



Scaling up CCUS – market insights

A report by Decarb Connect in association with Carbon Clean

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Welcome

CCUS is rising up the industrial agenda. Over the next five years we expect to see hard-to-abate sectors re-evaluating their strategies as the pressure to decarbonise increases on all fronts and 'low hanging fruit' solutions such as process efficiency measures are exhausted. CCUS certainly feels like a strong solution to reduce carbon emissions, but many questions remain around rollout, costs and business models.

For many companies there are questions around how quickly to select decarbonisation technologies: commit too soon and risk losing out on newer developments but leave it too late and risk falling behind as the demand for low carbon materials accelerates. This first of its kind benchmark report aims to address the questions which remain around CCUS solutions, and to help leaders in hard-to-abate sectors understand how and when CCUS solutions can make the most impact for their businesses.

I'd like to thank everyone who took the time to share their views and experiences through the survey, our expert panel of contributors and, of course, our sponsors Carbon Clean, who have enabled us to put together this important piece of work.

We look forward to your feedback and comments on the report and hope it plays a useful role in your discussions.



Alex Cameron
Founder & CEO
Decarb Connect



Aniruddha Sharma
Co-founder & CEO
Carbon Clean



We are on the cusp of a new era for carbon capture. A renewed determination to decarbonise, coupled with innovation in the sector and a shift in the economics, are resulting in a resurgence of interest in CCUS.

We see this through our growing order book and significant investor and partner interest. But is this view supported by those working in hard-to-abate industries? This Decarb Connect survey was conducted to find out, and we are delighted to be the survey sponsor.

The International Energy Agency has stated that to achieve net zero emissions by 2050, CCUS capacity needs to be ramped up 190-fold and that for heavy industry the value of CCUS is 'inescapable'.

At the same time, carbon capture solutions are becoming increasingly cost-effective and simpler to install, so past challenges to adoption are set to be overcome.

Gaining insight from those at the sharp end of industrial emissions is invaluable as we further develop solutions to scale up the adoption of CCUS. There is cause for optimism in the survey findings and we expect to see this grow in coming years as the next generation of carbon capture technology and services come to market.

Report Methodology and Contributors

This Decarb Connect Report combines both qualitative and quantitative techniques to give a thorough insight into the current state of play for CCUS strategies and projects across hard-to-abate sectors.

The report statistics and figures are taken from an anonymised survey of 70 hand-picked senior executives, chosen to represent prevailing thoughts and experiences across the industry, with just under 60% of respondents representing hard-to-abate asset owners, and 40% chosen from industry thought leaders such as policymakers, financial executives, academics in the subject area and industry experts.

In addition, we are honoured to have worked with a panel of senior experts on the qualitative stage of report research, who provided insight and context to the data gathered through a series of in depth interviews.

Many thanks to the Decarb Connect report contributing panel:



Brent Constantz
CEO
Blue Planet



John Norton, Jr.
Director of Energy,
Research and
Innovation
Great Lakes Water
Authority



Markus Rentsch
Technical Director
Jura Management
AG



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Equinor Ventures



Cem Gercek
Regional Operations
Manager and
Decarbonization
Leader
Carmeuse



Alfredo Carrato
Venture Architect
CEMEX Ventures



Dimitrios Koufos
Lead Direct Finance -
Associate Director, Energy
Efficiency/Climate Change
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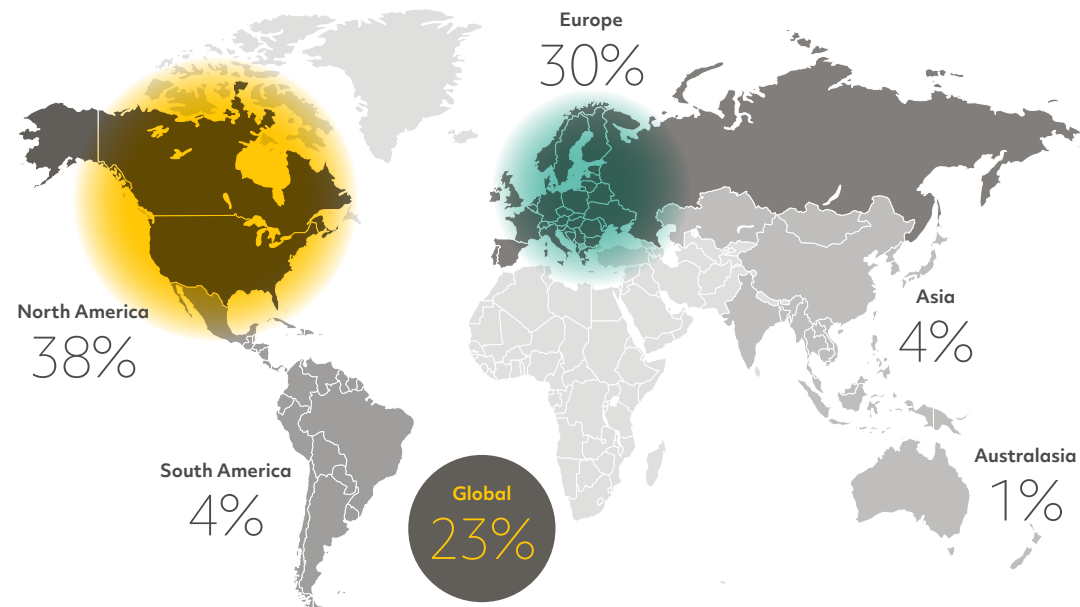
Survey Demographics

Decarb Connect selected a cross section of senior representatives from across our network, to gain as complete a picture as possible of prevailing attitudes to CCUS in hard-to-abate sectors.

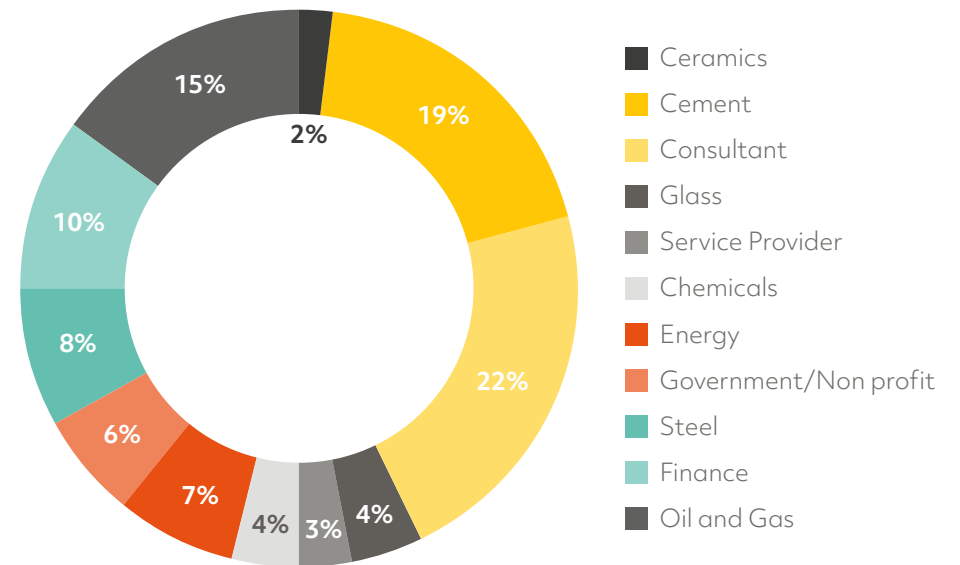
Unsurprisingly, North America and Europe represented two thirds of respondents by geographic responsibility, given these two regions lead in terms of incentives, technology and corporate commitment to decarbonisation. However, a third of responses came from executives with responsibilities in Australasia, Asia, Central and South America and from across the globe, suggesting interest and ambition is growing worldwide.

In terms of sector response, cement was the most highly represented hard-to-abate sector, followed by oil and gas and steel. Thought leaders from government, academia and specialist consultancies also contributed their experience.

Geographical responsibility of the respondent



Survey respondent sector





Section One: The Economics of Carbon Capture

The cost of carbon

While the environmental credentials of CCUS are generally fairly solid, the current economic case for rollout is less clear. Only a quarter of respondents to our survey felt that deploying a CCUS solution is economically viable for their business, with another quarter unsure and almost half feeling it isn't viable at all. See following page for full breakdown.

Our panel of experts were quick to point to the clear 'chicken and egg' situation hampering significant change: without the sequestration and utilisation infrastructure in place to make use of carbon, it's hard to see a viable offtake scenario, but unless carbon is captured on a large scale, supply is too limited to incentivise new players or solutions into the market.

'It's an issue regarding the economies of scale that should work well once people and or companies start implementing it: production levels will increase and costs will come down, but you've got to get across that economic barrier first,' explains Lorna Bennet, Project Engineer, at the Offshore Renewable Energy Catapult. 'The government often relies on the free market, i.e. big companies with deep pockets implementing and bringing the cost down for everyone else, but it still comes down to volume and initiative and that will likely need a change in policy to make it happen.'

Brent Constantz, CEO, Blue Planet, agrees that viable supply chains need to be in place, but argues that a more sustainable and long term understanding of how carbon can be used is needed to make the value chain work. 'What comes out of a power plant or a truck or

a cement plant isn't pure CO₂, often requiring further processing.' Brent also makes the point that with many schemes currently driven by subsidies, there's a need to see how future models can emerge that ensure the economics work in the long term.

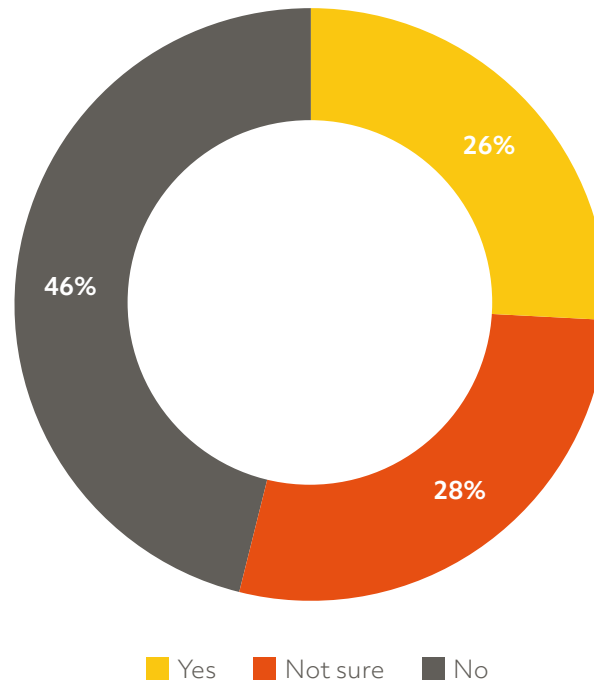
The need to develop carbon utilisation and storage use cases in industries other than oil and gas is something Cem Gercek, Regional Operations Manager and Decarbonisation Leader at Carmeuse, sees as critical for decarbonising the industry. 'Carbon tax schemes to support development aren't high enough or are non-existent in some countries and the capex to build capture equipment is extremely high. Even after capturing the CO₂, storage requires major infrastructure including pipelines. We need to work out how carbon can fit into existing supply chains for utilisation to make the carbon value chain viable.'

Dimitrios Koufos, Lead Direct Finance - Associate Director, Energy Efficiency/Climate Change sees safe sequestration as being vital to scalability. 'Using carbon in cement or animal feed is viable but these industries won't have the impact at scale to impact CO₂ emissions. We need to use existing underground storage to make sure CO₂ is safely taken out of the atmosphere.'

Pressure for next level solutions

As the carbon markets mature and pricing supports further investment, we can expect to see the rollout of CCUS solutions accelerating. When comparing CCUS to other higher-investment solutions, such as green or blue hydrogen, the numbers increasingly stack up on the side of CCUS.

Do you feel that deploying a CCUS solution is currently economically viable for your company?



It has been interesting to see that the results of the survey create a small curve (see page 7) with those most ready to implement CCUS requiring cost-effective carbon capture, and another cohort of industrials who will need to see a huge shift in the market to make it worthwhile.

Those who are further along the adoption path aren't necessarily simply more ideologically

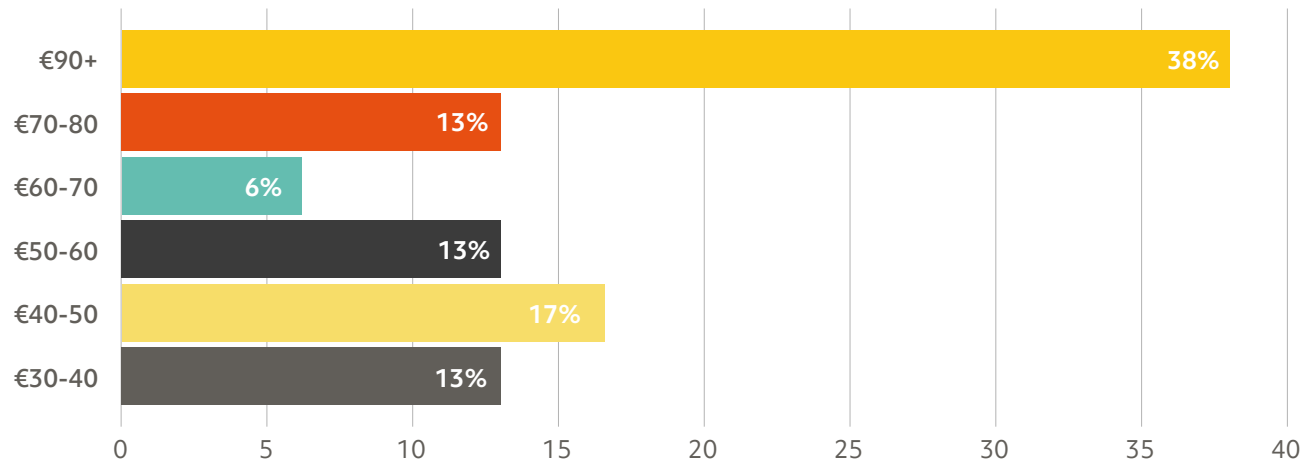
motivated; they also see the bigger picture and longer-term benefits of being among the first movers. Several of our panel spoke about the PR and IR wins to be gained from taking the initiative in carbon capture, and how switching to 'cleaner' processes will pay off in the longer term. Markus Rentsch, Technical Director at Jura Management AG explains the way Jura sees the issue: 'We don't have an option, CCUS has to be a viable option. The way we see it, the way we live and build on a global scale, we need to capture CO₂ and then either use it or store it. I see two big elements which need to fall into place before we can achieve scale with this: one is the technology but the other is also the political and societal framework to support it: laws, rules and specifications.'



Technological innovation in carbon capture is happening at pace and the cost of carbon captured is reaching a point where the economic case for CCUS is undeniable. We are already experiencing a huge uptick in demand from industry and we expect to see this gather pace once our latest modular and scalable solution comes to market. There is undoubtedly still a case for government support, and the implementation of carbon pricing is also key to ensuring that the economics align with policy objectives."

Aniruddha Sharma, Co-founder & CEO, Carbon Clean

What cost per tonne of carbon would make CCUS viable for you?



Making CCUS work in the field

We asked the industry about the most influential factors on their decision making when it came to CCUS rollout. Operational considerations are the highest, with the need for new staff to manage technology and supply chains, business interruption during installation and the pressures of ongoing maintenance making up well over half of the issues raised. On the other hand, pressure from shareholders and customers to reduce carbon emissions amounted to around a third of concerns, suggesting that the friction between strategic goals and operational pressures is still tipped out of favour of CCUS at present.

Investing in a CCUS solution is a huge commitment for industry, and the risk of obsolescence, or at

least of technology leapfrogging current offerings as research accelerates, is a major deterrent for those poised to invest. Luckily, an increasing diversity in financial models is emerging, allowing industry leaders to pay for results, rather than equipment. It's not surprising, therefore, that 41% of respondents are most interested in a fully funded CCUS model, and 59% prefer a mix of funded/operated and owned equipment, with no respondents choosing an option for an outright equipment sale.

The Decarb Connect expert panel agree that the one thing which needs to accelerate most of all is collaboration, whether between peers, between technology providers, or between academics and industry. As Siri Hoven, an

Investment Manager at Equinor, explains: 'I think the one thing missing is the relationships and partnerships to make things happen. We need to firm up our alliances for both capturing carbon and for the onward supply chain.'

How does CCUS stack up as a part of the decarbonisation mix?

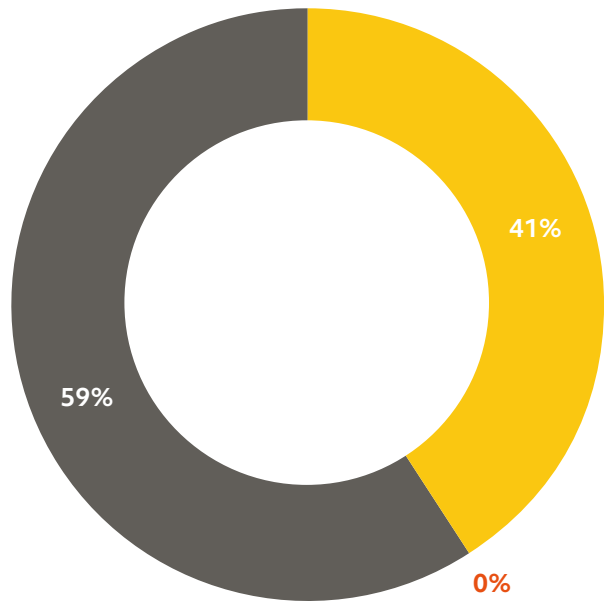
While the adoption of efficiency measures has been accelerating for years, such measures still won't get hard-to-abate industries close to their 2030 or 2050 targets. So what about additional technologies?

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There's no question, CCUS is needed to achieve global net zero targets. The IEA's CCUS in Clean Energy Transitions report (September 2020) makes this abundantly clear: 'We need to take urgent steps to ensure CCUS is available to contribute to net-zero goals. A major ramp-up of CCUS deployment is required in the next decade to put the global energy system on track for net-zero emissions.' Investors and other key stakeholders will expect hard-to-abate companies to have a CCUS implementation plan. The good news is that the cost of implementation is dropping rapidly.

**Aniruddha Sharma, Co-founder & CEO,
Carbon Clean**

What financial model for CCUS would work best for you?



- Fully funded CCUS (Build, Own and Operate model)
- Outright equipment sale
- Mix of the above

Brent Constantz of Blue Planet believes CCUS is a strong option, explaining that 'green hydrogen is a fabulous concept if you have green power, but if you use that power to electronically make hydrogen in order to generate more power, you might as well use the green power you generated in the first place. With regards to blue hydrogen, that requires carbon capture and faces the same problems with sequestration.'

In some industries, with cement and lime an obvious example, carbon is unavoidable. 'For hard-to-abates like lime and cement it doesn't matter what you burn to produce energy, CO₂ is emitted as a result of calcination reaction where CO₂ is driven off from calcium carbonate, so some form of carbon capture is a must. CCUS will always be a key part of decarbonisation, regardless of alternative fuels,' says Cem Gercek of Carmeuse.

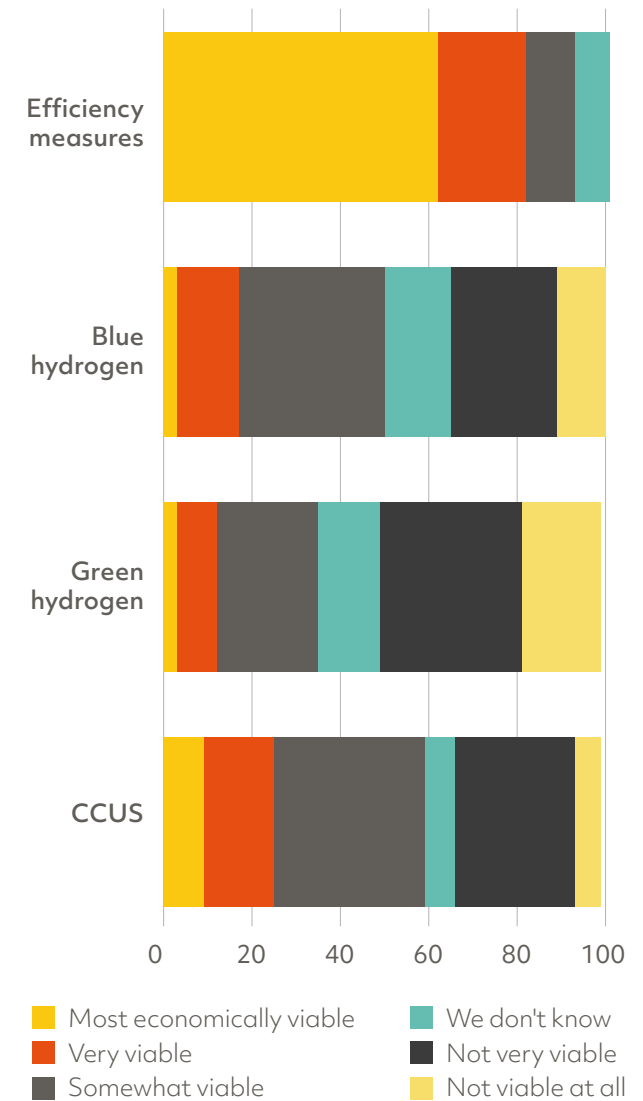


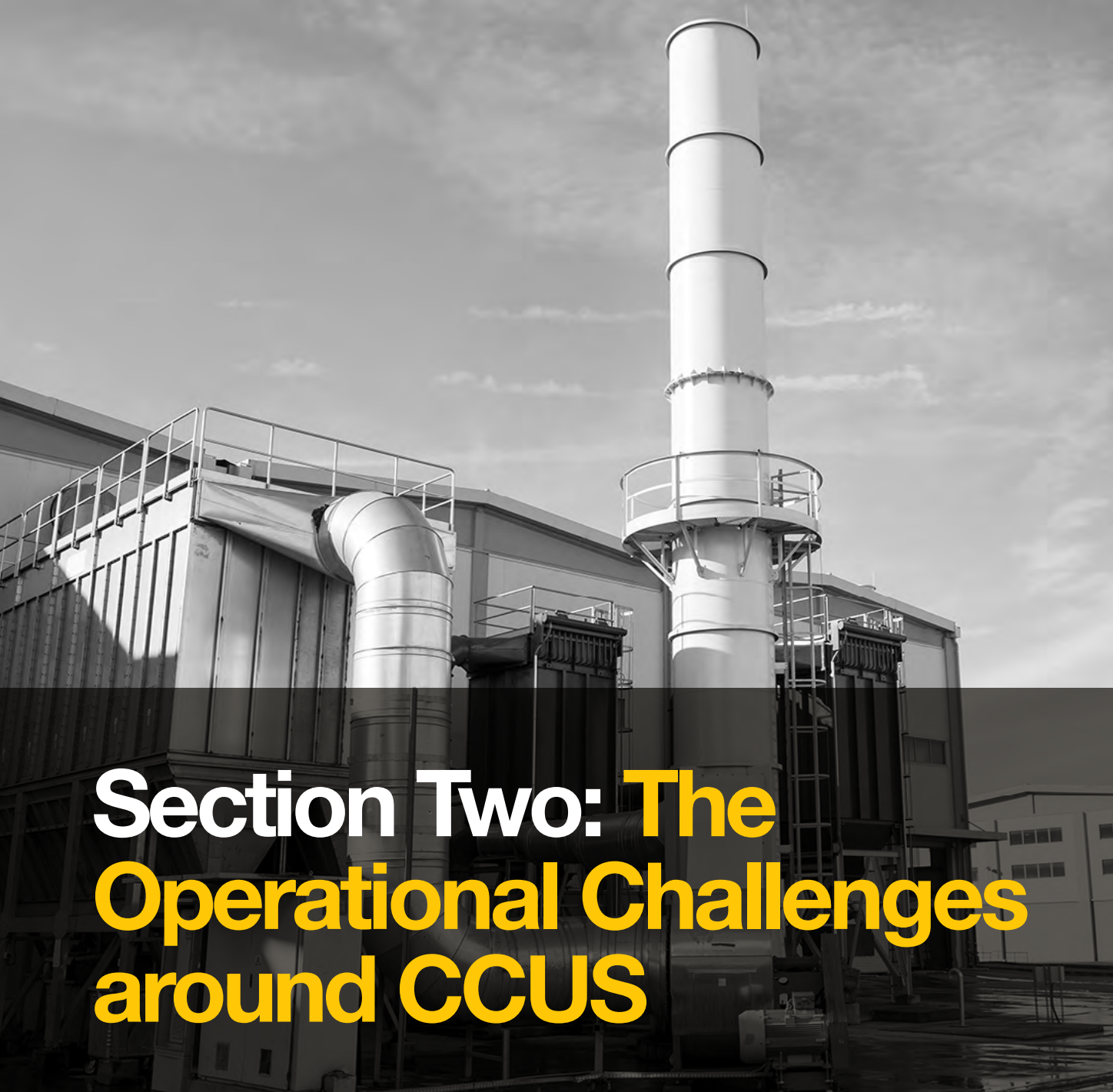
We know that a range of CCUS solutions will be needed and our Carbon Capture as a Service (CCaaS) offer is part of that. It will provide customers with a streamlined and simple means of capturing carbon – with payment for tonnes of carbon captured and all aspects of the service delivered by Carbon Clean. So, companies with minimal in-house experience and capacity to purchase and install carbon capture technology, will still be able to achieve the benefits of CCUS.

CCaaS makes carbon capture accessible to a much greater number of companies and is crucial to overcoming some of the main barriers to even wider global CCUS adoption.

Aniruddha Sharma, Co-founder & CEO, Carbon Clean

Which decarbonisation solution do you feel is most economically viable for your business?





Section Two: The Operational Challenges around CCUS

Business interruption

Respondents agree that implementing CCUS into their processes would be disruptive, with 79% of industry experts suggesting the installation of a carbon capture solution would be either 'highly' or 'somewhat' disruptive to their businesses, necessitating careful planning to roll out with minimum disruption.

The single most frequently mentioned concern to come up in the survey was around the onward transportation and disposal of captured carbon, from the distance to markets, to the development of transportation and storage infrastructure, as well as markets for carbon use. Operational issues around land and space requirements are the second biggest area of concern, followed by worries around project financing for such large scale and capex-intensive projects. Governmental support and incentives are also frequently mentioned.

Alfredo Carrato, Venture Architect at CEMEX Ventures, agrees that rollout at scale is going to be a headache financially. 'Right now industry players like ourselves have pilot projects that border profitability, but as you scale up additional sources of project finance become undoubtedly necessary.' He explains: 'public funding will have an important role to play, particularly when developing the infrastructure network, as it needs to show the potential of the market in order to attract private investors and drive scale in the longer term.'

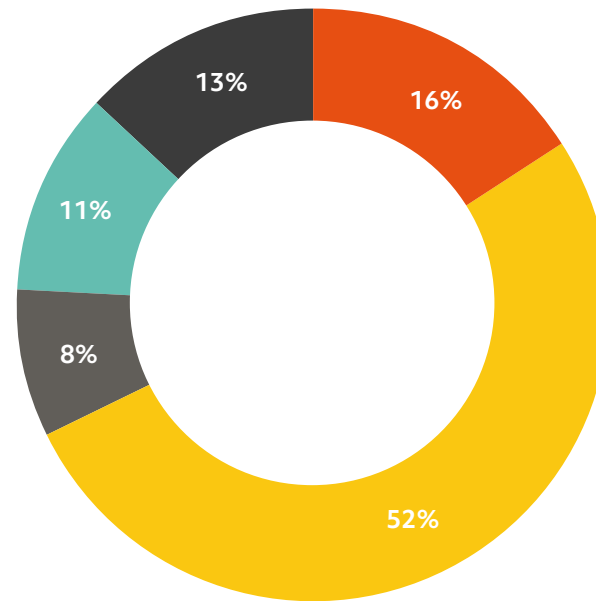
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Innovation in carbon capture is addressing many of the traditional operational concerns. Pre-fabricated, modular carbon capture technology will mean an end to costly operational disruptions and long installation times. For example, we are developing modular technology that can be manufactured off-site and which can reduce capital costs by up to 75% and operational costs by 50%.

The advent of Carbon Capture as a Service (CCaaS) will also reduce disruption for many companies – installation, servicing, and management of the technology will no longer be their responsibility.

Aniruddha Sharma, Co-founder & CEO, Carbon Clean

Will you need to recruit or change team structures in order to manage CCUS within your business?



- No, we can expand the remit of existing roles
- Yes, some change will be required
- No, this won't affect our business at all
- Yes, we will require significant change
- Not sure

Who manages CCUS?

The introduction of CCUS will necessarily introduce new responsibilities into business operations, with 11% stating that rollout requires ‘significant change’ to existing team structures and a further 52% anticipating some change. Only 8% of responses from industry foresaw no changes to roles across their business at all.

However, as CCUS solutions evolve, there’s an opportunity for many of the skills and processes needed to run the equipment to be outsourced. We

asked respondents what their ideal scenario would be in terms of system ownership, and only 9% want to take 100% responsibility post installation.

‘Of course, with time I think we’ll see that more and more functions need to collaborate on

CCUS, so you have sustainability and also finance, accounting and operational teams,’ says Siri Hoven of Equinor. Markus Rentsch of Jura Management agrees and is optimistic for the future: ‘We’ll need more people on the subsequent steps, where a new generation will come with new studies, new know how and new skills. It’s an exciting time for young people, exploring what can be done with CO₂.’

Operational priorities

Our research partners, Carbon Clean, asked us to investigate the appetite of industry for a CCaaS type solution, reducing the manpower and management needed by the site owner. It’s clear from feedback that the concept is gaining traction, with a quarter of respondents opting to ‘be as hands off as possible’ and, indeed, only 9% choosing to take 100% management of the system post installation. There are of course a number of mitigating factors involved in this decision making process, as shown in our contextual interviews, during which some panel members state a strong preference for maintaining control, while others are actively seeking to outsource as much as possible.

Indeed, even among our expert panel there is a full range of attitudes about how carbon capture could best be performed. Lorna Bennet, of Catapult compares the model to an existing case. ‘When a new wind farm is constructed, it’s quite common for the OEM to have a five year standard maintenance contract, then at the end of that five year period the wind farm owner can re-negotiate and take

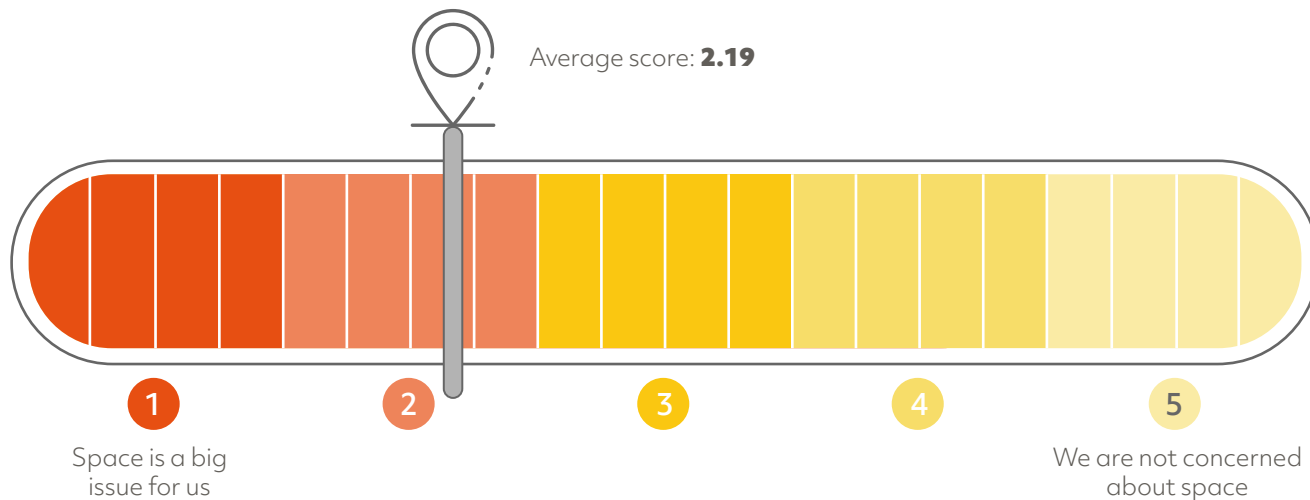
over responsibility themselves or find another service contractor. A similar model may be one way to get CCUS started and allow companies time to recruit or train the necessary skills required for O&M of the systems.' Her views are countered by Markus Rentsch at Jura, who sees carbon capture as an asset to be integrated. 'The technology to capture CO₂ in the cement plants will be ready soon and will be owned and operated by the cement plant operations. What still needs to be designed and arranged are downstream logistics or utilisation facilities in order to manage the very

large volumes of CO₂ that will be generated on a continuous base.'

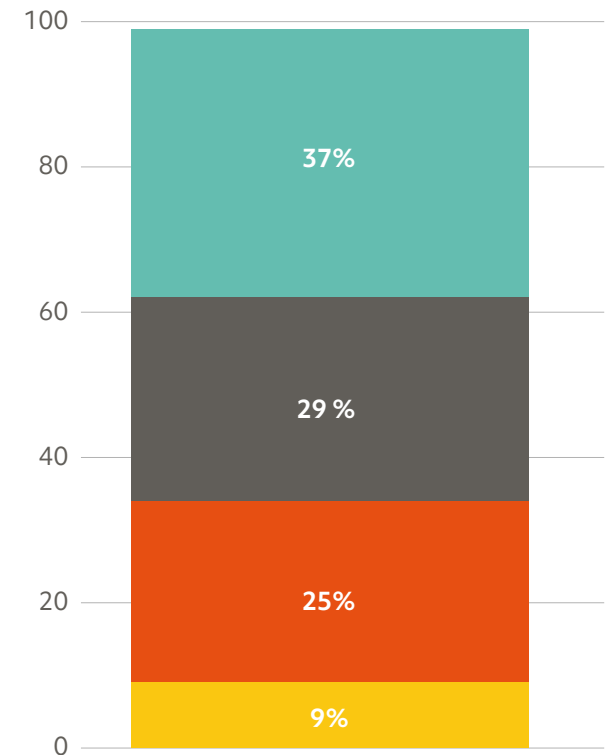
In terms of space, it's clear that for the majority of asset owners, space is at a premium, with respondents' marking space as a major concern. As John Norton, Jr. Director of Energy, Research and Innovation, at Great Lakes Water Authority says: 'Space is very, very challenging for us, we'd need a vendor that could understand how to integrate their facility within existing operations, within our existing footprint, something that fits right in.'

Would you consider space an issue when considering the rollout of a carbon capture system?

We asked participants to score the issue of space when considering a carbon capture rollout, with 1 showing 'space is a big issue for us' and 5 equating to 'we are not concerned about space'. The average score across all participants was 2.19.



Which decarbonisation solution do you feel is most economically viable for your business?



- Work with a partner who can provide help and support throughout
- Take ownership of the system with dedicated support from the vendor
- Be as hands off as possible and leave a partner to manage the CCUS system
- Take 100% ownership of running the system once it is installed



Section Three: The Pace of Rollout

The role of CCUS in hitting decarbonisation goals

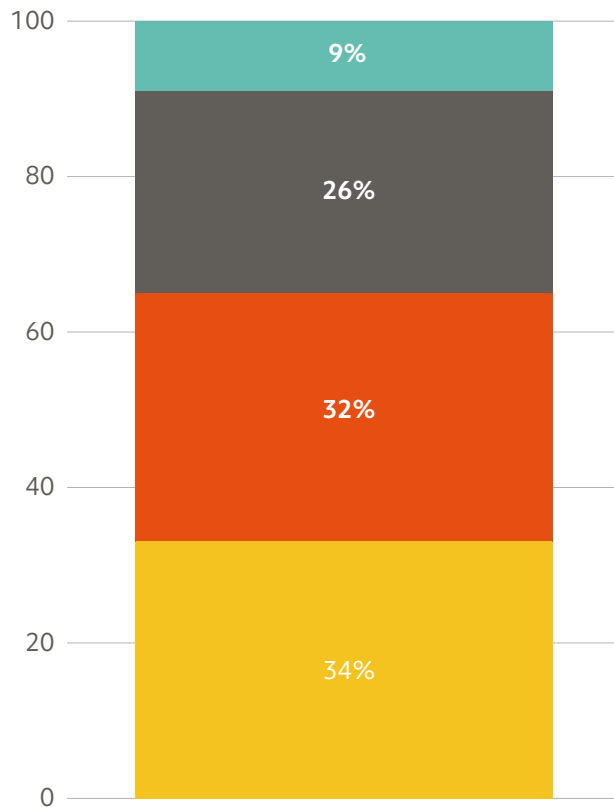
Our survey uncovers something of a paradox in terms of attitudes to CCUS. Three quarters of respondents don't feel (or weren't sure if) the CCUS value chain offered a clear path for their business however 65% see it as 'critical' or 'important' and plan to use it to reach their 2030/2050 goals.

There's a clear friction between the longer term, strategic vision for a low carbon world and the short term need to overcome operational and economic hurdles to create a pathway to get there. Asset owners are currently stuck between the potentially challenging task of rolling out a carbon capture solution, and a carbon value chain which only 12% of the market feels offers a clear path for their business.

However, the fact remains that CCUS offers one of the best routes to reducing carbon emissions for hard-to-abate industries. 'CCUS isn't the sole solution, but it's critical,' says Siri Hoven from Equinor. 'We don't have time to develop new solutions, it will take a decade and we need to move this decade. The question is how fast are we able to scale up and put this in motion? Hopefully there will be more solutions a decade from now but it takes time and we need to act now.'

In terms of infrastructure, there isn't time to set up new pipelines or develop adequate sequestration capacity, our expert panel agrees that we need to

How important do you consider CCUS to be for you to reach your 2030/2050 goals?



- Not important - it's not something we're planning to roll out
- Quite important - we'd like to use CCUS if we can
- Important - CCUS is a key part of our planned decarbonisation mix
- Critical - we won't hit our goals without CCUS

use existing supply chains and reuse whatever we already have in order to make it work.

The good news is that many experts feel we're on the cusp of acceleration. With the will of major governments in the US, UK and European Union behind CCUS projects, we can see at-scale rollouts happening over the next decade.

Alfredo Carrato at CEMEX Ventures feels that public investment will be diverted away from carbon capture after 2025. 'Subsidies will gradually be reduced by the second half of this decade so private investors can enter the game. After 2025 we will see public funding shifting more to utilisation and storage, so more hubs and players become available across the entire CO₂ value chain.'

Dimitrios Koufos, Lead Direct Finance - Associate Director, Energy Efficiency/Climate Change agrees with this timescale, saying we'll see a sharp acceleration in CCUS rollout from 2035. 'That's where the low carbon pathways for hard-to-abate industries will start to be viable. We'll also see the regulatory environment slotting into place – between now and 2030 governments will be finalising their plans for regulations and infrastructure, then it'll take around five years to roll out.'

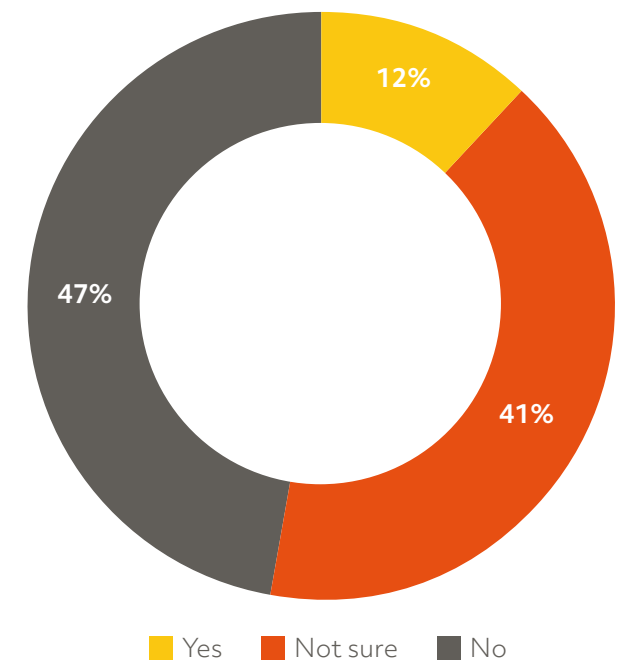
Building a business case for CCUS

The business case for CCUS has some way to go. Only 12% of respondents feel they have all of the information they need to go ahead and choose a supplier, with others either awaiting the results of their own pilots or of industry test cases.

When will we see CCUS rollout start to accelerate?

Despite the headwinds facing CCUS rollout, the news for medium term rollout looks strong: 34% of respondents plan to roll out a CCUS solution in the next six years, increasing to 60% with plans into the next decade. However, just under 40% currently have no plans to install CCUS, which points to the need for a better understanding of the market and business case as minds are made up.

Do you feel the CCUS value chain currently offers a clear path for your business in terms of carbon markets and uses



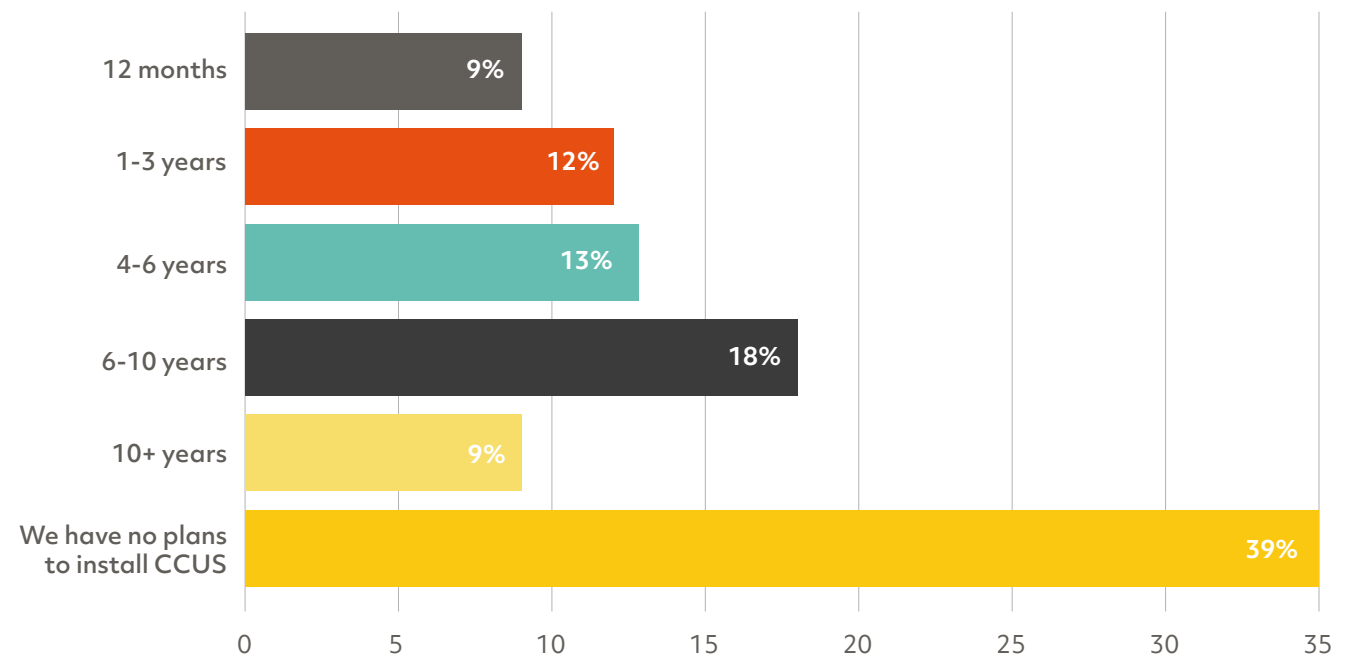
In general, there's a fear of 'first mover disadvantage' driving much of the current hesitancy, with only 12% of those surveyed feeling confident about making the choice to choose a supplier, and over three quarters waiting to see how either their own pilots or other roll outs go before making a commitment.

'In the long term I hope we won't need CCUS anymore, because we will be able to use renewable energy,' explains John Norton, Jr. at the Great Lakes Water Authority. 'However, as a combined water and wastewater utility, our energy supply must be rock solid reliable, both in terms of power supply but also power quality. We cannot risk our operations by depending on poor quality power supplies.'

Solutions which have gained traction during the survey are listed below:

- Direct air capture
- Post-combustion capture
- Pre-combustion capture
- Geological sequestration
- Oxycombustion
- Mineralisation
- Absorbtion
- Membranes
- Amine-based solutions
- Anaerobic digestion
- Compression
- CO₂ use in manufacturing chemicals, materials, liquid and gas e-fuels, silicate sequestration, agriculture, agrifeed and protein

Do you plan to install a CCUS system in the next:



Many technologies will have a role to play in helping us decarbonise – but while we should invest in solutions that will be here tomorrow, it is critical that we back those that are making a difference today. The technologies needed to achieve the necessary cuts in global emissions by 2030 already exist. It's going to be policies and innovative business models that will drive these forward.

Aniruddha Sharma, Co-founder & CEO, **Carbon Clean**

In Conclusion

It is positive to see the level of support for CCUS as a decarbonisation tool, with 65% of respondents citing CCUS as critical or a key part of their plans to reach their 2030/2050 decarbonisation goals.

Some concerns remain – operational issues, finance and space considerations for example – and there is clearly still some reticence in the market, but over a third of respondents are conducting their own research/pilots so there is a tangible commitment to exploring the potential of CCUS.

The advent of new carbon capture technologies and services, such as Carbon Capture as a Service (CCaaS) and modular carbon capture units, will also address many of these operational concerns. Given pressure from shareholders and customers is only going to increase, there is every reason to believe the adoption of carbon capture will accelerate massively.

There are also some great business utilisation cases out there – the use of carbon dioxide to deliver carbon neutral marine fuel by Liquid Wind, a consortium we're proud to be a part of, for example.

This survey confirms the likely demand for CCaaS, with 41% of respondents most interested in a fully funded CCUS model, and 59% preferring a mix of funded/operated and owned equipment, and no respondents choosing an option for an outright equipment sale. This is an important signal to the market, confirming the likely future demand for these services that are already under development.

Talent is also going to be crucial for CCUS development and attracting young people with new skills and fresh ideas into the industry is vital.

There are many routes to net zero and technologies that can help industries achieve their climate goals, but this survey supports the role that CCUS is already playing and will go on to play in the coming decades.

Aniruddha Sharma, Co-founder & CEO, **Carbon Clean**



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We focus on hard-to-abate sectors including cement, steel, O&G, power & utilities, ceramics and more. The events and reports support those leading the deployment of decarbonisation plans including heads of corporate strategy, CTOs, Innovation/R&D, project directors & heads of carbon management. Decarb Connect works with industry to set an annual agenda for essential research, benchmarking data, live events, retreats and more.

If you're selecting technologies, establishing high performing collaborations, initiating pilots or working out how to scale innovative projects – each element of our offering helps you solve the systemic and technical barriers to decarbonisation.

Decarbonisation Leaders Network

A new ecosystem of tech and partners is emerging bringing new kinds of collaborations.

Membership of the Decarbonisation Leaders Network brings the opportunity to meet with peers and cross-sector allies from across the energy-intensive sectors. By learning with your peers, including sharing your own successes, we're creating a network that can jointly progress – speeding up decisions & making robust choices that will accelerate decarbonisation.

Decarb Connect Insights - Podcast & Reports

In our mission to accelerate industrial decarbonisation we will be bringing you regular insight, articles, interviews and podcasts from those who share our vision.

Decarb Connect Events

Each event – whether digital or in-person – is constructed to balance your need for information and benchmarking.



Carbon Clean is a global leader in cost-effective carbon capture technology and services. The company has a long-track record of innovation in carbon capture and its technology is already operational across more than 38 sites globally in over 10 locations, including the UK, USA, Germany, India, Norway, and the Netherlands.

Find out how its carbon capture solutions can help you:
www.carbonclean.com/contact