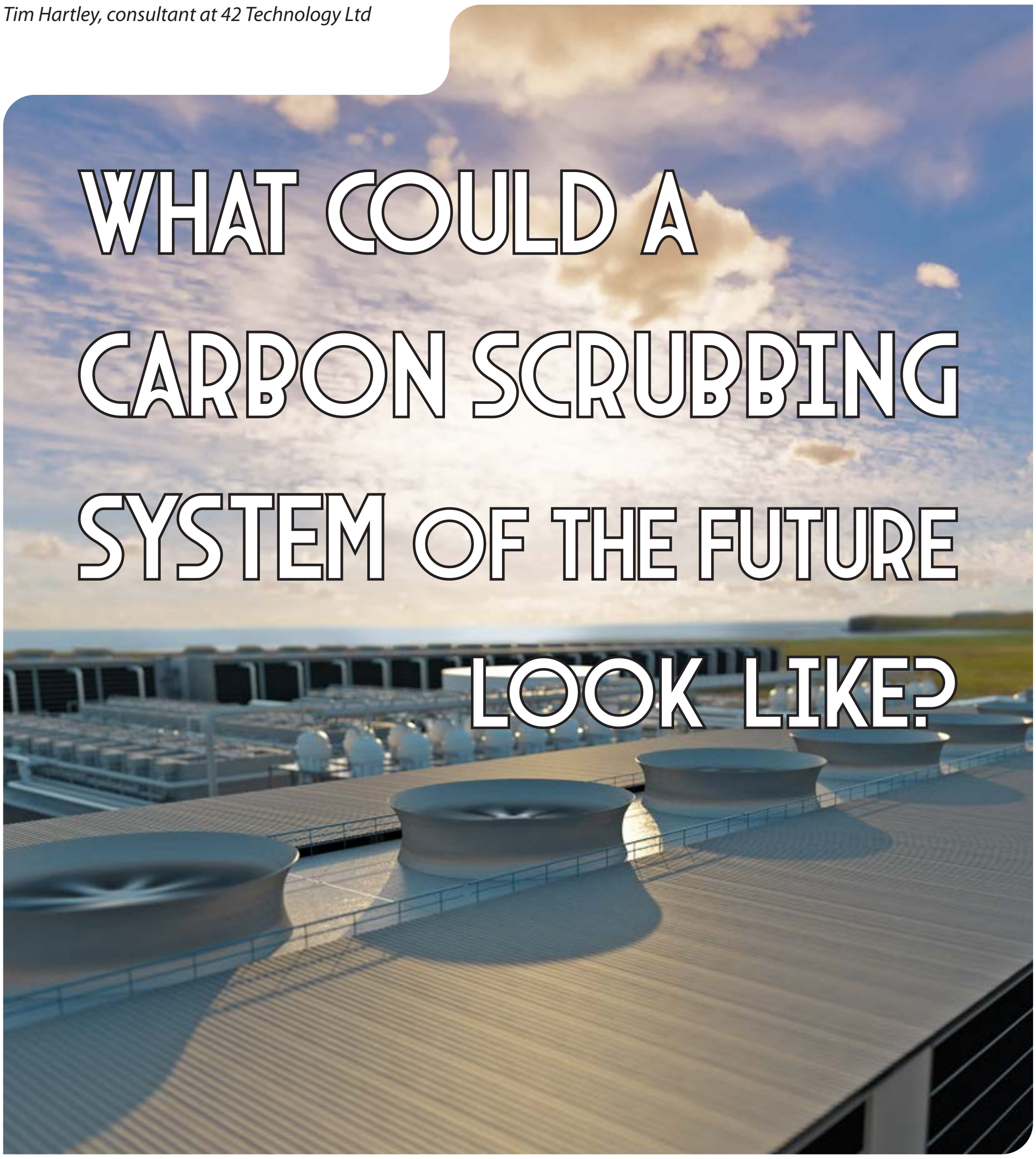
Tim Hartley, consultant at 42 Technology Ltd



What could a carbon scrubbing system of the future look like?

Above Right: An upcoming direct air capture facility in Canada.

Source: *Carbon Engineering Ltd.*

Despite carbon capture's relative infancy, it has a part to play in realising the global cement and concrete industry's aim of net zero CO_2 emissions by 2050. One interesting avenue for this technology is membrane carbon capture.

Membrane carbon capture is a modular form of carbon capture which can be deployed at different scales at competitive costs. Improvements are currently being made to bring the technology to commercial viability on a larger scale. This article will examine the potential of this technology, explaining how it works and why it might be suitable.

What is carbon capture?

There are three main categories of carbon capture, based upon the point at which they happen.

1. **Pre-combustion capture** - This removes the carbon from the fuel, converting it to hydrogen, which is then used instead.

2. **Carbon capture during combustion** - Combustion of the fuel in pure oxygen or using a metal oxide produces exhaust gas close to pure CO_2 and water, making the exhaust components easy to separate.

3. **Post-combustion removal** - Removal of CO_2 from a mixed gas source, preventing it from reaching the atmosphere.

Of the three types of carbon capture, post-combustion capture has gained much of the publicity and interest. This is largely due to its ability to be retrofitted to current processes, reducing the level of change required to meet climate targets. It has now begun to be adopted in some industries at a commercial level.

Post-combustion carbon capture

Once the carbon is removed at any point in the system, it is then compressed and transported for use in another process, or for sequestration. Selling the captured carbon on for use in another process such as in greenhouses, drinks carbonation or other industries provides a reimbursement for the cost of capturing. Sequestration removes it from the system more permanently than use, often placing the CO_2 in geological formations under pressure to prevent its climate change effects.

There are two main areas where post-combustion carbon capture has been deployed – removal at emissions source and direct air capture. Removal at the emissions source removes carbon dioxide from an exhaust where the concentration is highest and therefore requires less effort, whereas direct air capture removes the carbon dioxide by filtering large quantities of air, but can be placed wherever is convenient.

Both approaches use similar technologies and have separate advantages and disadvantages. Removal of emissions at source requires a smaller amount of energy per tonne of CO_2, but requires space to house the processing equipment locally. Direct air capture is the inverse, with large, centralised removal of carbon dioxide, but at a high cost.

Carbon capture technology - options

There are several key technologies for carbon capture:

- **Absorption** - A chemical, usually an amine solution, reacts with the CO_2 to strip it from the gas mix. The solution requires energy input, usually in the form of temperature and pressure, to release the gas from the solution for reuse.

- **Adsorption** - A process where the carbon dioxide adsorbs, or sticks, to the surface of a material, from which it can then be later released by the input of energy.

- **Membrane filtering** - The exhaust gas is passed through a membrane where CO_2 is selectively filtered out of the gas stream.

- **Cryogenics** - The solidification temperature of CO_2 is used to selectively filter it out of a gas stream.

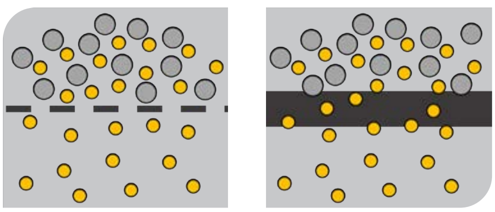
Of these technologies, membranes filtering has great promise due to the modular nature of the membranes and their ease of scalability. In addition to this, the energy required to remove the carbon from the exhaust stream is relatively low compared to other conventional methods.

The capital cost of these modules, already relatively low, will likely reduce as volumes of production increase. Installation of this technology also does not require a high skill level and the membranes often do not require the complex system design that other forms of carbon capture methods require.

How does this technology work?

Membrane technology is relatively simple in principle. Membranes are formed of materials that selectively let through or prevent CO_2 from passing. There are various methods to accomplish this, such as having a membrane which lets through gases below a certain size or through diffusion, where the target gas can preferentially move through the membrane layer. The key features of a membrane are the selectivity (how well the membrane filters the CO_2 from the other gas) and the permeance (the amount of gas that the membrane can filter per unit time).

In order for the exhaust gas to pass the filter, there needs to be a pressure applied to the input of the membrane which is where the majority of the energy required for this process is used. Current membranes tested outside of a laboratory record an energy penalty of 20 - 30%. This is comparable to the energy penalty of amine-based absorption methods. As this technology improves, the pressure required is decreasing and the amount of gas that each membrane can filter is increasing, reducing both capital and operational costs further below those of other carbon capture technologies.



Left: Exhaust gasses passing through a partial size selecting membrane (L) and diffusion membrane (R).

Source: *42 Technologies Ltd.*

Membrane technology and cement

Carbon capture membranes for cement production have been trialled outside of lab conditions most extensively at Norcem's Brevik cement plant in Norway. Membranes were trialled with other carbon capture technologies in an effort to find the most suitable for the application.

After months of testing *in situ*, membrane technology was found to be viable for the application, with good resistance to the harsh conditions. An economic feasibility study following the trial estimated the cost of carbon captured to be around US$50/t. The project was approved as one of the shortlisted technologies to be trialled for a further nine months. The study concluded that, whilst the membranes showed promise, they needed to be at a higher technology readiness level (TRL) before full deployment.

A more recent project that is currently ongoing is the collaboration between Cemex and Membrane and Technology Research. This 18-month feasibility study will highlight whether or not the advances in membrane technology since the Norcem project are sufficient to invest in a full-plant-scale carbon capture system.

The future of membrane technology use

Compared to other carbon capture technologies, membranes are better suited to deployment at different scales. In experimentation and initial deployment in other industries beside cement, membranes were placed in modules that could be combined to expand capacity. This feature makes them very attractive for plants whose production of CO_2 would not make it commercially viable to install an amine absorption unit, or where the process has many exhaust points which would all need separate units. It also means that, when demand increases, modules can be mass produced and be applicable to many different applications, provided the composition of the exhaust gas is known so that the correct filtering can be applied to the mixture.

Challenges facing membrane technology

Membrane technology is still in development and has not reached the commercial stage where it is widely available.

One of the key downsides to these membranes are the materials that many are made from. Due to the reliance on polymers, the flue gases for these types of membrane must be below 100°C, potentially limiting the applications or increasing the energy demand by adding active cooling.

Whilst there are methods that exist for storing captured CO_2 long term in minerals and geological formations, more research and development needs to be conducted on both the methods for achieving this on a larger scale and to better understand what potential formations would be suitable with minimal leakages.

There are also significant infrastructure changes that would need to occur before a large-scale shift to carbon capture technologies of any form, such as new methods for transporting the carbon to suitable sites from the point of capture.

Conclusion

Despite their relative infancy, membranes have already demonstrated exciting properties that could aid carbon capture to become more widespread in a more diverse range of sizes and applications. Whilst they are not a fully green technology - such as technologies like hydrogen have the potential to be - they may be the stepping-stone between a fully green future and the current fossil fuel-based economy.

Bibliography

1. MDPI, 'Recent Progress in the Engineering of Polymeric-Membranes for CO_2 Capture from Flue Gas,' 20 November 2020, https://www.mdpi.com/2077-0375/10/11/365/pdf

2. Benson, Kelemen, Pilorgé, Psarras and Wilcox, 'An Overview of the Status and Challenges of CO_2 Storage in Minerals and Geological Formations,' 15 November 2019, https://www.frontiersin.org/articles/10.3389/fclim.2019.00009/full

Right: Norcem's Brevik cement plant in Vestfold og Telemark, Norway.

Source: *HeidelbergCement.*