secure access to end markets, including through the production of 'blue' hydrogen.
- Collaboration across the value chain and with policymakers is essential to make CCUS projects viable.
- CCUS requires a novel set of skills, many of which – but not all – are found within oil and gas companies. Firms that can develop these capabilities and form the required partnerships will have a competitive advantage.
- CCUS can eventually become a large industry in its own right, not just an enabler to an existing oil and gas business.

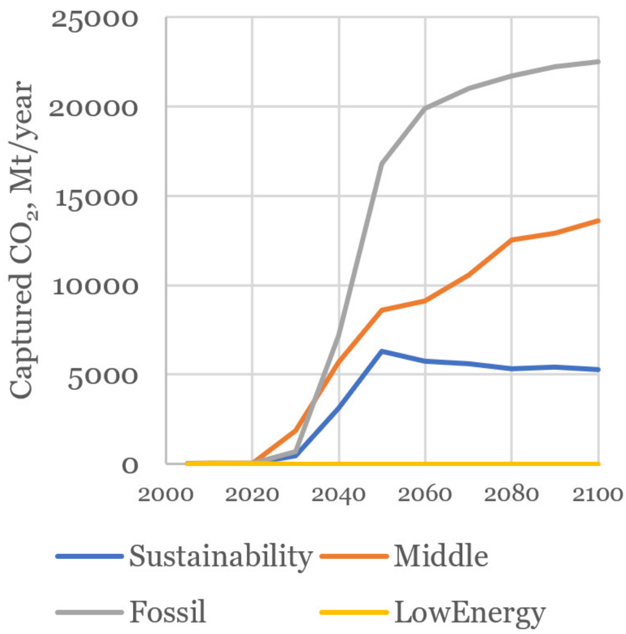
CCUS HAS BEEN WIDELY IDENTIFIED AS A CRUCIAL APPROACH TO LIMIT CLIMATE CHANGE

Carbon capture, use and storage represents a range of technologies that capture carbon dioxide (CO_2) from human activities, such as the combustion of carbon-containing fuels (coal, oil, gas, wood) or from the air, separate and purify it from other gases (nitrogen, water and others), and inject it underground for safe and very long-term storage, or use it to make valuable products or convert it to solid minerals[i]. This allows the continuing use of carbon-containing energy sources while reducing or largely eliminating emissions of carbon dioxide into the air, the main greenhouse gas (GHG). As such, CCUS is potentially a vital component of a future low-carbon energy system along with renewable and nuclear power, electric vehicles, batteries, improved energy efficiency, hydrogen and other approaches.

Carbon dioxide injection began to be used commercially for enhanced oil recovery (EOR) in the United States in 1972[ii], and the first CCUS project designed specifically for safe long-term CO_2 disposal was on the Sleipner field in Norway starting in 1996. Since then, CCUS has gradually expanded. But most approaches for limiting climate change ascribe it a much more important future role than it meets today.

The IPPC presents several scenarios for meeting the Paris Agreement's target of limiting warming to no more than 1.5°c by 2100. Four of these are shown in Figure 1. About 40 Mt of CO_2 are currently captured per year, a little over 0.1% of all emissions from fossil fuel combustion (not including other sources). In the Low Energy scenario, CCUS is not employed, but in the Sustainability, Fossil-Fuelled and Middle-of-the-Road scenario, CCUS rises rapidly between 2030 and 2050 to reach between 5-22.5 gigatonnes (Gt) of CO_2 each year, a scale-up on current efforts of between 125 and more than 500 times.

Figure 1 CCUS in IPCC scenarios 2000-2100[iii]



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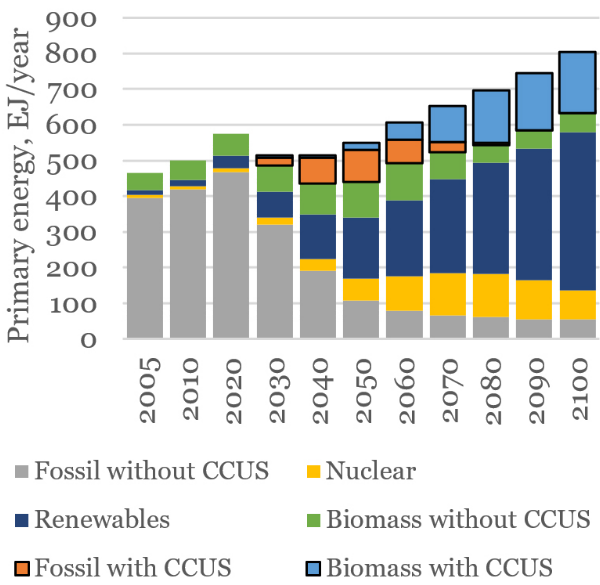
In the 'Middle-of-the-Road' scenario (Figure 2), CCUS on fossil fuels and bio-energy (BECCS) rises to about 20-22% of primary energy by 2050 and stays there to 2100. A maximum of 43-44% of fossil energy uses CCUS in 2040-2050 before falling off as unabated fossil fuel use continues only in non-capturable applications, such as small-scale uses or transport. But the share of CCUS in biomass rises to 75% by 2080-2100 as a way of offsetting emissions elsewhere and actively reducing atmospheric CO_2, as discussed below.

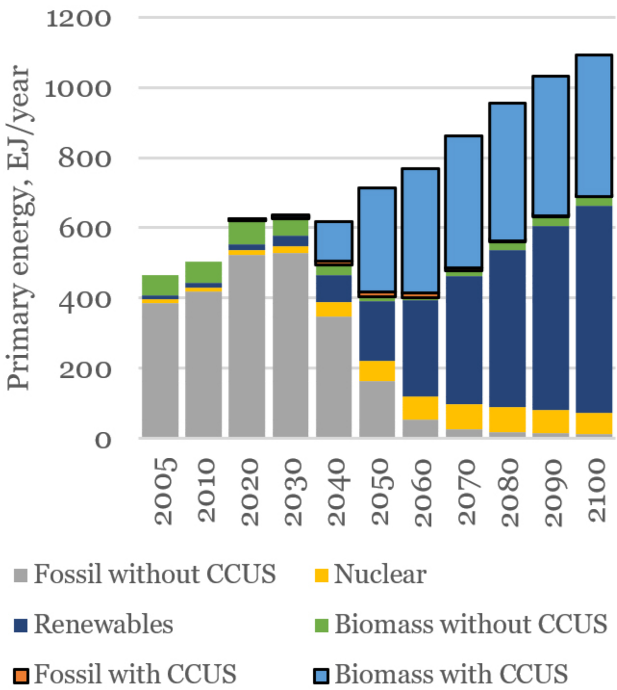
Figure 2 Primary energy in 'Middle-of-the-Road' IPCC scenario[iv]



The 'Fossil-fuelled' scenario (Figure 3) has higher fossil fuel use and a later peak in emissions, less use of CCUS on fossil fuels, but a very large application of CCUS on bio-energy to draw down the 'overshoot' of atmospheric CO_2 levels.

The uptake of CCUS depends on a number of factors, such as overall growth in energy demand; the strength of climate policy in general; societal support and government backing; evolving economic competitiveness

Figure 3 Primary energy in 'Fossil-fuelled' IPCC scenario[v]



versus other low-carbon energy options; and the availability of sustainable biomass for BECCS. These lead to a wide range of estimates for total CCUS deployment, from zero to 16.8 Gt in 2050 (for comparison, the IPCC's range for total emissions, with and without CCUS, in that year is 10.1-32.6 Gt). This implies that in the IPCC's scenarios, about 40-50% of emissions are being captured; the figure in BP's scenarios is smaller, 9-30%.

Table 1 Selected scenarios for CCUS use to 2100

Scenario	CCUS in 2050 (Gt CO2)	Peak use of CCUS (Gt CO2)	Peak year of CCUS
BP Rapid [vi]	3.9		
BP low	1.0		
BP high	7.1		
IEA Sustainable Development	5.6		
DNV [vii]	2.1		
IPCC 2°c, 10th percentile	5.4		
IPCC 2°c, 90th percentile	15.3		
IPCC Fossil-fuelled	16.8	22.5	2100
IPCC Middle-of-the-Road	8.6	13.6	2100
IPCC Sustainability	5.3	6.3	2050
IPCC Low-Energy	0	0.04[viii]	2020

The capture of 16.8 Gt of CO_2 in 2050 can be compared to current oil production (4.5 Gt/year), coal production (8.1 Gt/year), and LNG trade (0.36 Gt/year). Possibly a better comparison is with another oil-field waste, produced water, which is about 15.3 Gt/year[ix], and is mostly treated on-site and re-used or reinjected. In any case, CCUS would clearly be an enormous industry in its own right, even if most of the CO_2 is reinjected or re-used close to source instead of being transported globally as with much of current fossil fuel use.

Of course, there are many ways to construct feasible scenarios. The importance of CCUS lies in four areas:

1. It enables the continuing use of fossil-fuelled infrastructure, potentially reducing transition costs;
2. It allows large combustion power plants to operate with minimal emissions, to support variable renewables, improve reliable and reduce system costs, otherwise very large amounts of long-duration energy storage would be required;
3. It can eliminate process (non-combustion) emissions such as from cement production, 'blue' hydrogen generation and chemical manufacture, which cannot be tackled by switching to renewable energy;
4. It can reduce atmospheric CO_2 directly, as discussed below.

The value of the CCUS industry

- By 2050, 16.8 Gt CO_2 captured per year at $50/tonne would represent an industry of $840 billion
- Oil today is about $2.2 trillion per year in revenue
- LNG is currently about $120 billion per year in revenues

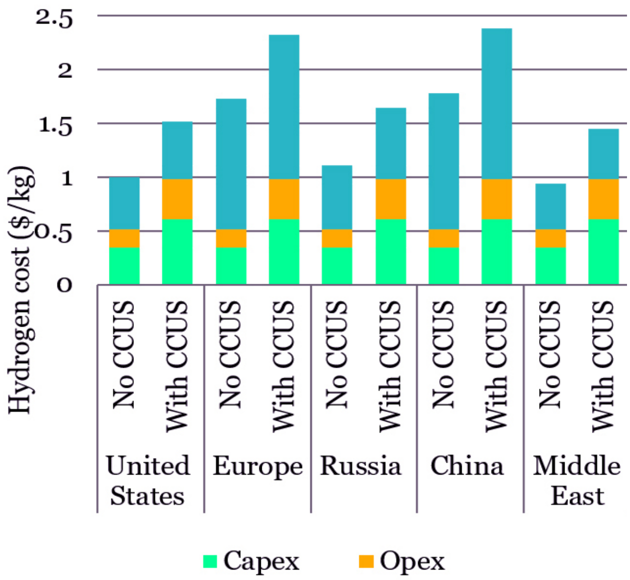
THE EMPHASIS OF CCUS HAS CHANGED IN FIVE WAYS

In the last few years, the emphasis of CCUS has altered in five main ways. These are the function of developments in world energy markets along with the increasing adoption of net-zero carbon targets.

1. Shift from coal to gas and industry. In the early 2000s, CCUS was perceived as a technology that could allow coal to continue being a major fuel. Now, after more than a decade of generally low natural gas prices and sharp drops in the costs of renewable energy, the economics of coal look poor and its use has sharply declined in major consumers including Europe, the US and Australia. The use of CCUS would further worsen these economics. Instead, it has become clear that gas power will also have to decarbonise.

2. Growing realisation that hard-to-decarbonise sectors may find CCUS the most viable solution. These include 'blue' hydrogen produced from fossil fuels with CCUS, which is itself is an option in decarbonising iron and steel production, synthetic fuels, fertilisers and heavy long-distance transport. CCUS is also applicable to petrochemicals, cement, pulp and paper, and iron and steel. Figure 4 suggests that blue hydrogen costs would be substantially below current costs for 'green' hydrogen (via electrolysis of water using renewable electricity), which are about $4 per kg. CCUS adds substantial costs over 'grey' hydrogen (made from fossil fuels with emissions of CO_2), about an extra $0.5/kg depending on the region. Russia, the US and the Middle East, with low natural gas prices and good geological storage conditions, appear the most promising for blue hydrogen.

Figure 4 Blue hydrogen production costs by region[x]



3. Creation of CCUS clusters. Instead of past projects based on single facilities, CCUS proposals now focus on setting up clusters which include a number of large emitters with a pipeline or marine access to a suitable storage site. For instance, the UK has identified Teesside, Humberside, Scotland and possibly South Wales; Norway's Langskip, linked to the Northern Lights CO_2 transport and storage system, covers cement, waste-to-energy and other industrial emitters. In the Netherlands,

Porthos and Athos are clusters of power and industrial sources around Rotterdam and Amsterdam respectively. This is designed to save costs and to tie in relatively smaller industrial emitters which could not invest in a transport and storage solution on their own.

4. The appearance of 'U'. Carbon capture and storage was typically referred to as CCS. The change to CCUS – including Use – accelerated sharply from 2018, as Google searches show. This in turn is the result of four other trends:

- A marketing impression that storage was not positively regarded and that emphasising use (or re-use) was preferable;
- The hope that sales of CO_2 could support the economics of capture projects, though in practice this is unlikely in most cases (other than CO_2-enhanced oil recovery);
- Realisation that carbon dioxide could be a useful feedstock for other materials and processes;
- The concept of the 'circular carbon economy' (CCE) as a way to adapt the fossil fuel and petrochemical industry to zero-carbon goals.

5. Net zero targets. Some 51% of the world economy, notably the EU, UK, China, Japan and South Korea, have now adopted net-zero carbon targets by 2050-60, and this would increase to 63% if Joe Biden follows through on his campaign pledges for the US to make a similar commitment. India is reportedly also considering a net-zero ambition by 2050[xi], which would take coverage to 70% of the global economy. Corporations and sub-national entities have also set net zero targets. It is likely then that other countries would fall in line.

THE EMPHASIS OF CCUS HAS CHANGED IN FIVE WAYS

The very sharp pace of emissions reductions required to hit net-zero by 2050, and the exhaustion of options such as coal-to-gas switching, leads to the realisation that there will still be some level of emissions by mid-century, probably a significant amount. In any case, currently committed emissions still lead to dangerous levels of warming. CCUS methods are therefore required to offset unavoidable emissions and draw down atmospheric CO_2 directly. This can be achieved by biological methods (e.g. reforestation), bioenergy with CCS (BECCS), and direct air capture (DAC). Bio-sequestration is probably the cheapest method but socially complicated to apply on a large scale and challenging to certify reliably and consistently and to assure long-term storage. BECCS is limited by the availability of suitable biomass without disrupting ecosystems. DAC is currently costly, but has no inherent limits of scale, and technology development and deployment experience could possibly bring its costs down to around $100/tonne, which would be feasible for large-scale use. Occidental Petroleum plans a 1 Mt/year plant for EOR in the Permian Basin in the USA, operational by the mid-2020s.

Several leading oil companies, mostly European (Shell, BP, Equinor, Total, ENI and others), but also including Occidental (US), have set targets to be net zero-carbon around 2050, in line with national and Paris Agreement targets. Since they will still be producing oil and gas at this point, they will need offsets, particularly to neutralise their 'Scope 3' emissions (those from the use by others of the products they produce, refine, trade or sell). Even now, producers of LNG in particular are seeking competitive advantage by offering low-carbon or carbon-neutral

products. CCUS is a vital part of reducing upstream and liquefaction emissions, as well as end-use emission in some cases (the power, petrochemical and industrial sectors. This can be seen in:

- Norway's Northern Lights project, which partners Equinor, Shell and Total;
- Qatar Petroleum's plans for 7 million tonnes/year of CCUS to reduce the carbon footprint of its new LNG trains;
- NextDecade's scheme for 5 Mt/year capture at its Rio Grande LNG plant to reduce emissions by 90%[xii];
- Novatek's plans to install CCUS at one of the Arctic fields feeding its LNG plants in Russia;
- Abu Dhabi National Oil Company's intention to capture 5 million tonnes of CO_2 per year by 2030.

PROGRESS ON CLIMATE TARGETS HAS BEEN SLOW

Progress in CCUS has been slower than the IPCC or IEA scenarios show is required to meet the Paris Agreement targets. This is for a variety of reasons, but the key ones include:

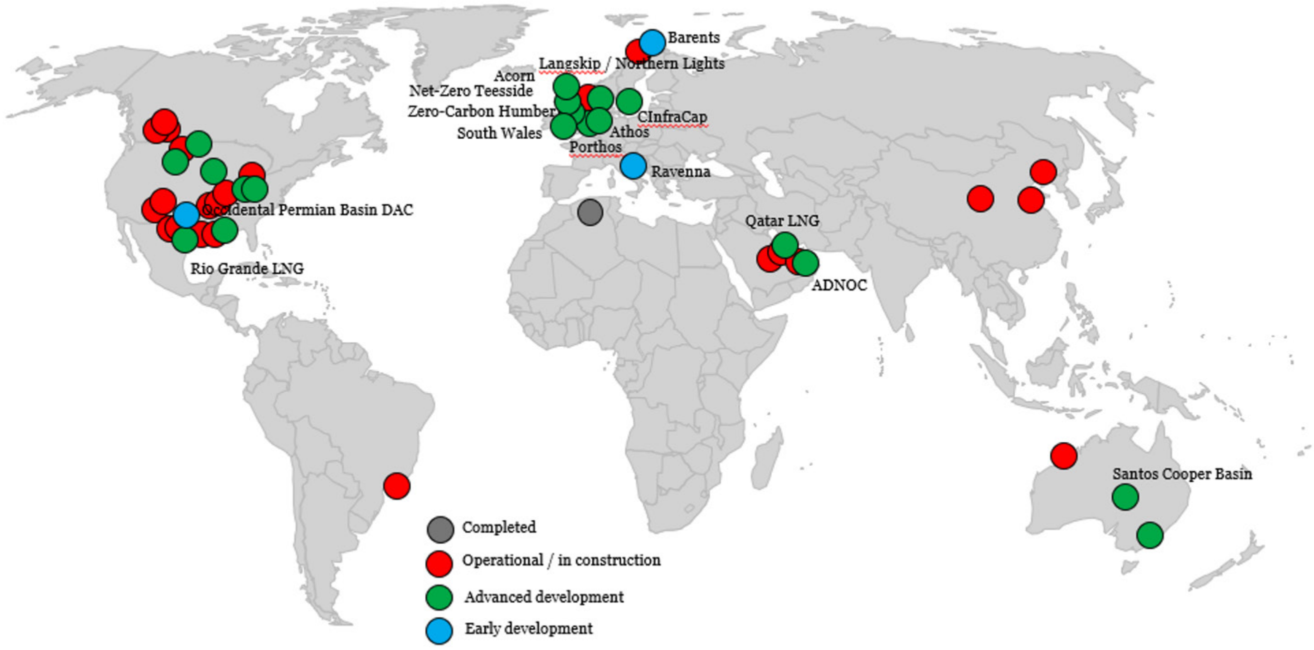
- Insufficient financial backing by governments to support the initial projects;
- Slowness of the fossil fuel industry to commit;
- Lack of a sufficiently high carbon price in most jurisdictions to support CCUS implementation and ongoing operations (until recently);
- Opposition or at best limited support from environmental groups, due to the links to the fossil fuel industry;
- Worsening economics for coal power and less perceived necessity, because of falling gas and renewables costs;
- Difficulty of integrating several players along the CCUS value chain (power or industry, CO_2 transport and underground storage);
- Commercial failure of a few high-profile projects (Kemper County and Petra Nova), which have attracted disproportionate and inaccurate media commentary;
- Perceptions, still widely repeated, that CCUS is an 'unproven' technology;
- Public opposition to underground CO_2 storage, particularly in Germany and the Netherlands.

Despite these obstacles, the CCUS industry deployed about 20 Mt/year of additional capture capacity between 2010 and 2020. Notable projects included Boundary Dam in Canada (1 Mt/year, 2014), Al Reyadah on the Emirates Steel plant in Abu Dhabi (0.8 Mt/year, 2016), Petra

PROGRESS ON CLIMATE TARGETS HAS BEEN SLOW

Nova in Texas (1.4 Mt/year, 2016), and Gorgon LNG in Australia (3.4-4 Mt/year, 2019). Figure 5 shows a selection of current commercial-scale CCUS projects, with other significant ones in development. The concentration of activity in the onshore US and around the North Sea is notable, including several important and innovative new ventures and hubs. The Gulf is another centre of activity, but so far confined to the UAE, Qatar and Saudi Arabia. On the other hand, there is a near-total absence of projects in Latin America, Africa, India and Russia.

Figure 5 Selected CCUS projects[xiii]



To meet the IPCC's 'Middle-of-the-Road' scenario, 1.8 Gt of CCUS will have to be deployed by 2030, 45 times the currently existing global capacity. Currently about 40 Mt is in construction or advanced development, and another ~40 Mt in early development. If this can be scaled up by a factor ~4 and delivered every year, the 2030 target could be met. In practice, this appears unlikely, but CCUS could catch up and come closer to the required levels by 2040-50.

Recent CCUS progress has been encouraged by a number of developments.

Net zero-carbon targets, as discussed above.

In turn, net-zero carbon targets have caused governments to realise the importance of plans for their hard-to-decarbonise sectors. Solutions for decarbonising power generation (renewables, nuclear) and ground transport (electric vehicles) appear technically and commercially feasible after progress in recent years. European governments in particular have made increasing sums of money available for funding CCUS design and deployment, as well as other required technologies such as hydrogen.

Improving economics. Developments in the US and EU provide greatly improved economics for CCUS projects. In the USA, the 45Q tax credit, reformed in 2018, offers \$50/tonne CO_2 stored in geological formations, and \$35/tonne used in EOR or other utilisation options[xiv]. In January 2021, the Internal

Figure 6 ETS carbon price 2008-21 (€/tonne CO_2)[xvi]

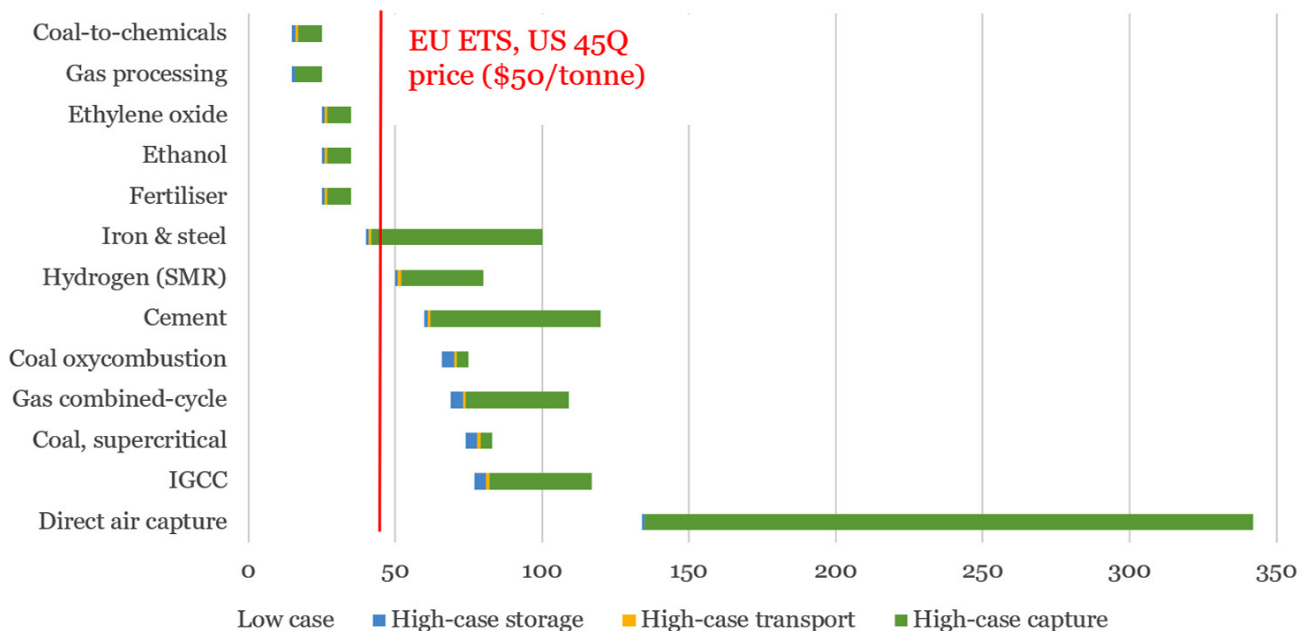
Revenue Service issued the final guidance to make the 45Q section effective. However, it only applies to projects starting construction by 1st January 2024, and only to large facilities (>500 kt CO_2/year in the case of a power plant). It could therefore be improved and extended to make it more generally applicable. Meanwhile, California's Low Carbon Fuel Standard can pay almost $200/tonne CO_2 for qualifying fuels (such as those produced via CO_2-EOR or DAC with low life-cycle emissions), and can be used in combination with 45Q.

Carbon prices in the EU's Emissions Trading System (ETS) have shot up recently, passing €40/tonne CO_2 for the first time in March 2021 (Figure 2). This is high enough to make lower-cost CCUS projects viable. Norway has announced plans to raise its carbon tax from about $69/tonne currently to $233/tonne by 2030. Sweden's carbon tax is currently $126/tonne, and Canada plans to increase its from CA$30 to CA$170/tonne (US$136/tonne) by 2030[xv].

At such prices, a wide range of CCUS projects would become viable. Figure 5 shows estimated first-of-a-kind (FOAK) costs for a variety of capture options. As shown, $50/tonne (coincidentally the US 45Q tax credit is, as of the date of writing, almost exactly equal to the EU ETS price), capture from low-cost options would be viable.

PROGRESS ON CLIMATE TARGETS HAS BEEN SLOW

Figure 7 Capture, transport and storage costs per source, first-of-a-kind (US$/tonne CO_2). SMR = steam methane reformer, IGCC = integrated gasification combined cycle (coal power station)[xvii]

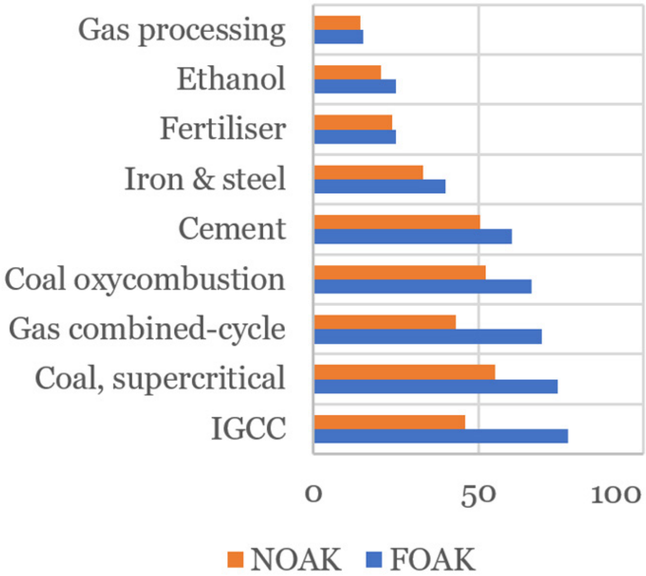


The costs of CCUS are dominated by capture. In the examples in Figure 5, transport is taken as $0-2/tonne (zero for capture at the storage site, as for gas processing), and storage as $7-12/tonne for the power sector and $11/tonne for industrial. Offshore storage costs would be higher, from $15-35/tonne. Low-cost capture sources are those which produce highly concentrated CO_2 streams; in this case, drying, cleaning and compression are the main processes required. At $50/tonne of CO_2 emissions avoided, various chemical processes, bio-ethanol fermentation, and possibly iron and steel and hydrogen, would be economically feasible. Cement and power generation, which produce more dilute streams, have higher costs, but most of coal and gas generation could be viable with a carbon price of less than $100 per tonne. Direct air capture, the most dilute source of all, has by far the highest costs. To give an example from the LNG sector, NextDecade costs its CCUS scheme at Rio Grande at $63-74/tonne CO_2, before the benefits of the 45Q credit.

Costs are expected to fall as more projects are built, experience is gained, the supply chain develops and the cost of capital drops as financers become more comfortable with CCUS's risk profile. The development of clusters helps cut costs for transport and storage by sharing infrastructure. CCUS could potentially access 'green' funding from Environmental, Social and Governance (ESG)-focussed investors. Some breakthrough technologies also offer substantial cost reductions, for example the gas turbine under development by NET Power, which uses CO_2 as a working fluid and offers high efficiency and a pure output stream of compressed carbon dioxide[xviii]. The combination of experience, finance and technology is similar to that which has driven the cost of new renewable energy to record lows in recent years.

The potential for cost reduction is shown in Figure 6, and ranges from 5-28%, with the greater reductions in the power sector. This would bring most coal and gas power within the $50/tonne range.

Figure 8 CCUS costs, first- and nth-of-a-kind, \$/tonne CO_2[xix]

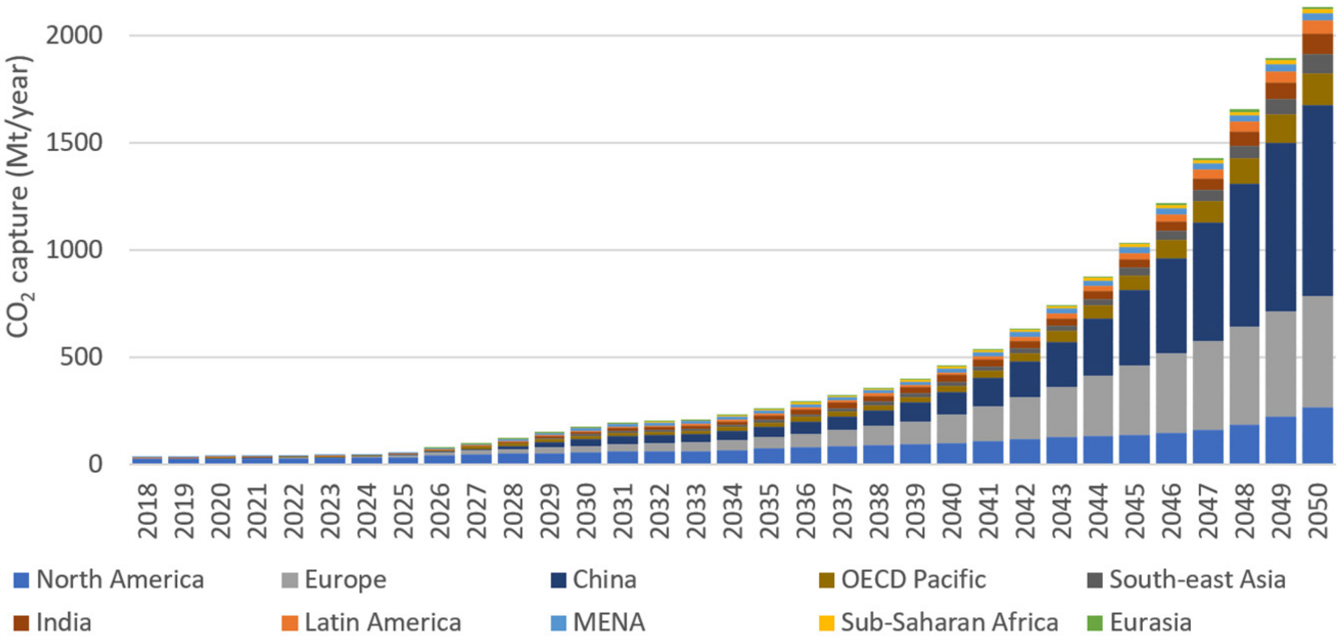


The addition of CCUS would raise the costs of energy or products delivered to varying extents. NextDecade's increased LNG cost would be \$0.05-0.09 / MMBtu (note this applies only to the LNG's plants emissions, not the emissions in final use).

CCUS IS MAINLY APPLIED IN NORTH AMERICA AND EUROPE, BUT OTHER REGIONS WILL FOLLOW

Figure 7 shows one view of CCUS deployment by region to 2050 (note that deployment in this scenario is rather low compared to the IPCC and BP scenarios). In this view, CCUS is largely applied in North America, Europe and China. OECD Pacific is likely primarily to represent Australia. However, this scenario probably understates the role of the Middle East-North Africa, given its need to decarbonise its oil and gas industry, its existing CCUS projects, and its excellent subsurface conditions. Eurasia (primarily Russia) might also advance if policy pressures for decarbonisation become strong and/ or if CO_2-EOR is widely adopted for mature oil-fields. However, policy support in MENA and Eurasia needs to advance to make this a reality. China has moved slowly on CCUS despite several pilot projects.

Figure 9 CCUS deployment by region[xx]



THE POTENTIAL FOR CO_2 RE-USE IS BEING EXPLORED, BUT SO FAR IS MORE LIMITED

As discussed, political, public opinion and economic drivers have led researchers and companies to explore the possibility of CO_2 reuse instead of geological storage. Such uses have to be on a very large scale to take up a material portion of future captured CO_2 of 1 Gt or more annually.

The major bulk use of CO_2 currently is for enhanced oil recovery, which was 65-72 Mt/year in 2011-12 and has increased since[xxi], of which 55 Mt was from natural carbon dioxide fields and 17 Mt from anthropogenic (human-made) sources. CO_2-EOR is proved and value-generative, primarily in the US and Canada but also in Brazil, Hungary, the UAE, Saudi Arabia and elsewhere. It could be more widely employed in the Middle East, Russia, China and other mature oil-producing areas. However, long-term future use of EOR may be constrained by oil prices and falling oil demand.

Other potential uses are shown in Table 2.

Table 2 Example CO_2 uses

Use	Pro	Con
Beverages, dry ice	Proved commercial	Small volumes CO2 is released almost immediately
Enhanced agriculture (greenhouses)	Proved commercial Moderate volumes	CO2 is released when plants consumed
Fertilisers (urea)	Proved commercial	CO2 is released by urea in soil
Methanol	Proved commercial	CO2 is released if/when methanol is combusted
Synthetic fuels	Potentially large volumes	CO2 is released when fuel is combusted
Cement	Early commercialisation Very large potential volumes Long-term storage	Not yet technically / commercially mature
Carbon nanotubes[xxii]	Potentially high value per tonne	Early-stage technology Small volumes
Plastics	Moderate volumes	CO2 is released if plastic breaks down, is biodegraded or combusted

GOVERNMENT POLICY NEEDS TO ADVANCE IN SOME KEY AREAS

As noted, recent government policy has contributed to an upsurge in activity in CCUS. However, several key areas need to move further. These are:

- Carbon neutrality targets for those countries that do not have them yet, including intermediate goals;
- Extension of carbon pricing or equivalent on a consistent basis and at sufficient levels ($50/tonne or more);

- Systematic assessment of CCUS opportunities within each country and region, prioritise on cost and feasibility;
- Further support for the development of 'clusters' including capture and an assured transport route to viable large-scale storage, with synergies and future capacity availability for application to a range of nearby emitters;
- Inclusion of CCUS in 'green taxonomies' including that of the EU, currently under development, and eligibility of CCUS for 'green' financing;
- Support for CO_2 reuse, for instance mandates for new low-carbon versions of materials such as plastics, steel and cement;
- Early-stage deployment support for advanced new technologies, including carbon re-use, carbon mineralisation and DAC.

In particular, several of the major hydrocarbon-producing / using regions where CCUS has been little-adopted to date should accelerate progress, notably the Middle East-North Africa (outside the three GCC states which are actively working on CCUS), China, Russia and India. International cooperation to share best practices and leverage conditions for deployment is important, and can be facilitated by organisations such as the Global Carbon Capture and Storage Institute (GCCSI), based in Australia, the Carbon Capture and Storage Association (CCSA), and the Oil and Gas Climate Initiative (OGCI), which groups a number of the world's major international and national oil companies.

CONCLUSIONS

CCUS adoption has been much slower to date than advocates would have hoped and than required to meet climate goals. However, there has been significant expansion over the last decade, and recent policy development is supportive, at least in the US, Canada and EU. The push for hydrogen, a large part of which will be 'blue', at least initially, will also require substantial CCUS development. The experience gained from recent activity, and the trend towards clustering projects, will help to reduce costs.

Oil and gas companies, and oil- and gas-exporting countries, will increasingly find CCUS vital to maintain market access and to meet corporate and national pledges on carbon neutrality. Those that move fastest to develop the required skills, technology access, infrastructure and partnerships will have a competitive advantage. CCUS can ultimately be a large business in its own right, not just an enabler to continued hydrocarbon production and use.

APPENDIX

i. https://www.hurstpublishers.com/book/capturing-carbon/
ii. https://www.api.org/~/media/Files/EHS/climate-change/Summary-carbon-dioxide-enhanced-oil-recovery-well-tech.pdf
iii. Data from https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/workspaces/2
iv. Data from https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/workspaces/2
v. Data from https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/#/workspaces/2
vi. BP Energy Outlook 2020
vii. https://www.dnv.com/feature/energy-transition-outlook-2020-faq.html#:~:text=A%3A%20We%20forecast%20a%20significant,century%20to%20420%20EJ%2Fyr.
viii. Not actually in the IPCC scenario, but the actual CCUS in 2020
ix. Based on an average worldwide water-cut of 3 barrels water: 1 barrel oil (75% water-cut) as in http://www.worldoil.com/April-2008-Well-optimization-through-downhole-water-control.html; this may have increased since 2008. Typically saline oil-field water assumed density 1.02 g/cm3; average crude oil 0.9 g/cm3.
x. International Energy Agency
xi. https://www.bloomberg.com/news/articles/2021-03-17/india-considers-net-zero-goal-around-2050-a-decade-before-china?sref=IUPsko0S
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xx. Data from https://www.dnv.com/feature/energy-transition-outlook-2020-faq.html#:~:text=A%3A%20We%20forecast%20a%20significant,century%20to%20420%20EJ%2Fyr.
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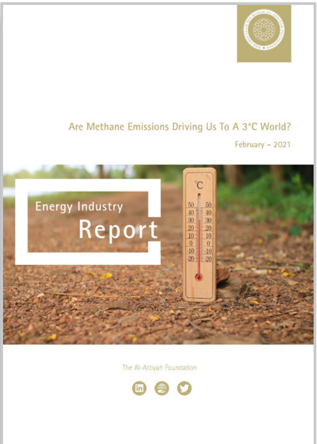
PAST ISSUES

Have you missed a previouse issue? All past issues of The Al-Attiyah Foundation's Research Series, both Energy and Sustainability Development, can be found on the Foundation's website at **www.abhafoundation.org/publications**



February - 2021

Are Methane Emissions Driving Us To A 3°c World?

The United Nations Environment Programme suggests that the world is on track for an average temperature rise of 3°c, with CoVid-19 likely to result in just a 0.01°c reduction in global warming by 2050. NASA announced that Earth's global average surface temperature in 2020 tied with 2016 as the warmest year on record.

(QRCO.DE)

January - 2021

One Year On:The Impact Of The Coronavirus On Energy

The global energy sector endured a dramatic year in 2020, as the coronavirus (Covid-19) pandemic slashed demand and upended markets. Investor confidence slumped, with oil and gas one of the hardest-hit industries, as flights were grounded, fleets parked, factories and refineries closed, and work from home orders imposed.

(QRCO.DE)

December - 2020

Unconventional Fossil Fuels:Stranded in a Climate-Constrained World?

'Unconventional' fossil fuels cover an extensive range of resource types (heavy oil and oil sands, shale/tight hydrocarbons, gas hydrates), some commercially competitive today, others a long way from viability. The resource base is huge and will be a large contributor to production up to 2050. How will unconventional fossil fuels develop worldwide? Will environmental policies block their adoption?

(QRCO.DE)

OUR PARTNERS

The Al-Attiyah Foundation collaborates with its partners on various projects and research within the themes of energy and sustainable development.

Barzan Tower, 4th Floor, West Bay, PO Box 1916 - Doha, Qatar

Tel: +(974) 4042 8000, Fax: +(974) 4042 8099
www.abhafoundation.org

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