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Carbon Capture and Storage: Hiding dirt under the rug or a real clean up?

- Carbon Capture and Storage (CCS) consists of retrieving carbon dioxide (CO_2) from industrial exhaust fumes, transporting it and storing it underground
- Although there are mature, or quickly maturing, capture technologies, transport and storage ecosystems have yet to be developed in most places
- The economic equation of CCS is improving but remains challenging. Putting a price on carbon is a necessity for CCS to really take off
- We believe the scale of CCS development envisaged in several net zero scenarios set out by major institutions is not yet credible
- CCS is both a structural and a temporary solution for the energy transition: It is a critical technology for unabatable process emissions – for instance in the cement industry – and a transition technology while industrial processes and energy consumption patterns evolve
- Social acceptance of storage sites – especially onshore – and risk perceptions could be significant roadblocks
- The priority is first to reduce and avoid emissions. CCS has a role as a mitigation tool in some cases, and should not be used as an excuse to avoid emissions reduction

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What is Carbon Capture and Storage?

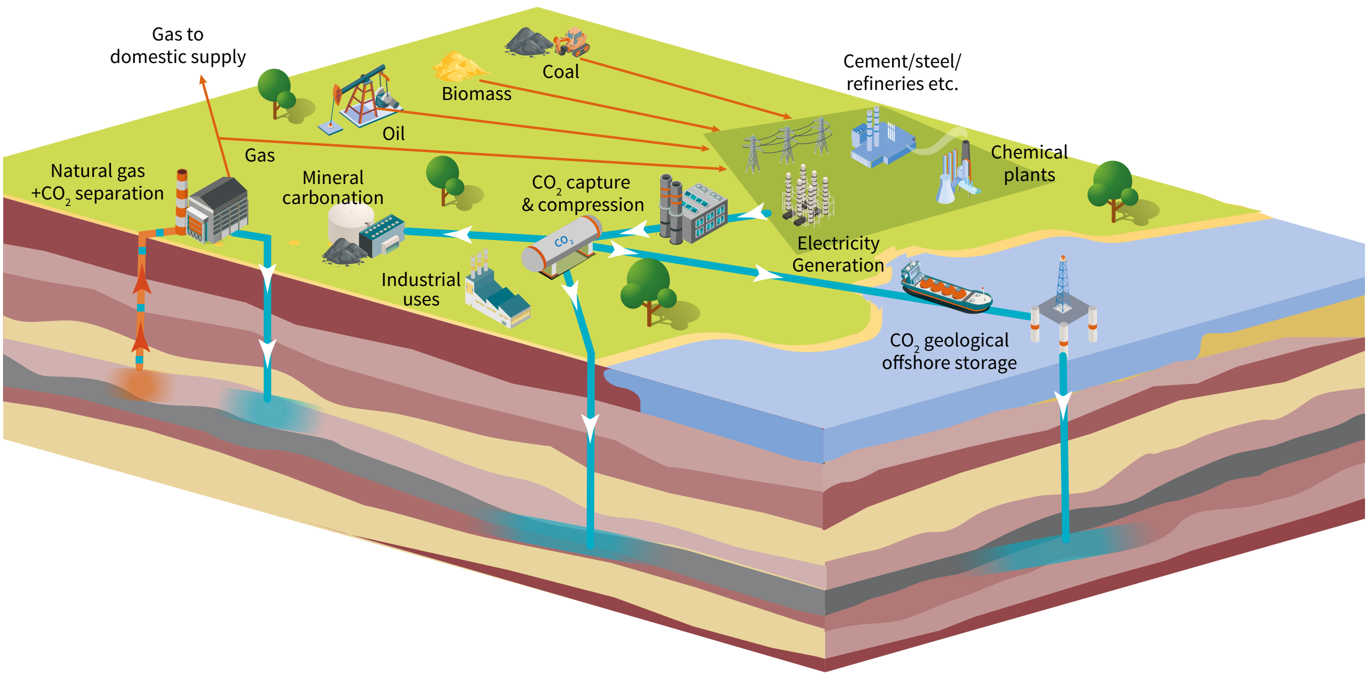
The Intergovernmental Panel on Climate Change (IPCC) provides the following definition: "A process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere."[1] CCS has a close cousin in carbon capture, usage and storage (CCUS) – where CO_2 can be used as a valuable product, for instance to provide the fizz in carbonated soft drinks or to freeze food.

The technology to extract CO_2 from a flue gas is not new. The hydrocarbon industry has used technologies to remove contaminants such as hydrogen sulphide from raw natural gas streams since the 1930s. The CO_2 was, however, mostly released into the atmosphere. According to the International Energy Agency (IEA), venting CO_2 accounts for 7% of the greenhouse gas (GHG) footprint of natural gas production.[2] The first formal CCS facility started in 1972 in Texas, where CO_2 produced alongside natural gas was stripped out and used for enhanced oil recovery, a process where the CO_2 is injected into oil fields to maintain pressure and sustain production levels.

Fundamentally, CCS is a Scope 1 abatement technology for large CO_2 emissions from fixed sources, i.e. mostly industrial sites, be they power plants, refineries, or steel blast furnaces.[3] It is not a relevant technology to address emissions from mobile sources – such as cars or planes – and more generally does not address emissions from transport.

For investors, it is important to understand in which industries CCS is relevant and where it is not. The car industry, so prominent in any discussion about emission reduction, is not part of this discussion, while the cement industry is central when assessing the potential.

The CCS value chain



Source: CO_2 Cooperative Research Centres

1 Carbon Dioxide Capture and Storage IPCC, 2005
2 World Energy Outlook 2018 (page 491)
3 Scope 1 emissions are direct GHG emissions linked to a company's own operations

Why does CCS matter?

The energy transition is about shifting away from fossil fuels – the primary source of GHG emissions – to limit the impact of global warming. CCS technologies are increasingly presented as an important lever to decarbonise our societies and economies. They are part of the path to achieve net zero emissions by preventing GHGs reaching the atmosphere. A subset of technologies – namely Direct Air Capture or DAC – is about removing CO_2 from the air.

In its net zero scenario published in May 2021, the IEA explicitly relies on a massive development of CCS. It factors in the annual capture of 1.7 gigatons[4] (GT) of CO_2 by 2030 and 7.6GT by 2050 – with 95% being then stored permanently underground. This 2050 level is equivalent to more than 20% of today's CO_2 emissions.

The IPCC published in 2018 a special report on the impact of temperatures rising by 1.5°C compared to pre-industrial levels. It presented various pathways to reduce greenhouse gas emissions. It included CCS, ranging from a very limited use to several gigatons per annum.

In December 2020, Princeton University released a detailed study on how to achieve net zero emissions for the US by 2050. It developed several scenarios where the scale of CCS use varies from 0.7 to 1.8GT per year.

Those three reports all envisage a large-scale deployment of CCS technologies, mostly post-2030, and its application across the economy, notably in power generation and many industrial processes. Gross zero, i.e. cutting absolute emissions to zero, is not put forward as an achievable or even desirable goal in those analyses. In short, there is no net zero without CCS, and a failure to achieve the scale of CCS implied by those studies would demand a more drastic and potentially unmanageable pace of reductions in absolute emissions.

Scale of CCS in 2021

According to the Global CCS Institute, there were 26 operating CCS facilities mid-2021, with a stated capacity of 38.4 million tonnes (MT).[5] The vast majority – 69% of the capacity – relates to restricting the venting of CO_2 produced alongside natural gas. At less than 10MT, the kind of CCS most commonly cited in the decarbonisation analyses mentioned above, i.e. catching emissions from power plants or industrial processes, is modest at best.

As a reminder, global CO_2 emissions for 2021 are estimated to be 36.3GT, and global GHG emissions to be above 50GT.

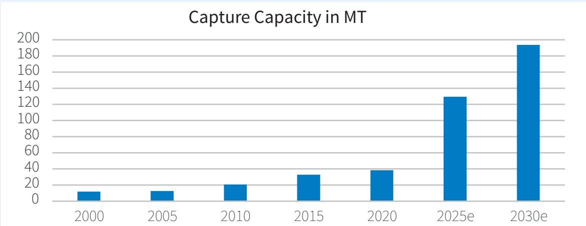
Capture technologies and costs: Today and tomorrow

For CO_2 capture, as for most technologies, there is not one cost, but a cost curve, depending primarily on the CO_2 concentration in the flue gas from which it is being removed. This is linked to physics, specifically Dalton's Law and the concept of partial pressure. Simply put, the lower the concentration of CO_2, the lower the partial pressure and the more difficult it is to transfer the CO_2 from the source gas to the media used to capture it – very often an amine solvent.

Whatever the future holds for CCS, we can identify two key challenges:

1. **The upscaling implied in the aforementioned reports is massive**
   In a recent review of current projects, BloombergNEF identified more than 150MT of planned new capacity. Although this would be more than a four-fold expansion, the IEA net zero scenario implies a required multiplication of more than 40.

   In its latest global status report, the Global CCS Institute has identified 108 projects – at different stage of advancement – for a total capacity of 111MT.



Source: Bloomberg NEF, August 2021

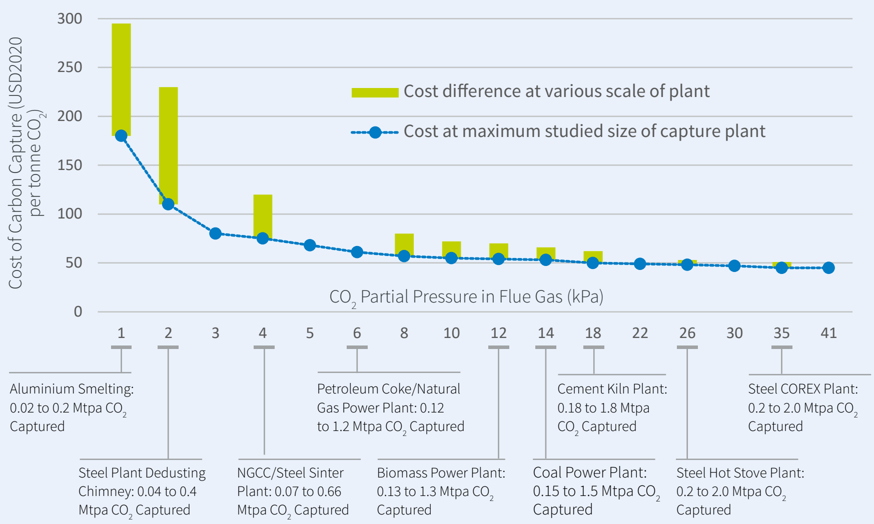
2. **CCS facilities must be developed in many new sectors, beyond natural gas processing**
   Very prevalent in the current development pipeline are power generation and hydrogen production – the so-called blue hydrogen, where methane molecules are broken down into hydrogen and carbon, with the latter being captured instead of vented into the atmosphere. Over time, the cement, steel, and chemical industries will need to appear on the radar. Everywhere that smoke pours out of an industrial chimney, efforts can be made to strip away the CO_2.

[4] One gigaton is one billion metric tonnes
[5] This database is large but not exhaustive. For instance, French industrial gases group Air Liquide has been operating an unreported 0.1MT CCS facility since 2015 in the hydrogen plant of the Port-Jérôme refinery in France, and there are many pilot plants and technology trials.

The cost structure of capture is expected to improve and unit cost to be lowered.

The CCS cost curve

Impact of CO_2 partial pressure and scale on the cost of carbon capture. Studied flue gas streams are at atmospheric pressure. The circle marker indicates the cost at the maximum studied size of a single carbon capture plant. Each green bar indicates the capture cost ranges from 10% to 100% of the scales shown in the callouts for that particular application.



Source: Technology readiness and costs of CCS, Global CCS Institute, March 2021. kPa = Kilopascal or 1,000 pascal, a unit of pressure. 100kPa is the average atmospheric pressure on Earth; Mtpa = million tonnes per annum

Looking at this subject from a less technical perspective, when the CO_2 density is low, there is a need for more substantial equipment and higher energy consumption to "pull out" the CO_2. In financial terms, a low density means a higher upfront investment and higher operating costs.

Another commonly used term when analysing the cost structure of capture is "energy penalty". This refers to both the energy required to run the capture unit and to the observed reduction in efficiency of the facility, most notably for power plants. A plant fitted with a CCS unit will consume more energy than a plant without one. This penalty can be reduced through heat recovery or improved design but cannot be entirely erased.

A key point is that many cost estimates are indeed just estimates. Because there are so few operating capture plants, the cost structure remains an unclear variable. Many serious engineering studies, pilot plants and spreadsheet models have led to the establishment of cost ranges, but in many cases there are no "live" facilities currently operating. For instance, in the cement sector – where CCS is seen as a critical technology to abate process emissions – there are only trial and pilot plants.

The cost structure of capture is expected to improve and unit cost to be lowered in the future,[6] notably through scale, industrial developments, and improved know-how. The cost reduction is not, however, expected to be at the same level seen in solar and onshore wind generation, where unit costs have fallen by 85% and 56% respectively between 2010 and 2020[7].

[6] Energy Technology Perspective – CCUS, IEA, 2020 (page 118 and onward)
[7] Renewable Power Generation Costs 2020, IRENA, 2021

Transport and Storage

Once captured, CO_2 has to be compressed and transported to the storage location. CO_2 can be transported in two forms:

- As a gas: CO_2 is compressed at a pressure below 74 Bar
- As a liquid or a dense form gas: CO_2 becomes liquid under a pressure of at least 5.2 Bar and between temperatures of -56.6°C and +31.1°C. At a pressure above 74 Bar, the CO_2 is said to be in a dense form.

The CO_2 can be in a gaseous or dense form to travel by pipelines, but it must be in its dense form to travel by ship and to be injected in the storage site.

Most cost estimates point toward a range of $5-$20 per ton for transport and about the same for storage.[8] The main drivers of costs are scale, distance, and utilisation.

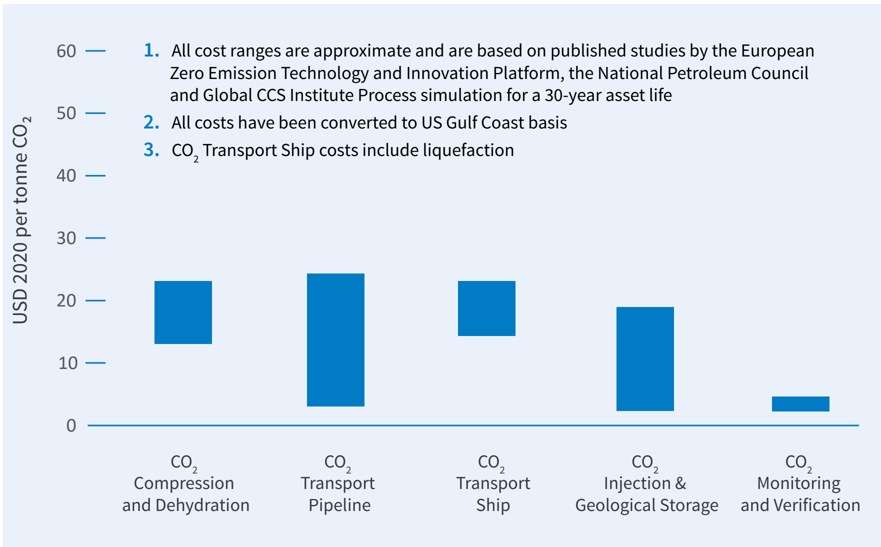
Transport by pipeline is especially scalable and is the most economic option for volume above 500,000 tonnes per annum. Shipping is the only option for offshore storage sites that cannot be connected by pipelines.

A key difference between the capture and the logistical sides of CSS, i.e. transport and storage, is that while capture will occur at multiple individual points, transport and storage are very much about common infrastructure. Industrial hubs and basins are ideal places for CCS to be developed as they provide multiple carbon sources and allow for a common carbon logistical network. It is therefore logical to see projects in sites like Antwerp in Belgium, Teesside in the UK, or Houston in the US – all large industrial basins with a strong concentration of carbon-intensive activities.

Beyond the development of modified capture technologies for specific applications, the logistics of CCS is the bottleneck for future development. Capturing emissions will be of no interest if there are no solutions to transport and store them. Some initiatives today are built on a "pull logic", starting from the storage side – a modern-day equivalent of the chicken and egg paradox. For instance, the Northern Lights[9] project in Norway consists mostly of developing a transport and storage infrastructure, with the rationale that it will trigger investments in capture by industrial companies.

If we broaden this out, it raises the question of the long-term viability of isolated carbon-intensive industrial sites, without CCS and with no alternative solutions to decarbonise. The cost of connecting them to a logistical carbon system may be too high and such sites may become stranded over time. Isolated refineries or cement plants, especially if they are small, could face a dire future. It may be sensible for investors to screen their holdings for companies where this may be a material risk. This also has implication in terms of the Just Transition theme, as this could clearly impact jobs and local communities.

Indicative Cost Ranges for CCS Value Chain Components (excluding capture) – US Gulf Coast



Source: "Technology readiness and costs of CCS", Global CCS Institute, March 2021

[8] Transport and storage could cost less than $10/tonne when there is a very short distance to an onshore storage location
[9] Northern Lights (northernlightsccs.com)

A word on storage

Storing CO_2 underground is very similar to extracting hydrocarbons from oil and gas reservoirs.[10] It requires geological and technical skills, and it is not by chance that oil and gas companies are active in this area. They have sub-surface expertise, know how to drill wells, and have experience in monitoring reservoirs. In this situation, they would be injecting instead of extracting. Many reservoirs identified to store CO_2 in current projects are indeed depleted oil and gas fields. CO_2 can also be injected in deep saline aquifers – underground layers of water-bearing rock.

A commonly presented risk associated with CO_2 underground storage is the risk of leakage. A well-functioning CO_2 reservoir must be permeable so that the CO_2 can be trapped within the pores of the rock and be sealed by low permeability rocks on top – a geological trap. The trapping mechanism is essential to avoid leakage, just as it is for natural gas reservoirs. The real-life case of the Sleipner field offshore Norway has so far provided reassurance on that front, in addition to many other learnings, notably on the behaviour of CO_2 post-injection.[11]

Another option to emerge more recently is the injection of CO_2 into mafic and ultramafic rock, such as basaltic lava, where the CO_2 reacts with calcium or magnesium and becomes a stable carbonate mineral after a few years. The CO_2 is hence stored in a solid form, which removes the risk of leakage. This is currently done in Iceland, although at a small scale.

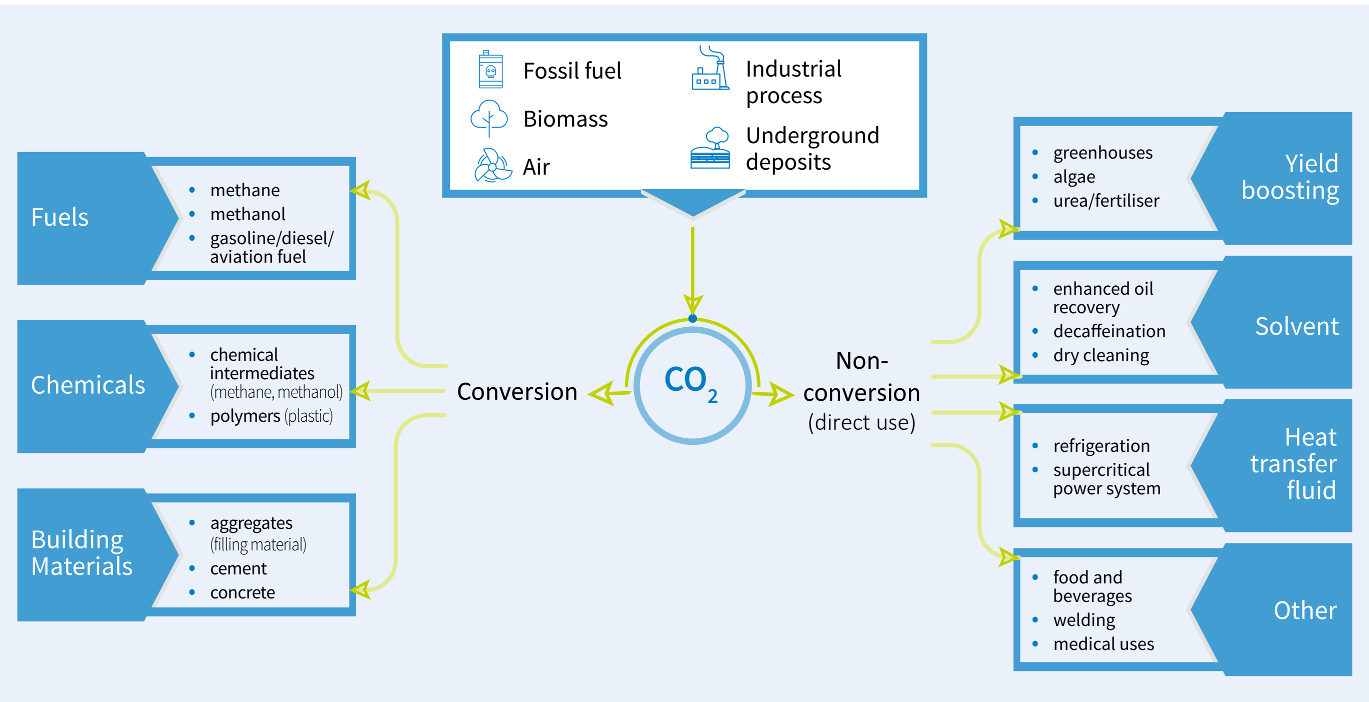
The estimated availability of storage capacity is not seen as a constraint, with a visibility for several centuries of storage even if CCS grows as much as factored in by the most optimistic scenario.

What about the U in CCUS?

The core difference between CCS and CCUS is that in the latter, CO_2 becomes either a usable product or a raw material, and not "just" waste to be stored underground at a cost. It is already the case in small volumes for some applications in the food industry, notably to freeze food or to carbonate sodas.

The holy grail would be to create a circular carbon economy. For instance, captured CO_2 could be combined with hydrogen – produced in a sustainable way – to produce synthetic fuels or synthetic polymers. It could also be used to grow algae, that could themselves be used to feed animals or to produce biofuels. The point is that CO_2 would be used, then consumed and emitted, then captured and reused again. Although some technological elements are ready, the economic equation is far from solved today.

Simple classification of pathways for CO_2 use



Source: Putting CO_2 to use, IEA, September 2019

[10] An Overview of the Status and Challenges of CO_2 Storage in Minerals and Geological Formations - Frontiers in Climate
[11] See also Estimating geological CO_2 storage security to deliver on climate mitigation - Nature

Another promising use could be to store CO_2 into materials with very long lives, hence combining storage and a valuable use. The building material industry is notably looking at accelerating concrete curing with CO_2 – front loading the natural absorption of CO_2 by concrete over its lifetime. There is also potential in synthetic aggregates – a component of concrete – by combining waste from the building industry with CO_2. Those two technological pathways are becoming rapidly credible.[12]

A key challenge when CO_2 is not used in its original form is that it is a chemically stable molecule requiring large quantities of energy to be activated or converted to another material. The process can be costly and have its own carbon footprint, unless of course it uses renewable energy.

Overall, usage is likely to be a part of the solution, but not in the short to mid-term. Many technologies are still immature and need further developments. In addition, and as always, it is necessary to run full lifecycle analyses of those solutions to properly assess their carbon footprints and compare them to other decarbonisation pathways. However, if the technical and economic equations for synthetic fuels and synthetic building materials can be significantly improved, then usage of CO_2 could become an important contribution to decarbonisation.

Risks and hurdles for CCS development

Although it is deployed at a small scale today, CCS has momentum, with many projects – at different levels of maturity – under development and review. The journey forward, however, will face several potential roadblocks.

Economics: The full estimated cost of CCS falls in a wide range, from \$50 to far above \$100 per tonne of CO_2. There are regions where the cost of CO_2 is high enough to justify CCS projects, but this is not the case in many places. Beyond the need for costs to go down, which is expected to happen as greater scale and industrial developments occur, there is a need for a common cost of carbon. This would indeed incentivise CCS projects, but more broadly the deployment of technologies to reduce, avoid and mitigate emissions.

In addition, as seen for wind and solar power, public support to kick-start developments is an important mechanism. For instance, Norway funds 85% of the Northern Lights project.

Logistical bottlenecks: Capturing CO_2 will only be of use if it can be transported. CO_2 pipelines must be built, which implies proper funding and adequate regulation. It is not far-fetched to think of a utility-like Regulated Asset Base framework, often used to plan long-term investment in major infrastructure.

Social acceptance: CCS could suffer from 'NIMBYism',[13] notably around the passage of CO_2 pipelines and the location of onshore storage sites. The perception of the risks associated with CCS will likely be different from the actual risks.

Bad publicity: The case of the Gorgon project in Australia is emblematic. This is a large liquefied natural gas development, with a CO_2-rich resource, where CCS was designed to avoid venting the CO_2. The operator, US energy firm Chevron, recognised that the volumes captured and stored have clearly been below expectations since the start up in 2019.[14] Such a case, with a large discrepancy between targets and reality can damage the reputation of CCS.

Moral hazard: Some stakeholders argue that CCS could act as an incentive to continue burning fossil fuels, even when alternative solutions are available.

What should CCS be used for?

As we have seen, the core purpose of CCS is to abate Scope 1 emissions for products or processes where they cannot be mitigated otherwise. In those cases, CCS can be a structural or a temporary solution:

- Structural for processes where there are no alternatives, such as cement making
- Temporary for processes where decarbonisation routes are in development, whether with changes in demand (new decarbonised products or new technologies) or in supply (new decarbonised industrial processes replacing carbon-intensive processes). This temporary status could well last for two or three decades.

[12] Paving the way to truly circular concrete with recarbonation | Holcim.com
Vicat accelerates its circular-economy drive with the CO2ntainer system
TECHNOLOGY | Blue Planet Systems

[13] NIMBY is an acronym for the phrase "not in my back yard", used to reflect the difficulty of gaining local support for projects perceived as disruptive

[14] Source: Financial Times, 26 July 2021. Monster problem: Gorgon project is a test case for carbon capture LNG production started in 2016 but the CCS facility only in 2019

A central question then is whether many CCS investments are warranted if they are only here to facilitate the transition and are not ultimately needed in a decarbonised energy ecosystem. If we take the example of a refinery, is it worth investing in CCS if the gasoline and diesel produced are bound to be displaced by electric power or biofuels? In other words, CCS assets could become stranded assets. The time horizon of the transition is an element to take into account, as the lifespan of certain assets could be long enough to justify investing in CCS. Given the urgency of reducing emissions, it would be better to deploy CCS and reduce emissions in the near future, all things being equal.

There will also be cases where CCS competes with other technological options. For instance, steel-making could be decarbonised by adding CCS to the existing blast furnace route, where metallurgical coal is used to reduce iron ore into iron, or by changing the process to use hydrogen instead of coal. The relative costs of both options ought to be considered, as well as their duration. CCS could be seen as a sticking plaster on a carbon-intensive process, while adapting the process itself could structurally change its carbon footprint.

It is also important, as always, to think in terms of entire value chain, for technological solutions as well as for emissions.

How can investors respond?

CCS is one of the many technologies in the decarbonisation toolkit. It should not be dismissed, as it is clearly needed, but equally should not be overly relied upon. At the risk of repeating ourselves, reducing and avoiding emissions should be the first priority. Mitigation – which is the realm of CCS – should follow, not lead.

Investors must make sure that any discussion around CCS is relevant to a given company and its specific value chain. CCS is most essential to decarbonise process emissions for products that cannot be substituted by alternatives offering a better lifecycle carbon footprint.

It is also important to understand the CCS ecosystem that a company is plugged into, as there is a strong network effect and a clear advantage of being part of a collaborative effort.

Finally, investors should be prepared to adapt and reassess over time. Technologies are evolving, as is the policy environment – the economic equation is not fixed. CCS is likely to become a more attractive economic option with time. Companies already taking a thoughtful and nimble approach to CCS – learning the tricks of the CCS trade – could well be in a position to reap the benefit.