Decarbonising Cement with CO_2 Transport

Roadblocks, solutions and ways forward

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The cement industry accounts for about 7% of global greenhouse gas (GHG) emissions, making it one of the largest industrial emitters in the world[1]. With demand for cement continuing to grow, the sector must increase efforts to decarbonise to get on track for net-zero emissions by 2050[2].

Carbon capture and storage (CCS) will be critical to this effort; however, its value chain is complex. In particular, transporting captured carbon dioxide (CO_2) from asset to final storage (or utilisation) site poses a unique set of challenges for cement producers – yet the challenges of transport are discussed less often, compared to the attention given to CO_2 capture and storage.

Here, we at Decarb Connect seek to redress this balance by drawing on a survey of 43 cement industry professionals and interviews with selected industry experts to examine and offer preliminary insights into the status of transporting CO_2 within the cement industry. Specifically, this report will examine:

- How ready cement producers are to transport CO_2;
- Challenges to designing and implementing a CO_2 transport project; and
- What steps cement producers can take to better understand and action CO_2 transport strategies.

CO_2 transport is the critical link between CO_2 captured at a cement plant and the final storage or utilisation site; however, few people are talking about CO_2 transportation. Instead, the conversation tends to focus on carbon capture and storage.

> *"Few people are focusing enough on CO_2 transportation. Instead, we hear more about their focus on opportunities and business models around the capture or storage elements."*
>
> ***Alex Cameron, Founder & CEO, Decarb Connect & Decarbonisation Leaders Network***

Transport of CO_2 A critical link in the Carbon Capture and Storage Value Chain

Indeed, almost 40% of cement producers surveyed stated that they have not yet performed a CO_2 transport feasibility study (Fig. 1), despite 95% of total respondents agreeing that CO_2 transportation is important or very important to the industry's ability to meet decarbonisation goals (Fig. 2).

So, why is this? One reason may be that many producers want to see what others do first and are reluctant to allocate time and money for a feasibility study. Alternatively, some companies may think that they have more time. Regardless, it is clear that all producers will need to evaluate their transport options sooner rather than later, especially those located in more remote regions that lack existing infrastructure.

Fig 1: Has your company conducted a CO_2 transport feasibility study?

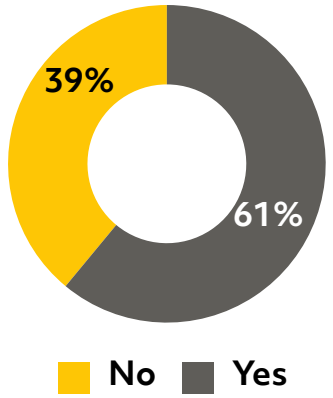
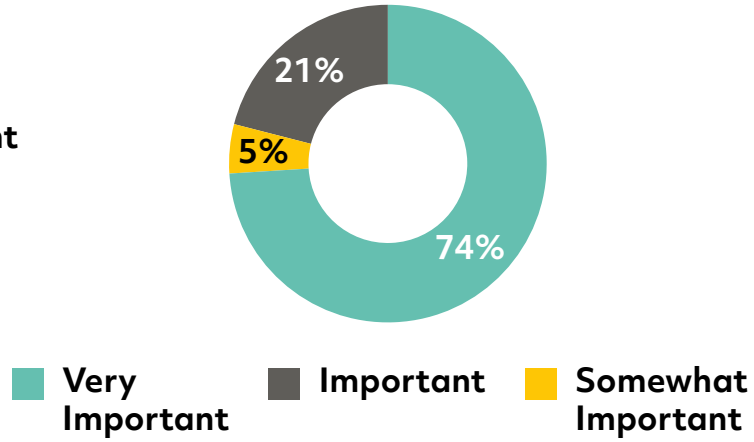


Fig 2: How important is CO_2 transportation to the cement industry's ability to meet its decarbonisation goals?



Pipeline is popular, but is it the only solution?

Of those respondents who have already conducted a feasibility study, all stated that they have evaluated the feasibility of CO_2 pipeline. This comes as no surprise: the 41 CCS projects currently in operation and under construction, globally, all use pipeline as the method of transporting CO_2[3].

But what about future projects, where pipeline transport may not be an option, or where pipeline can only cover part of the journey? This may be the case for facilities located in remote regions away from existing or planned pipeline infrastructure, or where underground storage sites are unavailable.

Pipeline Alternatives

There is emerging interest in alternative methods of transporting CO_2, such as ships, barges, road and rail, which add critical flexibility to the CCS value chain and facilitate greater access to storage opportunities for cement producers in a range of geographical, economic and geopolitical contexts.

For example, 11 shipping projects, and 28 others which use a combination of transport methods, are currently in development around the world[4]. In particular, shipping has several unique advantages over pipeline-only and other transport methods.

These include[5]:

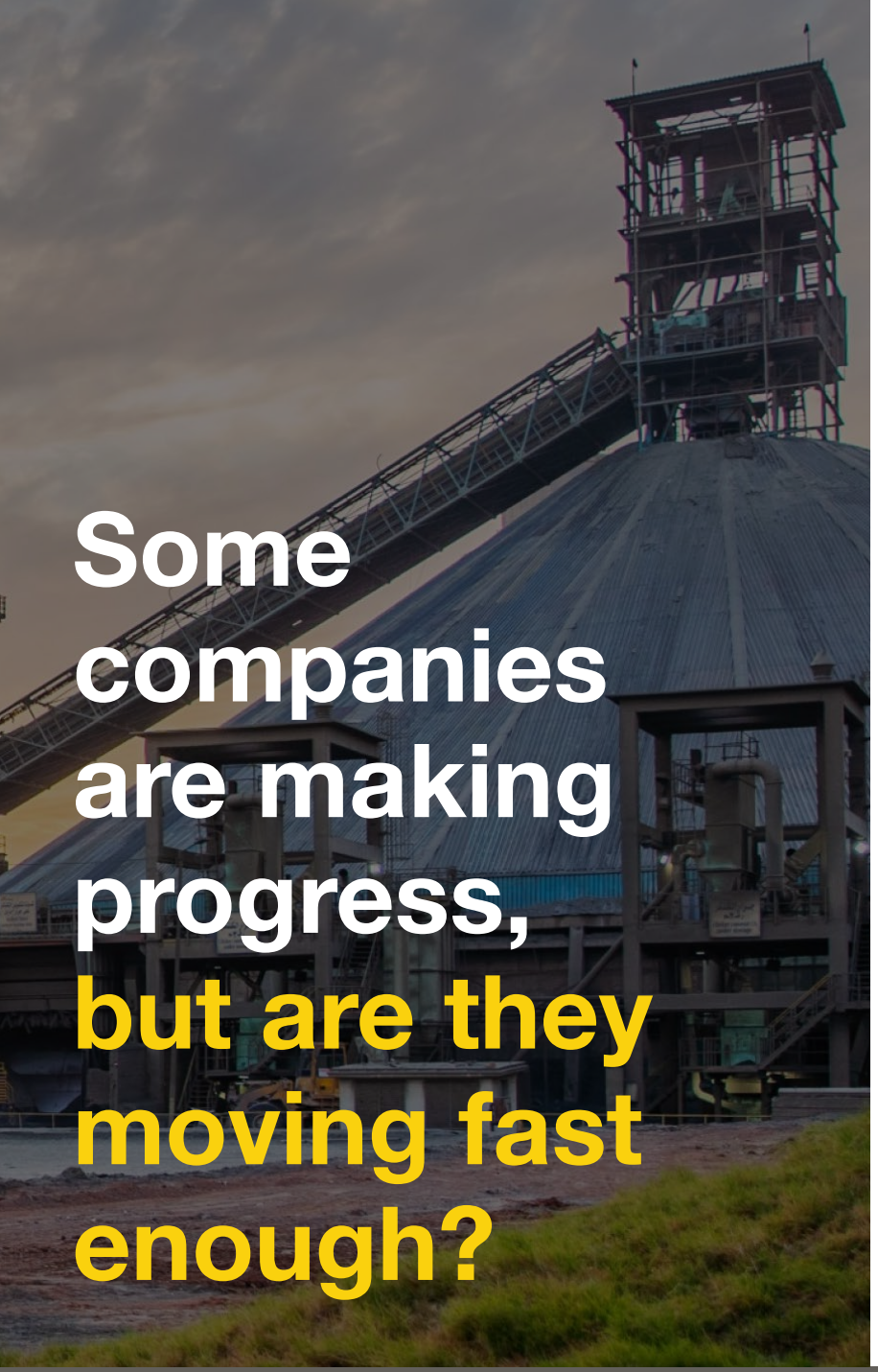
- **Capacity Scalability:** CO_2 ships enable transport capacity to be scaled with the changing needs of producers such that more, or less, CO_2 can be accommodated over time. Pipelines, however, may suffer capacity limitations or underutilisation as market demand changes.

- **Route Flexibility:** Unlike pipelines, ships can change routes and delivery locations depending on circumstances. For example, should a storage site become unavailable because of maintenance or operational reasons, CO_2 can be transported to alternative storage sites.

- **Storage Access:** In addition to route flexibility, CO_2 shipping can provide access to CO_2 markets and storage sites around the world. This is particularly important for facilities lacking access to local or regional markets and/or storage.

  To leverage the upside of CO_2 shipping, facility owners need to evaluate (through feasibility studies) factors such as regulatory opportunities (e.g. incentives or subsidies), proximity to a suitable port and, if there is sufficient capacity and availability to handle CO_2 collection, loading and temporary storage.

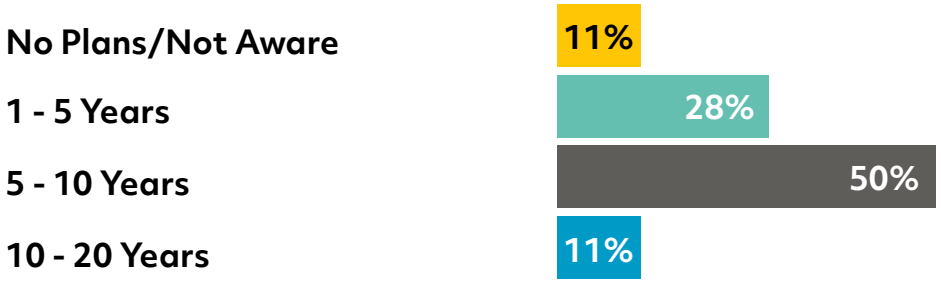
Alternative methods of transporting CO_2 could add critical flexibility to the CCS value chain.



Some companies are making progress, but are they moving fast enough?

When asked when they plan to implement CO_2 transport in their business operations, 78% of producers surveyed said within the next 10 years (Fig. 3). But are companies moving fast enough if – according to the International Energy Agency's Net Zero Emissions by 2050 Scenario – annual CO_2 intensity declines of 4% through to 2030 are required for the sector to get on track?[6]

Fig 3: What is your organisation's timeline to incorporate CO_2 transportation into its business operations?



> *Investment in CO_2 transport (and CCS) will only happen if it makes financial sense. Today, provision of funding is not the main issue; the key problem is whether companies can generate a return on investment. Longer term, given the huge capital costs involved, provision of funding in development economies may also be a challenge."*
>
> ***Ian Riley, CEO, World Cement Association***

Roadblocks to Progress

Many producers say that they are moving as fast as they can, but the pace at which the industry can implement CO_2 transport (and broader CCS) strategies is not solely a function of company ambition. Rather, as our survey suggests, there are other, often external, factors at play.

For example, survey respondents have identified three key roadblocks to progress (Fig. 4):

- **Financial Viability:** Most respondents point to unclear business models and the lack of clear return on investment. Indeed, companies will only invest if there is a strong financial case to do so.

- **Weak Policy:** Almost two thirds of respondents highlight uncertainty caused by the lack of a clear, consistent governmental policy signal. Without long-term policy, companies are reluctant to invest in expensive CCS and CO_2 transport projects.

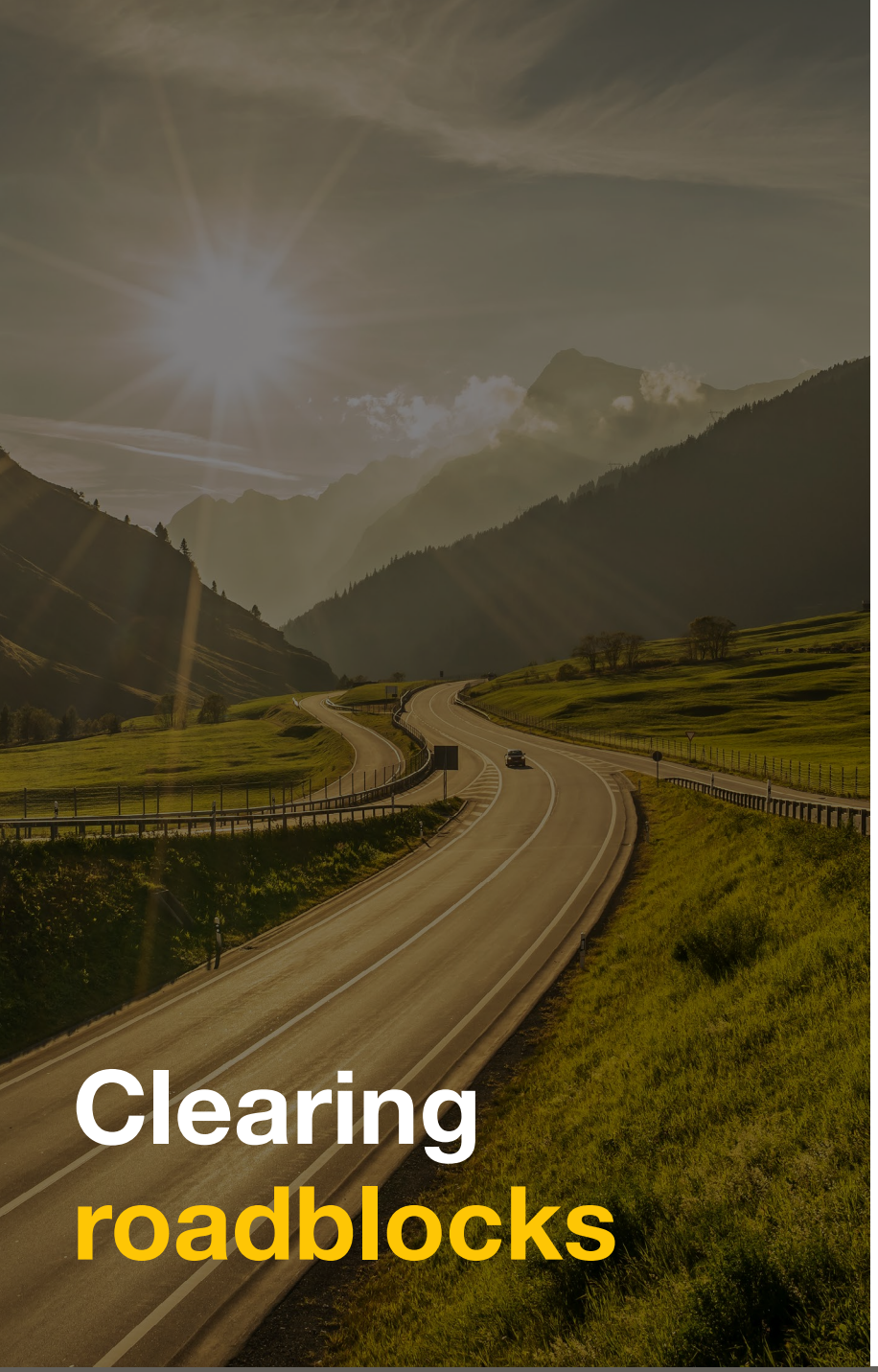
- **Technical Feasibility:** Just over half of respondents identify technical feasibility as a potential barrier to progressing CO_2 transport solutions. It is important to note that such challenges will differ from asset to asset as the length and complexity of the CCS value chain varies.

Other potential barriers identified include:

- **Social Licence:** Without local support, the delivery of CO_2 transport projects may be slowed or even halted, particularly land-based projects that intersect with local communities.

- **Awareness:** Some cement producers may not be aware of different transport solutions that may be available, either as an interim solution before a pipeline can be built, or where a pipeline is not an option.

Fig 4: What barriers does the cement industry face in transporting CO_2?



Clearing roadblocks

To get on track for net-zero emissions by 2050, Decarb Connect believes it is crucial that industry stakeholders accelerate the conversation and action around CO_2 transport and how it integrates with the wider CCS system.

Analysing survey and interview responses, six key areas have been identified that will be vital to progress: (1) developing pilot projects; (2) stronger regulatory policy; (3) financial incentives; (4) viable business models; (5) taking a holistic, full-value-chain approach; and (6) building awareness and social licence.

Pilot projects are needed to demonstrate CO_2 transport viability and integration

CO_2 transport pilot projects are a prerequisite for any investment and can help accelerate the design and deployment of technologies and best practices. Moreover, pilot projects can help build awareness of different transport options and how they integrate with other parts of the CCS value chain.

In Europe, CO_2 transport and storage projects such as Northern Lights[7] and Aramis[8], are leading the development and integration of transport solutions, including shipping and intermediate floating storage.

Crucially, these projects are advancing the development of innovative technologies. For example, Shell is helping to develop ships and barges specifically designed to transport liquefied CO_2 to consolidation and final storage sites (see Box 1 on the next page for more detail).

Box 1: CO_2 shipping: Vessel innovation and development

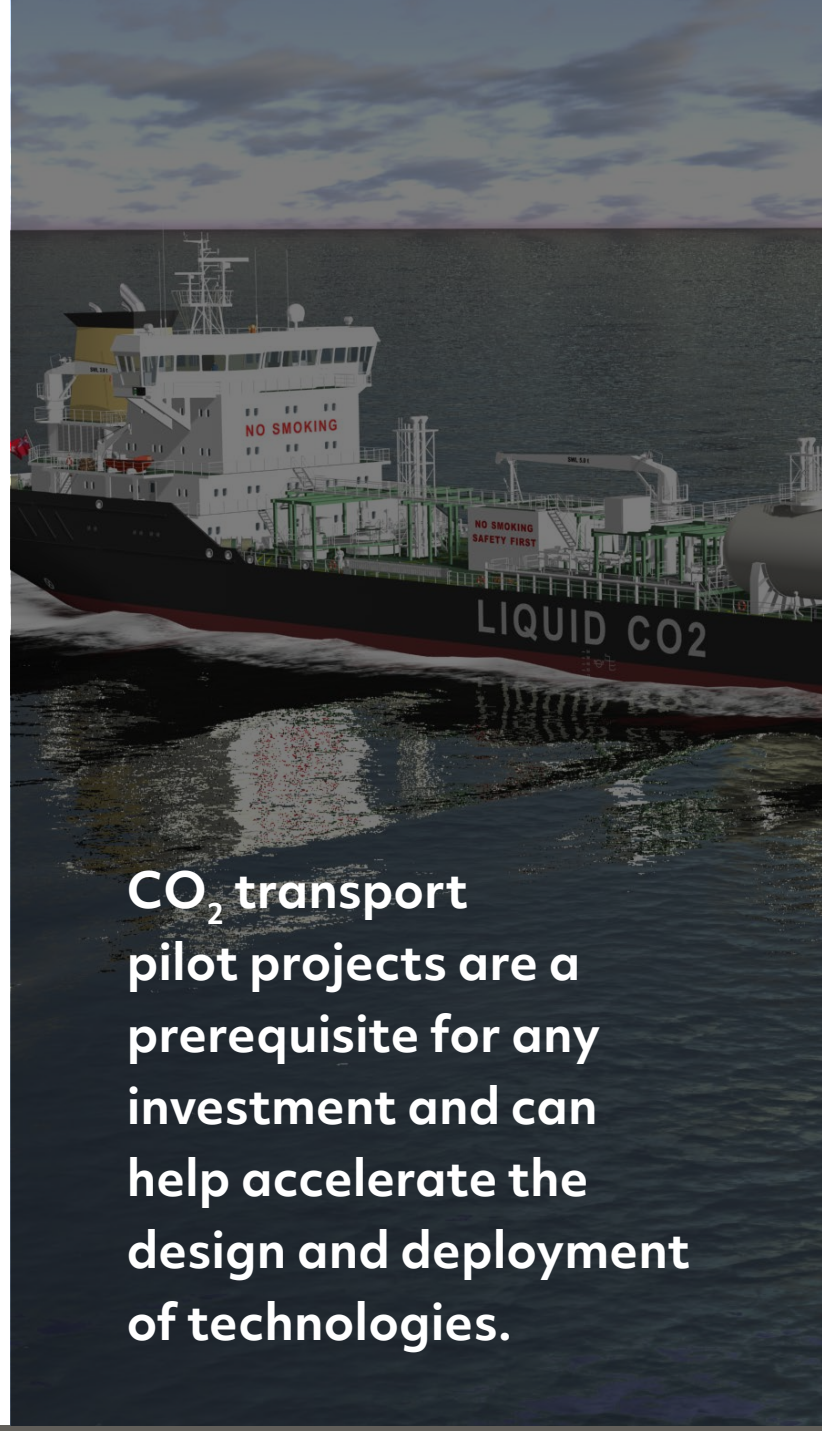
Leveraging its shipping and maritime expertise, Shell and its partners are developing specialised vessels needed to ship captured CO_2.

Currently, Shell is piloting the development of CO_2 vessels for the Northern Lights and Aramis projects in Northwest Europe, which are due online in late 2024 and 2028 respectively. Other projects in Europe and the Asia-Pacific region will follow from 2029 onward.

By developing larger vessels capable of holding up to 70,000 m^3 of CO_2 under low-pressure carriage conditions, Shell hopes to maximise economies of scale and reduce the cost of transporting CO_2 by ship for longer distances to destinations like Asia-Pacific.

Additionally, Shell is actively working to develop industry standards for CO_2 transportation by ship and is cooperating with the International Organization for Standardization (ISO) and Society of International Gas Tanker and Terminal Operators industry bodies.

> *Vessels will need to be tailor-made for each project and integrate seamlessly with connecting parts of the CO_2 transport value chain, such as ports, CO_2 consolidation points and temporary storage. By taking an integrated approach, Shell makes sure that all parts of the puzzle work together."*
>
> ***Steven Burthom, Manager, Fleet Management***
> ***Shell Shipping and Maritime***



CO_2 transport pilot projects are a prerequisite for any investment and can help accelerate the design and deployment of technologies.

Industry needs clear, consistent long-term policy

The cement industry needs a clear policy signal from governments to give producers the confidence to invest in CCS and CO_2 transport solutions. Example policy mechanisms include putting a price on carbon that is high enough to make CCS projects economically viable in the long term.

Additionally, restrictions on cross-border transport of captured CO_2 – which is classified as a waste product[9] – could limit potential access to international storage sites and CO_2 markets, particularly for companies located in remote regions or without access to in-country storage sites.

To counter this, London Protocol member countries are encouraged to ratify the amendment to Article 6, which allows for sea-based and cross-border transport and storage of CO_2. There also needs to be clear agreement on how liability for stored CO_2 will be managed when CO_2 captured in one country is stored in another. Furthermore, planning and permitting processes for CO_2 transport projects need to be streamlined as they are not designed for the speed and urgency of the decarbonisation task at hand.

Financial incentives are crucial for early movers

For early movers, financial incentives, such as grants, subsidies, and tax credits, will be key in helping to kick-start projects that enable economies of scale and cost reductions over time. Indeed, with such large investments needed, having a government pay a part of that could be hugely beneficial for producers.

To enable and scale pilot projects in Europe and around the world, continued investment from outside the cement industry is needed from public and private stakeholders. Indeed, when asked, almost 50% of respondents say it is unlikely that such projects can be funded by the industry alone (Fig. 5).

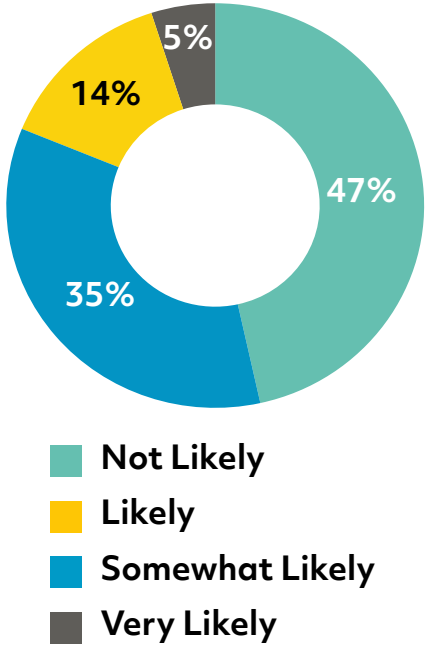
Producers need viable business models

Securing a return on investment is crucial for producers, so they need viable business models that can scale and adapt to evolving market and regulatory environments.

One business model growing in popularity and potential is "CCS as-a-service", which aims to offer cement producers the solutions they need to capture and sequester facility CO_2 emissions. This would otherwise be too complex and expensive for most producers.

A core part of CCS-as-a-service is providing CO_2 transport solutions and services, including logistics, planning and permitting, which can significantly reduce costs, risk and uncertainty for producers.

Fig 5: How likely is the cement industry able to fund research and pilot projects for CO_2 transportation without outside funding?



A holistic approach is needed

Developing CO_2 transport solutions should be done within the context of the whole CCS value chain, with seamless integration between capture, transport and storage systems.

However, each cement plant is different and there is no one-size-fits-all solution.

> *Cement producers should consider taking a holistic approach and explore different scenarios for each plant…This might include mapping out accessible CO_2 storage sites and different CO_2 transport options, evaluating the potential for creating consortiums to aggregated CO_2 transport demand and de-risking carbon capture technologies."*
>
> ***Haitham Sedik, Shell's Global Decarbonisation Manager for Cement***

Assessing the carbon footprint of different solutions and ways to reduce overall emissions is equally important. For example, "substituting fuels with lower-carbon alternatives, such as decarbonised hydrogen or renewable natural gas, can help reduce the number and size of capture units and the capacity needed for transport," says Haitham.

Developing awareness and social licence

Enhancing awareness of CO_2 transport challenges and solutions can help the producers make better-informed decisions. This can be done by developing and engaging with industry consortiums and solutions experts to exchange knowledge and best practices.

Furthermore, setting up community engagement programmes early in the planning process can help build trust and a social licence with local communities living near planned CO_2 transport infrastructure.

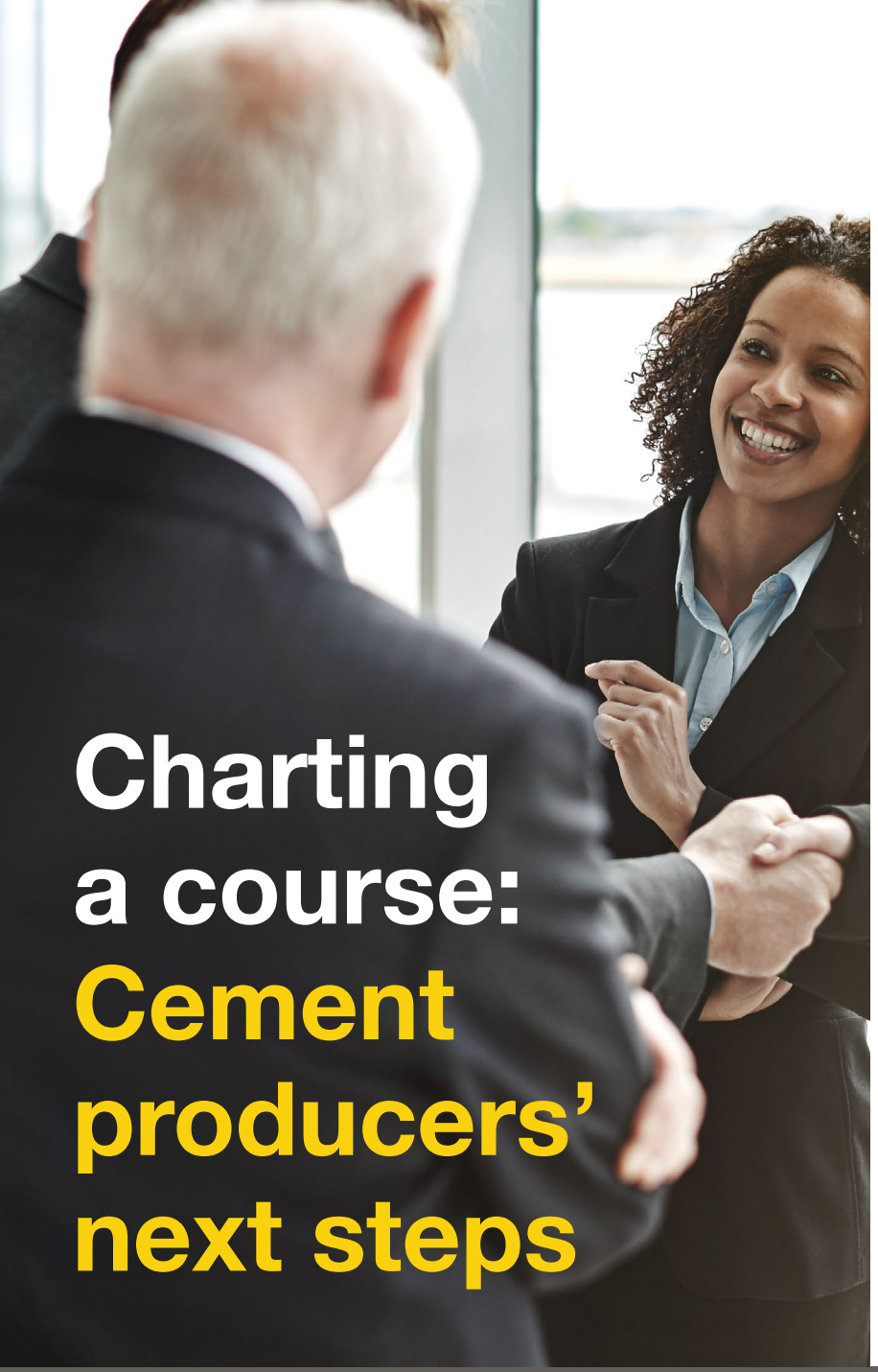
But what if CO_2 transportation is not an option?

There may be examples where transporting CO_2 for storage or utilisation is not viable, now or in the future. Nonetheless, there are still some options for producers to explore.

For example, carbon capture and utilisation (CCU) may be an option whereby producers sell their CO_2 as a chemical feedstock. The global demand for CO_2 is steadily rising and is estimated to reach about 272 $MtCO_2/y$ by 2025[10]. For most petrochemical and chemical companies, CCU is the only way that they can get the CO_2 at the scale they need.

Alternatively, cement producers may explore options to develop their own sequestration sites within or close to their plants. CO_2 mineralisation is also a possibility. Finally, if it is technically and economically viable, producers may opt to relocate facilities closer to a storage site – though this will likely be a last resort.

As the cement industry progresses the conversation on CO_2 transport, many producers may be left asking, "what are my next steps?". Indeed, knowing where to start and what direction to head in can be daunting.



Charting a course: Cement producers' next steps

Although external stakeholders, such as governments, will have a major influence on the direction and speed of progress, there are some key actions that cement producers can undertake to help them drive the narrative and make more informed decisions.

1) De-risking with feasibility studies

If a producer has not already done so, conducting a CO_2 transport feasibility study should be a priority to determine which solutions best fit the specific needs of their facility. Through performing a feasibility study, producers can:

- identify and reach out to CO_2 storage providers to map out potential CO_2 transport routes and scenarios;
- model the economic viability of different scenarios and determine possible return on investment; and
- identify challenges and de-risk technologies.

2) Engage with industry and other stakeholders

No producer can implement a CO_2 transport strategy alone, so engaging with other industry players and external stakeholders early on is vital. For example, producers can:

- create or join industry consortiums to build awareness through sharing knowledge, experiences and best practices;
- reach out to local industries to determine potential demand for aggregated CO_2 transport;
- work with industry partners to advocate for the right policies and incentives; and
- start speaking with local communities to forge early relationships and trust.

3) Selecting the right partners

CO_2 transport is one part of a complex supply chain and requires solutions that integrate seamlessly with upstream (capture) and downstream (storage) parts of the system. As a result, producers should seek partners that can:

- offer deep expertise in service integration, who can design and implement transport solutions that integrate with the whole CCS value chain; and
- design and implement emission reduction solutions that integrate lower-carbon and renewable energy sources.

Through this report, we at Decarb Connect hope to drive a deeper conversation around transportation of CO_2 – an often overlooked, yet critical, part of the CCS value chain. For CCS to be deployed successfully, there needs to be more focus on how captured CO_2 will be transported from source to sink, including the challenges it poses and the solutions available.

To learn more about Shell Energy's solutions for the cement industry, visit www.shell.com/shellenergy/cement.

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References:
1. McKinsey | Cementing your lead: The cement industry in the net-zero transition: https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/cementing-your-lead-the-cement-industry-in-the-net-zero-transition
2. IEA | Cement: https://www.iea.org/energy-system/industry/cement
3. Global CCS Institute | Global status of CCS 2023 p.66: https://www.globalccsinstitute.com/wp-content/uploads/2024/01/Global-Status-of-CCS-Report-1.pdf
4. Global CCS Institute | Global status of CCS 2023 p.66: https://www.globalccsinstitute.com/wp-content/uploads/2024/01/Global-Status-of-CCS-Report-1.pdf
5. Global CCS Institute | Global status of CCS 2023 p.67: https://www.globalccsinstitute.com/wp-content/uploads/2024/01/Global-Status-of-CCS-Report-1.pdf
6. IEA | Cement: https://www.iea.org/energy-system/industry/cement
7. Northen Lights: https://norlights.com/
8. Aramis: https://www.aramis-ccs.com/
9. IEA | The London Protocol's Export Amendment p.3: https://www.club-co2.fr/files/2021/04/IEAGHG-2021-TR02-Exporting-CO2-for-Offshore-Storage-The-London-Protocol-s-Export-Amendment-and-Associated-Guidelines-and-Guidance.pdf
10. IEA | Putting CO_2 to use https://www.iea.org/reports/putting-co2-to-use

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