

# Carbon capture and storage expanding in leaps and bounds

*Over the past 20 years or so, carbon capture and storage (CCS) has been progressing in leaps and bounds, fueled by adoption of the Kyoto Protocol in 1997 and its call to urgently reduce CO<sub>2</sub> emissions in the environment. **Dr David Kearns**, Principal, Carbon Capture Technologies, and part of the Knowledge and Analysis team at the Global CCS Institute, talked to the OPEC Bulletin about the technology's expansion, development and opportunities. By **Maureen MacNeill**.*



*Dr David Kearns,  
Principal, Carbon  
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**A**ccording to statistics, CCS has been advancing at breakneck speed recently. The Institute's Global Status of CCS 2024 report shows that there are a record number of active projects in the CCS pipeline – from 392 in the 2023 report to 628 in the 2024 report.

An important figure is how many million tonnes per annum (Mtpa) of total CO<sub>2</sub> capture capacity is in the project pipeline – Mtpa shows compound average growth rates of 32% since 2017.

The figures as of February 2025, updated by Kearns for the Bulletin, show the number of facilities that are operational at 65 (57.38 Mtpa), in construction at 42 (44.39 Mtpa), with 272 (215.95 Mtpa) in advanced development and 336 (130 Mtpa) in early development.

Thus, when projects in construction are added to those operational today, it will enable operational capacity to exceed 100 Mtpa in the near future, says Kearns. There are more advanced projects, with Asia-Pacific and the Middle East becoming key regions, particularly in Southeast Asia.

"We're seeing something like 60 projects underway across lots of major industries, with cement, steel, hydrogen production and cross-border CO<sub>2</sub> shipping all gaining momentum."

## Historical development

Historically, the industry that really got things going was natural gas processing, says Kearns. This was a good starting point because CO<sub>2</sub> is already captured and separated in the processing of natural gas.

"That is business as usual (BAU), you don't pay extra for that. So essentially you have a huge head start. Yes, you have to transport and store it, but you've already done a good chunk of the spending and effort to separate and purify that CO<sub>2</sub> in the first place."

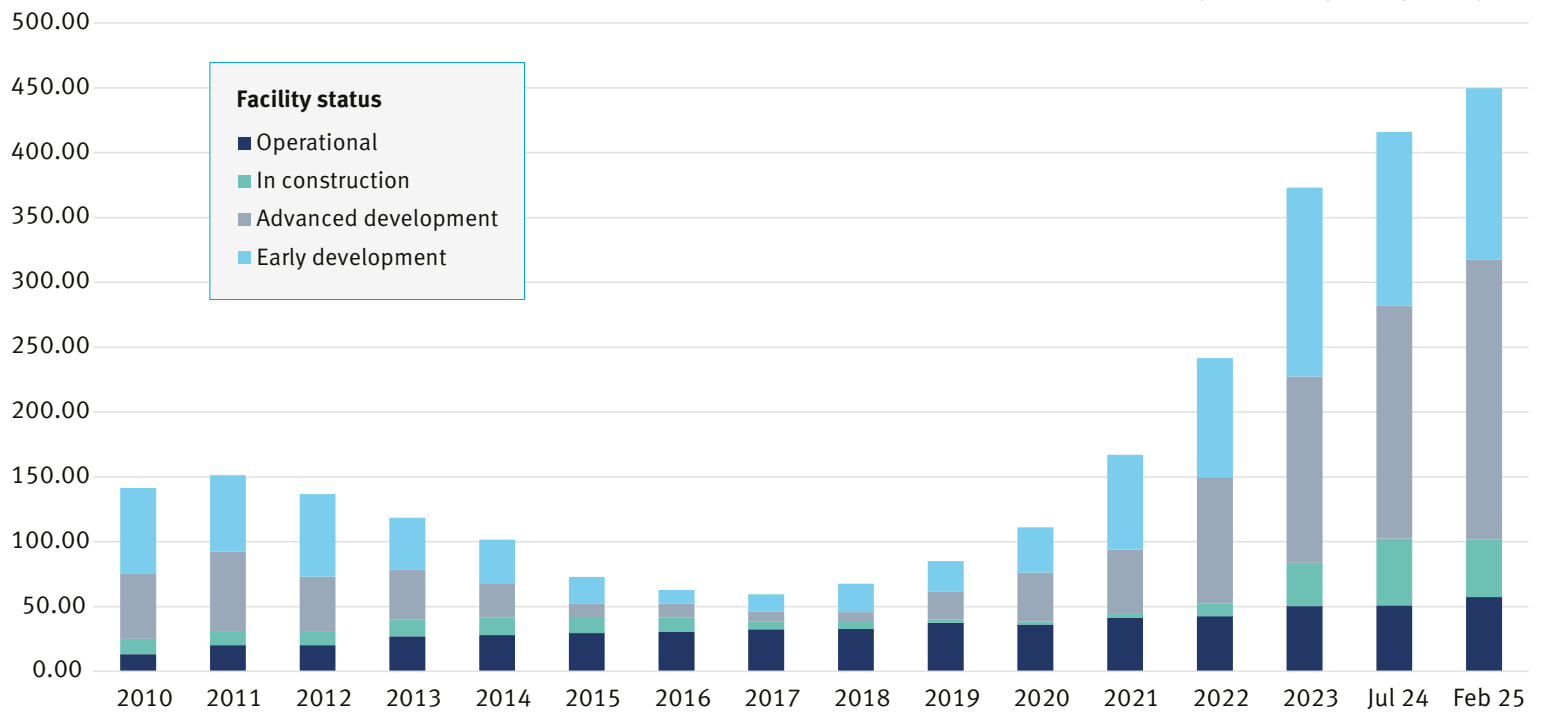
Before 2011, almost all CCS took place in natural gas. From 2011 to 2020, there was more of a split between natural gas and chemicals, like hydrogen, ammonia and fertilizer, says Kearns. In the period 2021 to 2025, there were lots of other industries in the early stages of development, including transport and storage projects.

"Those are projects that aren't necessarily going to be doing capture on their own, but they are building transport and storage infrastructure for others to use.

"We expect the trajectory to pretty much follow cost. So, the cheaper opportunities will be taken up first, and then as the incentives increase over time, which they will have to ... it will enable higher-margin opportunities to be exploited."

For example, Brevik – the world's largest commercial scale cement capture plant – officially opened recently in Norway. Cement is an industry that is going to need CCS in order to decarbonize, states Kearns. CO<sub>2</sub>

## CO<sub>2</sub> Capture Capacity (Mtpa)



production is a fundamental part of the chemistry of making cement, thus this project is really opening doors for a key CCS industry, he says.

Other new industries are emerging as well, such as the waste-to-energy sector, the first project of which is getting close to starting up. There are also projects in oil refining, a handful of projects in iron and steel, as well as bioethanol.

“One of the nice things about bioethanol is that you basically make pure CO<sub>2</sub> ... when you ferment grains to make ethanol for fuel. So, in effect it’s already captured, which means it is producing a high-purity CO<sub>2</sub> strain.

“Ethanol captures on its own without doing any extra work, but the challenge with ethanol is that the plants tend to be scattered around large areas, so the transport infrastructure is not as easy to build for that... in the US we’ve been seeing shared pipeline infrastructure for ethanol plants.”

### Roots in the oil and gas industry

CCS really got its start in North America, says Kearns, where it emerged from the growth of CO<sub>2</sub>-based enhanced oil recovery (EOR), which has been going on for decades in that part of the world.

“The technologies involved in capturing and storing CO<sub>2</sub> are identical. Whether you ultimately use the CO<sub>2</sub>

for dedicated geological storage or whether you use it for EOR, most of the supply chain looks the same. So of course, they’ve built up a lot of capacity and experience in running CCS in that part of the world.”

When people ask how old carbon capture is, Kearns says it has been around since the 1930s, when amine solvents were first used to remove CO<sub>2</sub> from natural gas, a technology being used for carbon capture today. It’s not new at all, he adds. “It was always used for processing natural gas, but the CO<sub>2</sub> was vented. There was no attempt to do anything with it.”

It’s fair to say the world was not seriously dealing with reducing emissions until the 1990s, says Kearns. “The Kyoto Protocol kind of kicked things off, but the idea of (removing CO<sub>2</sub> with) CCS was not particularly mainstream until then.”

Historically, until 29 years ago, almost all captured CO<sub>2</sub> was used for EOR, and then environmentally focused projects started to come into play, says Kearns. Norway was the first in 1996 in the North Sea. It separated the CO<sub>2</sub> from offshore gas then injected it back into a separate saline aquifer. The project is estimated to have injected over 20 million tonnes of CO<sub>2</sub> since it started.

“... they had essentially a financial penalty for emitting CO<sub>2</sub>, so that incentivized what is now Equinor to capture and store CO<sub>2</sub> from its gas operations.

“That was really important because it developed a lot of experience...on dedicated storage in saline aquifers, which are probably going to be the main type of formation storage used in the long term. We will use things like depleted oil and gas fields, we will use basalt formations, but saline aquifers are going to be the primary one. There’s just so many of them, and they’re very suitable.”

Since the mid-to-late 1990s, there has been a slow progression of storage dedicated to environmental purposes, with many of the projects currently in development focused on that, continues Kearns. Power projects that started coming online in the 2010s, with Boundary Dam in Canada and Petra Nova in Texas, were coal-fired power stations with CCS operations, both feeding into EOR.

“They were very good demonstration projects, with a lot of learnings,” states Kearns. “The International CCS Knowledge Center (in Regina, Saskatchewan) was founded off the back of Boundary Dam and had to share its knowledge with the world.

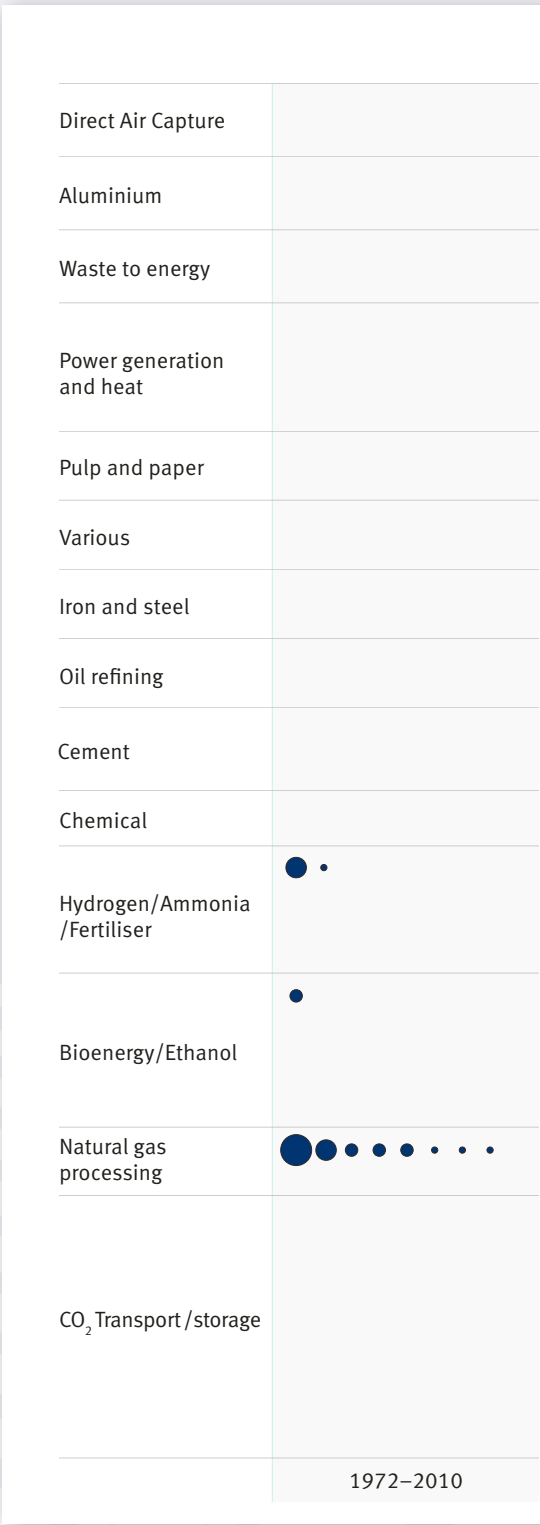
“That was a really valuable contribution by Canada to the world, because they had to build a first-of-kind plant, had to learn all the difficult lessons that come with first-of-kind technology and the fact that the rest of the world gets to access those learnings has been really valuable.”

Kearns adds that his institute encourages governments around the world to do the same. If they are going to provide grant funding for new technology and implementation, a string should be attached to that, he states, “...which is that you have to share the learnings on construction and operation of that plant with the world. That enables subsequent projects to have fewer problems and enables lower costs.”

The need for cooperation is really important, he states, because BAU would mean that a company develops a technology, learns from it and jealously guards that information.

“But we’re on a very, very tight time frame to try and decarbonize...we just don’t have time for companies to repeatedly learn the same lesson over and over...”

“That necessity of sharing knowledge and sharing learnings from project to project for other developers and between countries is really important because ultimately solving climate change is a global challenge, it’s not a challenge for any one company or country, it’s something we all need to do globally and collectively, and we’ll do it quicker and at a lower cost if we share as we go.”



As far as other parts of the world go, Europe is developing more projects both in the UK and the EU, as well as non-EU countries like Norway. The Middle East is taking off and has had some exciting developments, such as the world’s first CCS plant at a steel facility.

There is also increased activity in the Asia-Pacific. China, for example, is building new projects, some with



A view of the Northern Lights Carbon Capture and Storage project in Bergen, Norway.



locally developed technology, says Kearns, and is thus emerging as a technology development country. Projects have been developed in Australia as well.

### Cross-border transport

Cross-border transport is being strongly examined, and projects in the Asia-Pacific are being set up with the idea that in the future there will be receiving terminals for CO<sub>2</sub>, says Kearns.

“There is a bit of a chicken and egg situation when it comes to building CCS infrastructure. Someone has to take the first step to say we will provide a place for you to store your CO<sub>2</sub> and that will encourage others to build capture plants and supply chains.

“A lot of cooperation is needed, particularly for some of these larger-scale developments. It’s becoming less common that one company will build the whole thing end-to-end. It’s much more common now that you will have multiple companies in the value chain, and each will contribute in its own way.”

Northern Lights is a good example of a cross-border storage development, says Kearns, adding it grew storage in concert with its shipping supply chain.

“The two were developed hand in hand. They are doing it in a phased way and will likely see more of that in the future.”

The infrastructure isn’t necessarily all developed on day one in a plant, he says. A first piece is developed, then a second is rolled out, and a third and fourth phase. Northern Lights has a first phase pipeline and storage well in the North Sea and is now in the process of developing more storage and more pipelines to get the CO<sub>2</sub> to that storage over time.

“And essentially as they build more and more ships, pipelines and storage wells, it will grow and develop. Like any logistics operation, the chain is as strong as its weakest link. Whichever part has the lowest capacity in that chain will set the capacity for the whole chain. So, if you’re limited by ship capacity, you need to build more ships. If you’re limited by injection capacity at wells, you need to build more wells. You have to grow them in concert.”

### Ships and pipelines

Storage is necessary, but it is just one component of value chain, says Kearns. Transport is also very important. If you have, for example, domestic storage very close to your CO<sub>2</sub> source it can bring the cost down, because less is spent on transport.

“You’re not necessarily having to liquify it and put it on ships, you can just run it down a pipeline, which is cheaper. There’s a lot of benefits to that.”

He points to the Moomba project in South Australia, which is easy to manage because it is all in one country, and there is a 100 kilometre (km) pipeline on flat, empty territory. Thus, there are no issues regarding clearing land or making space for the pipeline, and the storage there is very good.

“They were very quickly able to build a 1.7 Mtpa facility because all of those factors were going to be in their favour.”

However, other projects are more complicated, such as those in Japan. “They’re having to work out not only how to capture the CO<sub>2</sub> and get it to port, but where to send it. So, they have to build a complete logistics supply chain; they have to build a fleet of CO<sub>2</sub>-carrying

ships, and thus it's a much bigger undertaking that requires a lot of cooperation."

Regarding transport costs, either pipelines work or ships work for most routes, with very few that could use both options. The cost crossover from pipelines to ships occurs in the 500-to-1,500-km range, he adds, depending on the situation. Under 500 km, pipelines are always used and over 1,500 km, ships are always used.

"For shorter distances pipelines will be cheaper and for longer distances, shipping is estimated to be cheaper, but, in practical terms, you don't normally get a choice. If you're sending CO<sub>2</sub> from Japan, you're not sending it by pipeline to Southeast Asia across the world's deepest ocean trenches, that wouldn't make any sense."

Bulk carriers are only now starting to come into the picture, says Kearns, but it is expected to be a very, very important transport mode, mainly because the world's storage resources are not evenly distributed.

"Some countries have more of them, some have fewer ... It's a particularly acute problem in Southeast Asia and Eastern Asia; Japan and Korea have lots of emissions and don't have abundant, local CO<sub>2</sub> storage, so they are looking afield, and the major emitters are looking afield at where they can find storage.

"If you look on a storage map, it's Southeast Asia, particularly Malaysia and Indonesia, as well as North Australia. We expect to see those as real growth areas."

Ships are generally built new for CO<sub>2</sub> transport, rather than retrofitted, states Kearns, adding the bulk CO<sub>2</sub> shipping is a new industry. Kearns lists a number of ships being built or which have already been delivered with a carrying capacity of between 2,000 cubic metre (cu m) to 22,000 cu m each.

"When you get longer and longer distances for transport, economics and logistics push you towards larger and larger ships, it's a very similar cost drive to what we see in liquefied natural gas. Tankers are large for good reasons. It's cheaper to ship that way than in lots of smaller ones.

"At the moment, none of those really large CO<sub>2</sub> tankers exist, but there are plans on the drawing board; until they're announced, we don't know the details. But, we have heard anecdotally from people that there are plans for 50,000 cu m and above-sized tankers ... It's just a question of the market being ready to use them before someone wants to build them."

In addition, there have to be CO<sub>2</sub> liquefaction facilities to cool and pressurize the CO<sub>2</sub>. There has to be dockside infrastructure that not only liquifies CO<sub>2</sub>, but

stores it for when ships arrive so it is ready for transfer onto a ship. Another set of storage tanks is required at the receiving port to offload the CO<sub>2</sub>.

"That's what they have at Northern Lights. The terminal has 12 individual CO<sub>2</sub> storage tanks in Phase 1, with more to come in later phases as capacity rises. This means that they can offload ships quickly, and the ships can head off to get the next load. You don't generally pump into storage from a ship, because that would hold the ship in place, and you want a ship to be actively transporting."

There is another hurdle to transboundary transport, states Kearns. Maritime movements are impacted by the London Protocol, whereas if transport is taking place on land or via an inland waterway, the countries concerned can sign agreements amongst themselves, in which case international law would not apply.

"Parties to the London Protocol are basically the different parties that signed up to it back in the day, and they have to take responsibility for complying with its provisions regarding transport and subsea storage of CO<sub>2</sub>. It was originally conceived of as an anti-waste dumping protocol...and CO<sub>2</sub> is deemed to be covered by that."

Bilateral agreements as defined in the London Protocol are needed between governments to enable cross-border transfer and storage of CO<sub>2</sub>, and it seems there is currently only one such signed between Belgium and Denmark. However, there are letters of intent and Memorandums of Understanding (MoUs) between other pairs of jurisdictions both in Europe and the Asia-Pacific.

"People want to do this, but getting two governments to agree on anything doesn't happen quickly ... I think the fact the intentions are being made clear means there is an appetite to do this. And that will be necessary for actual movements to commence. You can do development work, engineering and Final Investment Decisions, but nobody is going to commit serious money until they know the legalities are covered off."

A lot of the legalities regarding CCS are in new territory, with subjects to be considered like CO<sub>2</sub> accounting and who would be responsible for leakages during transport, etc. "None of it is insurmountable. It's a matter of people deciding they want to do this and pairs of countries agreeing to it."

### The importance of policy

It is hard to overestimate the importance of policy in getting CCS projects off the ground, states Kearns.

“Government policy is absolutely essential for CCS and carbon capture, utilization and storage (CCUS) projects to happen, because if you don’t have policy, the BAU is to emit for free, and it’s very hard to compete with free...”

“No decarbonization would happen if we didn’t have policy, not just for CCS, but regarding other decarbonization as well. Policy creates the conditions where CCS projects can develop a business case, and no one is going to invest the amounts of money required without a very solid business case.”

Each country and region is taking its own approach to this, he adds, but, overall, it is improving.

“I think there is a recognition that the activity which has occurred to date has not been sufficient to really dig deep in terms of emissions reductions.

“For example, there was a promising roll out of renewables across the world, but emissions keep going up because we keep using more energy and keep using other products and services that produce emissions. We have to do more across the board in every decarbonization option, and for all that to occur, supportive policies are going to be essential.”

Transfer of technology is also something to be considered, he adds. There are countries, for example, such as India, that are going to need very large amounts of CCS to decarbonize. Although they have a lot of good intellectual capital, they may not have a lot of domestic technologies developed, states Kearns.

Thus, they will have to license technologies from other countries. “That’s a good example of a country that could benefit from technology transfer. Any licensing fee you’re paying is going to increase the cost of doing CCS.”

Regarding financing, the main trend the Global CCS Institute is observing is that most projects are pulling funds from multiple sources.

“It’s not that common to see a project solely resting on one source of funding. So we will see some projects with a combination of government grant funding. We’ve seen a lot of that in the EU and the UK, where you get things like finance via tax credits and in the US with 45Q.

“In some parts of the world, like the EU, there are emissions trading schemes, and every tonne of CO<sub>2</sub> that you capture is one that you are not paying an emissions permit for, so that is essentially a source of benefit a project can bring forward.”

Thus, each location has a different policy mix, and there are differing appetites by governments to add money in terms of grant funding.

“I think longer term, we’re probably going to see more of an emphasis on these projects being able to stand in a more sustainable way on their own. That’s going to mean that in one form or another, in many parts of the world, a price will be placed on CO<sub>2</sub> emissions. In the EU, we’ve already got that in the form of the Emissions Trading System. In some other parts of the world, we don’t have that.”

There is also an interesting flow of money coming from private markets, states Kearns, particularly for technologies such as carbon dioxide removal.

“Some tech companies, like Microsoft, are interested in capturing and storing their historic CO<sub>2</sub> emissions. That’s a voluntary market and not something they have to do, but they’re doing it for their own purposes. This is fairly niche in terms of tonnage but quite interesting in that they’re prepared to pay a pretty high premium for that.

“It’s a precedent, and there is also recognition that that funding can help push those technologies out of the cradle and into a more optimistic projection in terms of getting cost down over time.”

## New manpower

The oil and gas industry has a lot to offer in terms of the future manpower required, according to Kearns.

The US Department of Energy specifically looked at this issue and identified some main careers that are needed for CCS, says Kearns, including traditional engineering disciplines, such as chemical, processing, mechanical and electrical engineering. Geology and environmental geoscience-type experts are required to understand storage formations and reservoirs. Operators and maintenance people are required as in any other industry, along with health and safety people to manage the regulations and associated risks.

“If you look at each part of the value chain in turn, they’ve got obvious analogues with other industries. CO<sub>2</sub> capture is essentially a petrochemical operation and so, in many cases, people who have experience in designing and operating petrochemical facilities can, with a modest amount of training, move across to being involved in that.

“We’ve seen in some instances people in CCS divisions of oil and gas companies be transferred across their chemical and refining divisions, for example. That is where they are sourcing a lot of their people.”

There has been some talk that CCS might be a helpful pathway for some workers in just transitions,

states Kearns. As certain industries like oil start to decline in some regions, some of those people can be reskilled in CCS.

“I think that’s a really promising thing in some parts of the world... you will need more new people as well, because faces need to be renewed over time as people age out and retire. We are going to need more people training in engineering programmes, people doing trades and also specific CCS programmes in regions with a lot of CCS activity.

“We don’t want the industry to be held back due to a lack of capable people, and I think we’re going to get them from all over the place. It’s also a global industry, and so we expect some places will see movement of people from one place to another to make sure those roles get filled.”

### Other CO<sub>2</sub> removal technologies

There are other CO<sub>2</sub> removal technologies that can remove gas from the atmosphere and in some instances from oceans as well, says Kearns.

“Those are still in the fairly early days ... They need really supportive policy frameworks to get off the ground, especially given the expense and the cost of building those facilities. It is going to take an ongoing effort in order to give CCS generally and direct air capture (DAC) in particular, the opportunity to grow and develop,” says Kearns.

The big question regarding DAC is how rapidly the unit cost can drop, he adds. “If it remains \$500 per tonne indefinitely, then it is going to probably remain a fairly niche industry. If they can get it down to \$200/t, it will have a bright future, and there will be a lot of potential for it.

“DAC can also displace other decarbonization options... Aviation decarbonization is a really good example. Sustainable aviation fuels are very expensive at the moment. If you can get DAC prices down, than you can just do DAC instead and continue to run with the standard fuels and fuel supply chains you have today.”

DAC is more difficult because it captures very diluted CO<sub>2</sub> in the atmosphere, about 400 parts per million, states Kearns.

“Every tonne of air contains 0.6 kilogram of CO<sub>2</sub>, so you’re dealing with needle in a haystack kind of molecules floating around in the atmosphere. This means you need to handle a very, very large volume of air. For every tonne of CO<sub>2</sub> capture, there are thousands

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of tonnes of air, and that means physically large equipment ... that’s capital cost, and it’s very hard to avoid that.”

Some interesting new DAC approaches are more passive and do not use fans, they just occupy a large area and soak up CO<sub>2</sub> naturally from the atmosphere.

“The other thing is thermodynamics. There’s a requirement for more and more energy to separate a diluted gas from the air than from a more concentrated CO<sub>2</sub> stream, say from a power station. The more diluted the CO<sub>2</sub> gets, the more energy you have to put in, and that’s operating cost.”

In terms of bringing the cost down, the industry will have to learn from earlier projects and implement learning by doing, as well as continuing R&D work. “Eventually we will hopefully see lower costs, but how that process goes is hard to say. It’s going to start bumping up against some very hard-to-overcome limitations.”

### Bright future

Ultimately, CCS is a globally developing industry, which has really taken off over the last few years, says Kearns, after quite a few years of discussions but no real projects on the ground.

“I think we’re now starting to see that acceleration we so desperately need...we have a long way to go, and that will require every decarbonization option, CCS included.”

There are many pathways with different amounts of removal attached to each decarbonization measure, but they all are not equal in terms of cost or timeliness.

“Our own team has a macroeconomic model called GENZO, which models the cost globally with varying amounts of CCS (removal).”

Achieving Paris Agreement emissions reduction objectives will be virtually impossible without CCS, he says. The more CCS that’s deployed, the lower the overall cost of reaching desired climate goals will be, adds Kearns. ■