Cost-effective CO_2 sourcing for utilisation and sequestration

The future of low-cost carbon dioxide sourcing and the most viable pathways to meet new demand as market dynamics evolve

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CO_2 is used in many commercial applications, such as beverage carbonation and food chilling. Its use cases also include pH control of wastewater and shielding gas during steel welding.

Traditional sources of CO_2 are in a major transition. Ammonia plants in Europe are closing, and smaller refineries are at risk. Corn ethanol production is unlikely to scale due to land use concerns in the food versus fuel debate.

On the demand side, production of e-fuels such as methanol and Fischer-Tropsch (FT) synthetic liquids is expected to create a demand for large quantities of biogenic CO_2 to react with electrolytic hydrogen. To minimise the cost of e-fuel production, the CO_2 will need to be sourced close to the hydrogen production location, which will most likely be near a cheap source of renewable electricity.

Additionally, a new application for biogenic CO_2 is emerging in the voluntary carbon market (VCM) for carbon dioxide removals (CDR). In this case, the CO_2 is permanently sequestered. To optimise the business case, biogenic CO_2 must be sourced close to the sequestration site.

Undoubtedly, CO_2 supply and demand will need to rebalance in accordance with these market dynamics. New supply chains will certainly emerge. The open question is which CO_2 sources will be most cost-effective to serve new demand in the locations where it is emerging?

Ammonia plant closures

Ammonia production has traditionally been one of the main sources of commercial CO_2 because CO_2 is captured within the ammonia synthesis process. Investment in CO_2 conditioning and liquefaction represents only a small additional operating and capital cost.

CO_2 shortages are increasingly common during the summer months. At this time of year, demand for CO_2 in chilled beverages spikes. Simultaneously, ammonia production falls after spring, and corn ethanol production eases off, awaiting the new harvest. Furthermore, ammonia plant closures by CF Fertilizers in the UK and BASF in Germany have removed some large commercial CO_2 sources. For these reasons, ammonia plants are no longer perceived as the most attractive commercial CO_2 sources.

Refineries at risk

In recent years, refinery steam methane reformers (SMRs) have been used to diversify commercial CO_2 sources. As an example, in 2016, BOC started up a 50,000 tonne-per-year (tpy) CO_2 capture and liquefaction plant at Refining NZ's Marsden Point refinery in New Zealand. However, smaller local refineries are progressively closing as larger, modern regional refineries come on stream. In line with this trend, the Marsden Point refinery closed in 2022, and the required refined products were imported from Asian refineries. As this refinery consolidation trend continues worldwide, investments in CO_2 capture and liquefaction from refinery SMRs will become increasingly risky.

Biomethane and CO_2 co-production

Biogas-to-biomethane ensures the biomethane is of sufficient quality to be injected into the natural gas distribution and transmission pipeline network. CO_2 is removed to achieve a high calorific value for the biomethane. Liquefaction of the captured biogenic CO_2 is low-cost because

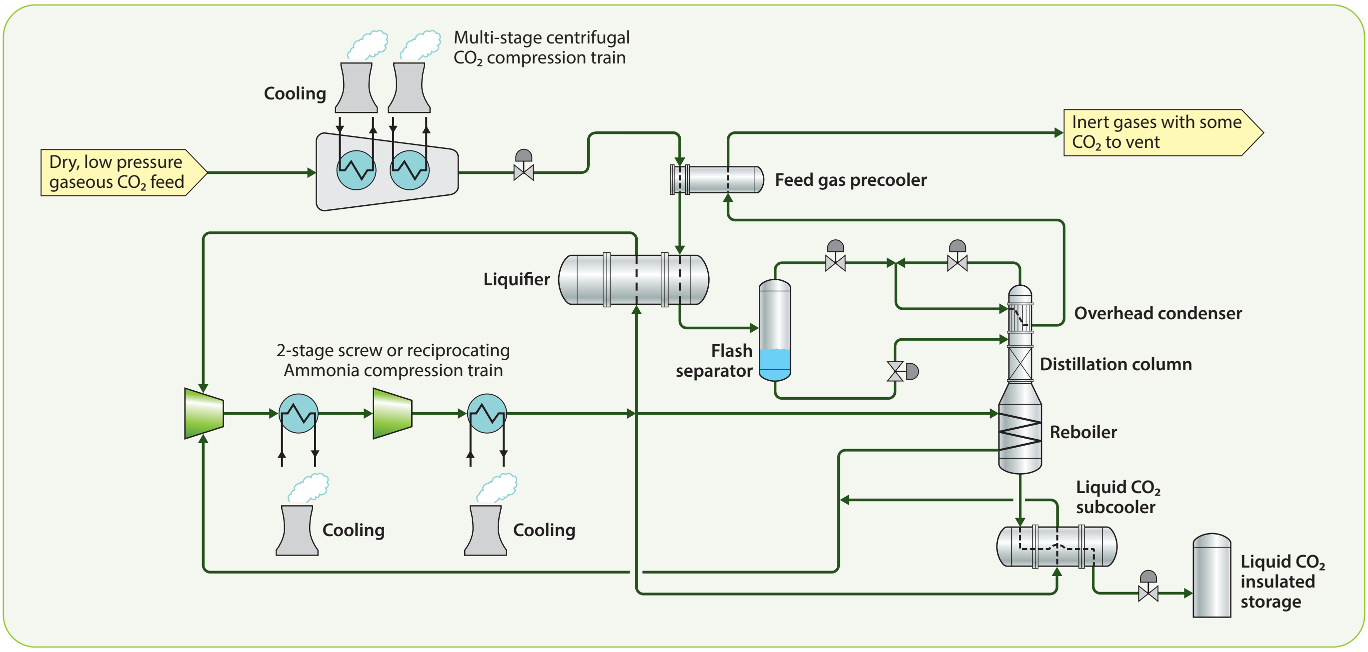

Figure 1 CO_2 liquifier with ammonia refrigeration cycle

it requires minimal additional Capex and Opex (see **Figure 1**).

CO_2 from biogas upgrading is used as a local, diversified source of commercial CO_2. For example, Bright Renewables has installed food-grade liquid CO_2 production plants at the biogas facilities in Heek and Brandis, Germany.

CO_2 from bioethanol

Bioethanol is the most significant liquid biofuel worldwide by production volume. It is produced during the fermentation of sugary broths on an industrial scale. The process is like making a hop-free beer from grain, then distilling it to make whisky.

In Asia and the Americas, the most widely used crops for bioethanol production are maize and sugar cane. Rice, sorghum, and cassava are also used in secondary quantities. In Europe, these crops are generally replaced by wheat and sugar beet. Corn ethanol fermentation yields a high-purity CO_2 stream, which is readily liquefied. This is a common CO_2 source in the US and is also used in Europe. For example, Messer France has exploited a bioethanol CO_2 source at Vertex Bioenergy at Lacq.

Demand for biogenic CO_2

Since 2020, a vibrant VCM has emerged. This exists in parallel to regulated costs of CO_2 emissions through national taxation programmes and emissions trading schemes.

The main buyers of CDR certificates in the Voluntary Carbon Registry (VCR) are cash-rich consulting firms and US-based mega-cap tech companies. Their vision is to offset the CO_2 emissions from their business activities. This is a cost-effective route to 'net-zero' for these knowledge-based sectors because their greenhouse gas emissions are diffused. Other industrial sectors with higher-intensity point-source CO_2 emissions can capture and sequester CO_2 at a lower cost.

The VCM prizes biogenic CO_2 for its ability to permanently remove CO_2 from the atmosphere.

Biogas monetisation with CDR

Capture and sequestration of biogenic CO_2 is one of the favoured methods to generate high-quality CDR certificates. For example, in November 2025, the German clean-tech start-up Reverion signed an agreement whereby Frontier (a trader of CDR certificates) will purchase 96,000 tonnes of CDR certificates for $41 million. This values each tonne of removed CO_2 at $427 (circa €370).

Reverion has developed a technology to convert biogas to heat and power. Its process does not require CO_2 to be separated from the biogas prior to entering its equipment. Plus, it produces a high-purity biogenic CO_2 stream ready for low-cost liquefaction.

Considering that €370 per tonne must cover the full value chain cost and that the cost of transportation and sequestration from Germany is in the order of €170 per tonne, there is a willingness to pay up to €200 per tonne for biogenic CO_2 from a biogas facility. This new, competing offtake market is pushing up the price of biogenic CO_2 to a level that is forcing merchant CO_2 businesses to reconsider their sourcing options.

In a similar arrangement, in February 2024, the Swiss clean-tech start-up Neustark sold 27,600 tonnes of CDR certificates to Microsoft. Neustark mineralises biogenic CO_2 into construction demolition waste to ensure its permanent sequestration.

There is now tremendous competition for CO_2 from biogas, driving up prices for commercial CO_2 from this source. Clearly, alternative commercial CO_2 sources must be found.

New low-cost CO_2 sources

For decades, commercial CO_2 sourcing has been driven by economics and reliable, year-round supply availability. These drivers remain relevant, but now that biogenic CO_2 has additional high-value applications, new low-cost commercial CO_2 sources must be found.

Several industries fit the requirements of commercial CO_2 sourcing. However, these are not biogenic sources. The future of commercial CO_2 sourcing will rely heavily on geogenic and fossil CO_2.

➊ **Diammonium phosphate (DAP) fertiliser production:** The most common phosphate fertiliser is DAP. It is popular because it can be applied as a liquid or granules and introduces both nitrogen and phosphorus to the soil.

DAP is produced from the phosphorus-bearing ore, apatite, which is mixed with sulphuric acid, to yield gypsum as a solid waste material and phosphoric acid. The phosphoric acid is reacted with ammonia, then granulated to produce DAP.

However, the apatite ore is not pure because it contains calcite, silica, and clay. During the ore treatment, or beneficiation, clay and silica are easily removed. However, much of the calcite cannot be separated from the apatite and is mixed with the sulphuric acid. During the reaction between calcite and sulphuric acid, CO_2 is released (see **Figure 2**).

The flue gas from the sulphuric acid mixing chamber is scrubbed with water to remove hydrogen fluoride (HF). The resultant gas mixture is hot, moist CO_2. Separation of the CO_2 can be easily achieved using cooling and condensation. The resultant dry, pure CO_2 can be liquefied at low marginal cost.

The idea to capture commercial CO_2 from phosphate fertiliser production will be implemented by OCP Nutricrops at its Jorf Lasfar industrial platform in Morocco. Applications for that CO_2 will include pH adjustment at a local reverse osmosis seawater desalination plant.

➋ **Ethylene oxide production:** CO_2 capture is essential in ethylene oxide (EO) production to avoid an accumulation of CO_2 in the reactor gas recycle loop. The equipment to capture CO_2 is generally a twin-tower absorber-stripper system using the hot potassium carbonate (HPC) solvent (see **Figure 3**).

The gas leaving the CO_2 stripper column is

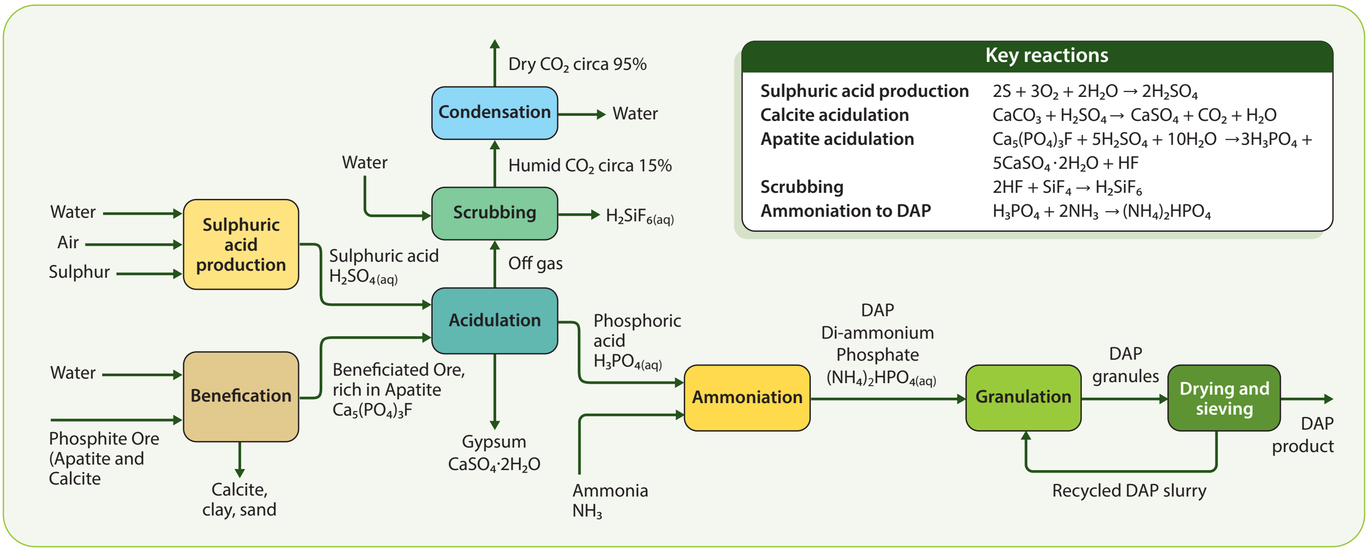

Figure 2 Geogenic CO_2 capture from phosphoric acid and DAP fertiliser production

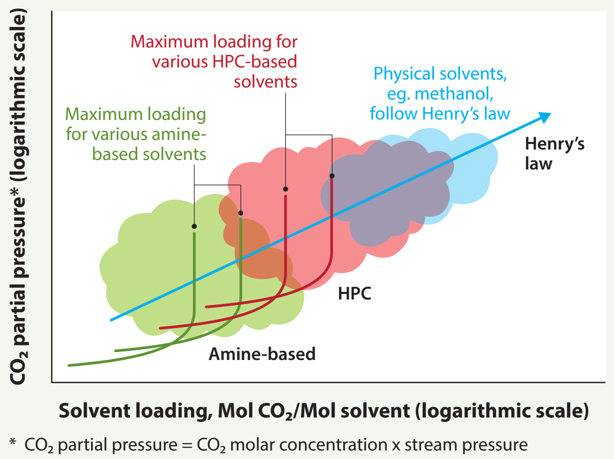

Figure 3 CO_2 capture technology selection – rules of thumb for initial screening of liquid solvent systems

rich in CO_2, with water vapour being the main additional component. The water vapour can be separated by cooling the gas stream to condense the moisture. The incondensable CO_2 gas can then be fed to a liquefier.

In the Middle East, where the petrochemical industry is thriving due to low feedstock costs, ethylene oxide production is the most common source of low-cost CO_2.

Gulf Cryo, an industrial gases company in the Gulf Cooperation Council (GCC) region, obtains CO_2 from one of Equate Petrochemical Company's EO plants in Kuwait's Shuaiba Industrial Area. A pipeline of several hundred metres transfers raw CO_2 from the stripper column on the EO plant to the Gulf Cryo site, where it is dried, liquefied, and purified to produce 55,000 tonnes of commercial CO_2 per year.

Gulf Cryo implemented a similar scheme at the EO plant operated by Petro Rabigh in Saudi Arabia. This plant came on stream in 2023 with an annual capacity of 100,000 tonnes of commercial CO_2.

Sourcing CO_2 as a byproduct from EO facilities avoids the use of a natural gas burner to generate commercial CO_2 and minimises fossil fuel consumption to support decarbonisation.

❸ **Town gas production**: Hong Kong has been using town gas for heating, cooking, and industrial applications since 1864. At that time, coal gasification was the source of town gas. In 1967, the feedstock for town gas production was changed to heavy fuel oil. In 1973, naphtha became the main feedstock.

The modern Tai Po Towngas plant commenced operation in 1986, producing hydrogen-rich town gas on four Catalytic Rich Gas (CRG) trains. Each train of the Tai Po Towngas facility has a CRG reactor (pre-reformer) and a tubular steam methane reformer at its heart.

The reformate is rich in hydrogen and CO_2 and contains less than 3% carbon monoxide (CO). However, this CO_2 concentration is too high, so CO_2 is captured from the reformate and is vented to the atmosphere. This CO_2 could easily be dried and liquefied for utilisation as commercial CO_2.

Singapore also runs on town gas. City Energy's Senoko Gasworks supplies 0.9 million commercial and domestic offtakers who use town gas for heating and cooking. Like Hong Kong's Tai Po facility, it is fuelled by a mixture of naphtha from local refineries and imported liquid natural gas (LNG).

❹ **Natural gas processing**: Natural gas processing is like crude oil refining: it converts raw gas into a usable commercial product. When natural gas rises from the reservoir, the methane is laden with light hydrocarbons, known as natural gas liquids (NGLs) and CO_2. Hydrogen sulphide is often present too.

Removal of CO_2 is essential for operational reasons to generate natural gas, which is transmitted to industrial and commercial users by pipeline or liquefied to make LNG. The capital investment and operational costs of CO_2 removal are borne by the natural gas processing. However, in most cases, the CO_2 is vented to the atmosphere. Two notable exceptions are the Sleipner West and Snow White CCS schemes, which are owned and operated by Equinor in the North Sea.

CO_2 from natural gas processing has also been identified as a low-cost source of merchant CO_2. In Australia, Air Liquide and BOC recover CO_2 from the Longford Gas Conditioning plant east of Melbourne. Air Liquide started up a 60,000 tpy liquefier to produce food and beverage-grade merchant CO_2 there in 2021. BOC followed with a tonne-per-year plant in 2024.

The amount of CO_2 that is captured in the acid gas removal facility depends on the sweetness of the gas. Longford is designed to process sour

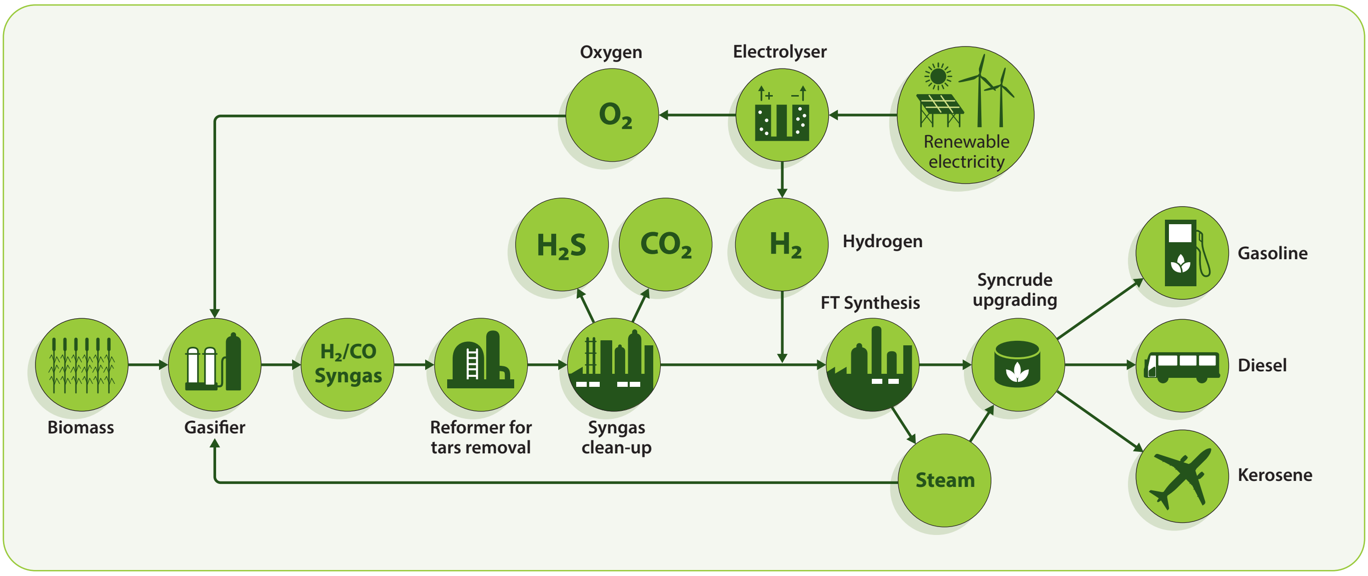

Figure 4 Hybrid electro-biofuel production for sustainable aviation fuel

raw natural gas from the Bass Strait's Gippsland Basin with 14% CO_2. On the other hand, sweet shale gas from the Appalachian Basin contains less than 1% CO_2.

❺ Biomass gasification for liquid fuels: Gasification of residual biomass, such as forestry cuttings and post-harvest waste, is a viable pathway to produce second-generation liquid biofuels.

The syngas produced by gasification is very rich in CO, but it does not contain sufficient hydrogen to produce FT synthetic liquid fuels such as kerosene and diesel. In bio-electrofuels production, hydrogen-lean gasifier syngas is blended with electrolytic hydrogen to maximise the carbon yield.

During gasification, the ideal chemistry would be for biomass to be converted only to hydrogen and CO. However, the gasifier cannot be controlled to this level of precision. Some heavier molecules break through as tars, and other molecules are combusted to produce CO_2 (see **Figure 4**).

Use of oxygen instead of air, injection of steam with the oxygen, and gasifier operation at high temperature around 1,400°C can maximise the conversion of carbon to CO and simultaneously minimise CO_2 production. This favours the use of a slagging entrained flow gasifier.

For effective downstream conversion of the syngas to FT fuels, CO_2 and other acid gases such as hydrogen sulphide must be removed. This is most suitably achieved using a solvent-based scrubbing and stripping system with an amine, HPC, or chilled methanol solvent.

The captured CO_2 is of high purity and can be liquefied for sale to commercial applications.

❻ Waste-to-energy (WtE): Biomass-fired power plants are premium targets for bioenergy carbon capture and storage (BECCS). They burn wood pellets, wood chips, or straw to create heat and power. Upcoming BECCS projects are responsible for more than 50% of all CDR certificates sold in the VCM to date.

WtE facilities incinerate municipal solid waste (MSW) rather than biomass. However, MSW contains between 40 and 60% biogenic material, even after paper has been sorted for recycling and food and garden waste have been removed for conversion to biomethane.

Since MSW facilities can only monetise the biogenic fraction of their captured CO_2 for CDR in the VCM, the business case for BECCS here is weaker than for biomass-fired plants. However, in cases where there is a meaningful cost avoidance from CO_2 emissions reduction, BECCS from WtE plants can be profitable.

Once a WtE facility has jumped the hurdle to invest in CO_2 capture to sequester the biogenic fraction of its emissions for CDR, it will be keen to monetise the fossil fraction to support the business case. This could be the next major low-cost commercial CO_2 source.

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