Blue chemicals with low-cost pre-combustion CO2 capture: The first places to look for CCUS opportunities

By Stephen B. Harrison on Dec 24, 2023 | 0 FEATURE | FEATURES

Post-combustion carbon dioxide (CO2) capture will be essential to produce green steel, decarbonise cement making and mitigate CO2 emissions from fossil-fired power generation.

However, post-combustion CO2 capture after air-fed combustion is expensive, since the CO2 concentration is low, and a huge volume of nitrogen gas must be processed.

Pre-combustion CO2 capture, on the other hand, is cost effective and can be retrofitted to more than 1,000 operational SMRs around the world to decarbonise hydrogen production.

Additionally, ammonia and ethylene oxide (EO) production must remove CO2 from the process gases to ensure the chemical reactions and catalyst performance are effective. In these chemical and petrochemical processes, the costs of CO2 capture are unavoidable. These applications must represent priorities for CCUS in the chemical and petrochemical sectors.

Blue hydrogen and pre-combustion CO2 capture

When capturing CO2 from an SMR, the location from which the CO2 is captured influences the cost. The lowest unit cost is to capture CO2 from the pre-combustion syngas stream prior to the PSA unit. At this point, the partial pressure of CO2 is at its highest.

On the other hand, the maximum CO2 recovery rate is capped at 70% because the post-combustion CO2 from the SMR burners is not captured. To achieve low-carbon (blue) hydrogen certification in some markets, such as the EU, it may be required to capture CO2 in the SMR flue gas to achieve the necessary low CO2 intensity of hydrogen production.

Pre-combustion CO2 capture has the benefit of operating at high pressure and often with a high CO2 concentration. The consequence is that the combined OPEX and CAPEX costs per tonne of CO2 captured can be only 50% of post-combustion CO2 capture. Retrofitting CO2 capture to steam methane reformers (SMRs) for refinery hydrogen production represents a cost-effective way to achieve impactful decarbonisation.

Porthos CCS case study

Air Products will retrofit a CO_2 capture facility at its existing Botlek SMR in Rotterdam. The SMR was built in 2011 with a capacity of around 100,000 tonnes of hydrogen per year. The annual CO_2 emissions at this production capacity would be more than 1,000,000 tonnes.

The retrofitted CO_2 capture, drying and compression facility is expected to be on-stream in 2026. Retrofitting CO_2 capture equipment to an SMR of this size could cost in the order of €100 million. This represents an additional 50% of the original capital cost of the SMR. Steam is required to operate the CO_2 capture facility and power is needed to compress the dried pure CO_2. These represent the main operating costs.

Once operational, this will be the largest low-carbon, or 'blue' hydrogen plant in Europe. The hydrogen from the Botlek SMR will continue to serve ExxonMobil's Rotterdam refinery and additional customers via Air Products' hydrogen pipeline and hydrogen liquefier.

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ExxonMobil aims to achieve Net Zero Scope 1 and Scope 2 emissions from its operated assets by 2050. Since Air Products owns and operates the hydrogen production facility, the CO_2 emissions reduction is categorised as Scope 1 for Air Products and scope 2 for ExxonMobil. This CO_2 capture retrofit with CO_2 sequestration in the Porthos scheme will allow Air Products to reduce its CO_2 emissions in the port of Rotterdam by more than half.

The Porthos CCS scheme is the first large-scale CO_2 transportation and storage infrastructure scheme in the Netherlands to achieve FID and regulatory approval. CO_2 will be sequestered 3km beneath the surface of the North Sea in depleted gas fields which lie about 20km from the coast.

Low-carbon ammonia cracking and import

Blue ammonia may be produced at low cost in the US Gulf Coast, where natural gas prices are low and CO_2 storage can be achieved in locations close by, such as the Permian Basin. Linde and OCI will collaborate to produce 1,100,000 million tonnes per year of blue ammonia. Partial oxidation (POx) will be used to convert natural gas to syngas. The process operates at high pressure which reduces the pre-combustion CO_2 capture costs. CO_2 liberated during hydrogen production will be captured and sequestered.

The cost-adder for CCS is around $120 per tonne of ammonia. This covers the additional equipment and energy costs to remove the CO_2 from the gas stream, transport it to a sequestration location and inject it for permanent storage.

Many projects have proposed to produce green hydrogen at scale. The optimal locations are where there is abundant renewable power generation potential from integrated wind and solar schemes, such as Western Australia. In the future, when electrolyser costs reduce and the efficiency of this technology improves, the cost of green hydrogen in these locations could potentially be comparable to blue hydrogen. Shipping and terminal infrastructure must be developed to connect the blue and green hydrogen producers with energy markets.

Air Products is also planning to make clean hydrogen available in western Europe from cracked green or blue ammonia. The ammonia will be imported through the ports of Rotterdam and Hamburg. In Hamburg, Air Products will construct a new ammonia terminal for this purpose. At Rotterdam, Air Products has partnered with Gunvor to develop the import terminal. In Hamburg, Mabanaft will partner with Air Products.

In addition to the potential to crack ammonia to make hydrogen, low-carbon ammonia can also be fired directly to generate steam in boilers or power on specially constructed gas turbines. At smaller scale, it will also see application as a maritime fuel and may also be used for industrial transportation applications in rail and trucking operations.

CO_2 capture in ammonia and EO production is essential

CO_2 must be removed from the gas stream prior to ammonia synthesis since any oxygen-containing molecules such as CO_2, carbon monoxide (CO) and water (H_2O) would poison the ammonia synthesis catalyst. Hot potassium carbonate (HPC) is commonly used for this pre-combustion CO_2 capture application.

In the UK, CO_2 has been captured, purified, and liquefied at CF Fertilizer's ammonia plants in Billingham and Ellesmere Port for many years. Rising natural gas costs have rendered these plants uncompetitive, leaving a gap in UK CO_2 supply.

The CO_2 emissions from a world-scale ammonia plant would be more than 2,000,000 tonnes per year. Since this CO_2 must be removed from the process to enable ammonia synthesis, there is no additional capital or operating cost associated with the CO capture aspect of CCS. With a small incremental investment in CO_2 drying and compression, CO_2 from ammonia facilities can be transported by pipeline to a suitable sequestration location.

CO2 capture is essential in ethylene oxide production to avoid an accumulation of CO2 in the reactor gas recycle loop. This CO2 must be captured and removed from the EO production process, and the associated capital and operating costs are absorbed in the EO production cost.

As with ammonia production, the incremental cost of CO2 transportation and injection at a sequestration site or for utilisation is low, in comparison to a discretionary post combustion CCS scheme where additional energy input would be required to capture CO2 from the flue gas. To achieve rapid, cost-effective decarbonisation within the petrochemical sector, sequestration of captured CO2 from EO production must be a priority.

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Blue methanol and gas heated reforming

Gas heated reforming (GHR) was developed by ICI in the UK in the 1980s and referred to as the Leading Concept Methanol. In a similar configuration, the Leading Concept Ammonia uses a GHR for ammonia production. The LCA was deployed by ICA at its Billingham ammonia plant in 1966. The site was more recently owned and operated by CF Fertilizers.

In the process, the GHR is followed by an ATR. Oxygen is injected into to the ATR, where some exothermic partial oxidation reactions take place. The heat from these reactions maintains autothermal operation in the ATR and is also used to heat the GHR. Since the GHR is heated using syngas from the ATR, there is no need to have a fired burner in the SMR. This avoids the need for post-combustion CO2 capture in this reforming configuration.

From 1994 to 2016, Coogee Energy operated a 70,000 tonne per annum methanol facility at Laverton in Victoria, Australia. The plant used a GHR and ATR in the LCM configuration. Rising gas prices in Victoria rendered the Laverton plant uneconomic after 20 years of successful operation.

To capitalise on the potential for a lower cost natural gas feedstock, Coogee proposed a $ 500m (AUD) investment in a 350,000 tonne per day methanol plant in Darwin Harbour, in Australia's Northern Territory. The potential for CCS in the South East Asia, north of Darwin is high and there would therefore be good prospects for blue methanol production at this location using the GHR process and pre-combustion CO2 capture.

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