LNG DECARBONISATION STRATEGIES FOR A CLEANER FUTURE

As the emphasis on decarbonisation and minimising greenhouse gas (GHG) emissions increases in many countries and markets, LNG is continuing to maintain and grow its share of the world's changing energy portfolio due to its lower intrinsic carbon content than oil and coal. Green energy sources like wind, solar, hydro, and nuclear present an opportunity for the LNG industry to push decarbonisation further throughout the LNG value chain.

The LNG value chain consists of three main sections:

1. Upstream – exploration, production, and processing of natural gas.

2. Midstream – liquefaction and transport by LNG carriers and bunkering vessels.

3. Downstream – storage, regasification, distribution, and end use.

GHG emissions occur in all three sections of the value chain. Upstream emissions occur due to leakage, flaring, and the generation and utilisation

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identify strategies for decarbonising the LNG value chain.

of energy for pipeline compression. Midstream processes contribute to emissions from liquefaction processes and LNG transportation. The downstream section of the value chain is responsible for the most GHG emissions, as carbon dioxide (CO_2) and other greenhouse gases are released when the LNG is regasified and combusted. To carry out decarbonisation of the LNG supply chain, a detailed understanding of the emissions produced by each stage is required to select the proper strategy. As a leading liquefaction technology licensor and equipment supplier, Air Products is developing solutions for decarbonisation of the liquefaction process.

Prior to liquefaction, natural gas requires pre-treatment to remove impurities such as mercury, CO_2, sulfur compounds, water, and heavy hydrocarbons. The high-pressure natural gas is cooled by heat exchange with one or more refrigerants to approximately -150˚C before it is reduced in pressure to remove nitrogen and helium and generate methane flash gas for fuel. It is then stored at atmospheric pressure for shipment. During LNG production, greenhouse gas emissions are produced from the following sources:

- Venting of CO_2 removed from the natural gas feedstock during pretreatment.
- Combustion of fuel to generate power to drive refrigerant compressors in the liquefaction process.
- Combustion of fuel to provide ancillary power and process heat for the facility.
- Flaring of natural gas during plant operation.
- Fugitive methane emissions.

Reducing the GHG emissions of LNG production requires consideration of these sources to reduce CO_2 and hydrocarbon emissions to the atmosphere. While the ultimate goal of decarbonisation is to achieve zero carbon, there is value in partial decarbonisation. Some strategies are lower in installed cost and may provide positive financial returns to the liquefaction project, while others are higher cost and may not be adopted without financial incentives or regulation that bring the reduction of carbon emissions within the project scope.

Pretreatment decarbonisation

Natural gas may contain from 1 – 10% or more CO_2, and this must be reduced to about 50 ppm prior to liquefaction to prevent freeze-out of the CO_2 and subsequent blockage of equipment in the cryogenic liquefaction process. For a natural gas feed with 6% CO_2 in the natural gas, the CO_2 content is about 0.14 t CO_2e/t of LNG. CO_2 is removed from the natural gas in an acid gas removal unit (AGRU) using an adsorbent or solvent and may be recovered for commercial use or vented to the atmosphere. Recovery of CO_2 for commercial purposes such as the manufacture of urea fertilizer, production of dry ice, or carbonation of beverages results in only temporary prevention of carbon emissions. Capture of the CO_2 followed by underground sequestration is being used to permanently reduce some of these emissions.[1]

Energy efficient liquefaction technology

The clean natural gas from the pretreatment system is cooled in the liquefaction unit by heat exchange with a circulating refrigerant. A discussion of the many refrigeration process cycles that are available is beyond the scope of this article, and references are included below.[2,3,4] The liquefaction phase incorporates refrigerant compressors which consume a large amount of power, on the order of 275 KWh – 375 kWh/t of LNG produced, depending on the process cycle selected and project details. The compressors are typically driven by gas turbines, with fuel supplied by the methane flash gas generated in the LNG pressure reduction step prior to storage. With simple cycle gas turbine drivers (about 35% thermal efficiency) the corresponding CO_2 emissions are about 0.15 t – 0.21 t CO_2e/t of LNG.

A straightforward way to reduce carbon emissions is to select a process cycle with high efficiency to reduce the power requirement and consequent fuel consumption. High process efficiency also provides a financial benefit: reduced auto-consumption of feedstock for fuel and/or reduced power import costs. Guidelines for choosing a higher efficiency process include consideration of:

- Vapour compression refrigeration cycles, such as mixed refrigerant processes and pure component cascade processes, use liquid refrigerants and generally have higher efficiency than gas expansion cycles with vapour refrigerants, due to more favourable thermodynamics and lower refrigerant circulation rates.
- Mixed refrigerant cycles such as single mixed refrigerant (SMR) can provide higher process efficiency than

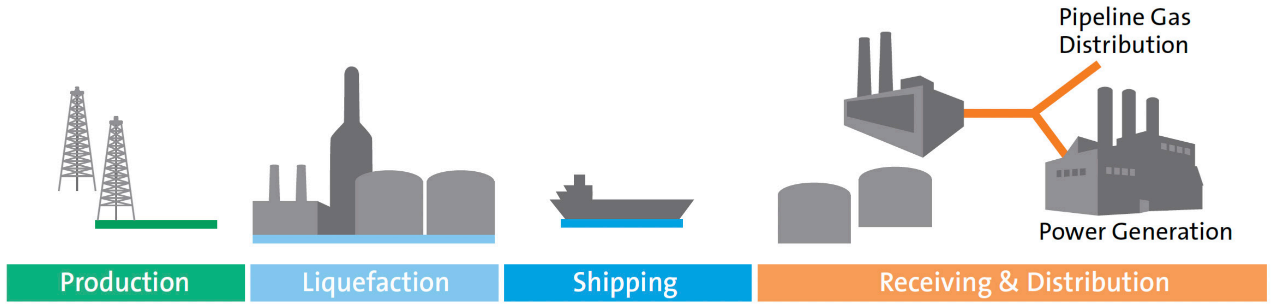

Figure 1. The LNG value chain includes liquefaction of natural gas.

pure component cycles due to smaller temperature differences between refrigerant and natural gas.

- Processes with separate precooling and liquefaction refrigerants such as propane precooled mixed refrigerant (C3MR) and dual mixed refrigerant (DMR) generally have higher process efficiency than single refrigerant processes such as SMR due to additional flexibility in optimising the process to meet specific cooling requirements.

A C3MR or DMR process typically has a 5 – 15% efficiency advantage over SMR or pure component cascade, and therefore 5 – 15% lower emissions. A similar production benefit provides a significant financial advantage to the owner as well.

Low emission power source options and CO_2 capture

Given a particular power requirement, the next step to reducing emissions is to generate that power at a lower carbon intensity. One method is to substitute combined cycle generation for the simple cycle generation that has been commonly used for LNG facilities. A single-shaft industrial gas turbine may have a thermal efficiency of 35%, and an aeroderivative gas turbine may increase that to 45%. By using waste heat recovery to generate steam for the direct or indirect drive of compression, the overall thermal efficiency may reach 55 – 60%, reducing fuel usage and the intensity of emissions by 20 – 40% compared to simple cycle drivers.

It should be noted that combined cycle generation can be applied to any liquefaction technology. Therefore, carbon intensity can be minimised by combining the high efficiency liquefaction processes described earlier in the article with the high thermal efficiency of combined cycle generation. Matching gas or steam turbine power capacity to compressor power consumption can be achieved in various ways to optimise the plant layout and use of capital:

- Direct drive of all compression with gas turbines and steam turbines provides high overall plant efficiency by avoiding electricity generation and transmission losses, and low capital by eliminating electrical infrastructure.
- On-site combined cycle electric power plant to power motor drives for all compressors allows flexibility to independently size individual turbines and motors.[5]
- Direct drive of some compressors with gas turbines and electric generation with steam turbines to power motor drives for other compressors may offer a useful intermediate solution.

Further emissions reduction can be achieved by post-combustion carbon capture from the flue gas using an absorption system similar to that used for removing CO_2 from the natural gas feed. The CO_2 then can be sequestered along with the CO_2 captured from the front-end pretreatment. While this can be performed for any gas turbine arrangement (simple or combined cycle, direct or indirect drive), there are several important considerations.

- Achieving high process and thermal efficiency will minimise the amount of flue gas to be processed, reducing CO_2 capture CAPEX.
- Space limitations may make integration more difficult with gas turbines for direct drive compared to gas turbine electric generators.
- The low pressure of the flue gas presents difficulty for the absorption process and may require either back-pressuring the combustion process or using a blower to pressurise the flue gas, both of which are not optimal.
- There is limited data on large scale post combustion CO_2 capture for flue gas derived from gas turbine exhaust.

An alternative to post-combustion capture is pre-combustion capture, such as the blue LNG process shown in Figure 2. The methane fuel provided by the LNG unit end flash gas is converted to hydrogen and carbon dioxide using well-referenced technologies.[6] The CO_2 is then removed to create a carbon-free fuel for the gas turbines. Considerations for this process include:

- The hydrogen production equipment increases CAPEX.
- The gas turbines must be designed to operate with hydrogen fuel.
- The conversion of methane to hydrogen includes a thermal energy loss that must be supplied by additional methane fuel consumption. Somewhat counterintuitively, sourcing more methane fuel from the pressure reduction flash step in the liquefaction process provides an LNG production increase for the facility due to improved liquefaction process efficiency.[7]
- Capture of the CO_2 is performed at high pressure, which reduces the size and cost of the capture equipment. The capture equipment can also be sited away from the gas turbines.

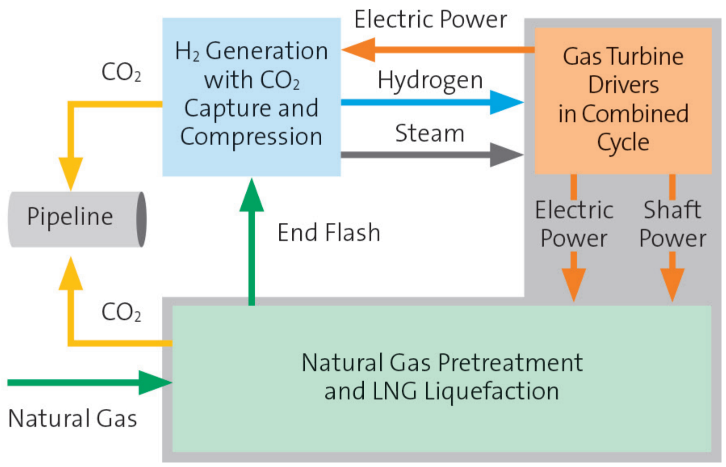

Figure 2. The blue LNG process uses pre-combustion carbon capture to lower emissions.

Zero-emission power source options and integrated nitrogen removal units technology

With carbon capture and sequestration, the strategies mentioned can be used to build a near zero-carbon emissions facility. Replacing the methane fuel used for power generation with electricity sources like solar, wind, hydro, and nuclear provides another path to zero-carbon emissions liquefaction.[8] On-site renewable generation can be coupled with grid-connected renewables and nuclear to power the liquefaction process by electric drive, although this strategy has some caveats:

- Suppressing the generation of flash gas, no longer needed for fuel, during the pressure reduction between liquefaction and storage requires further cooling of the LNG and higher power consumption (lower process efficiency). Alternatively, the flash gas can be recompressed and recycled to the natural gas feed, potentially requiring additional power consumption.

- Removal of excess nitrogen from the LNG cannot be performed through the combustion of flash gas used as fuel since no fuel demand exists. For natural gas feeds with excess nitrogen, additional equipment for a nitrogen rejection unit (NRU) must be included in the plant scope. While beyond the scope of this article, there are many references for this technology.[7,9] Integration of the NRU with the refrigeration system and main cryogenic heat exchanger (MCHE) can provide benefits of reduced equipment count and better efficiency.[10]

Design for low carbon operation

Operational sources of emissions include flaring of feed gas and hydrocarbon refrigerant as well as fugitive emissions. Flaring of natural gas and hydrocarbon refrigerants may occur during process upsets, start-up, shutdown, and other operations, and is highly dependent on process selection, plant design, and quality of operation. Leakage from flanges, valve packing, and other sources can also occur during operation. One study of three liquefaction facilities indicated a leakage rate of 0.07% of methane processed.[11] Strategies for low and zero-emission designs include:

- To reduce flaring during equipment cooldown and start-up, use best practice cooldown methods such as AP-AutoCool™ to minimise natural gas flows, and recycle natural gas to the plant front-end instead of flaring off-spec (warm) LNG.[12]

- Design with parallel refrigerant compression to keep cryogenic equipment cold in the event of machinery trips.

- Include lines for refrigerant recovery and holding vessels to minimise flaring during process upsets or while shut down.

- Use variable-frequency drive (VFD) electric motors or multi-shaft gas turbines to minimise refrigerant flaring on restarts.

- Minimise leakage from flanges and valves through both monitoring and equipment design, specifically the use of coil wound heat exchangers for liquefaction which incorporate aluminium/stainless steel transition joints to eliminate flanges and provide dual containment of high-pressure process streams to minimise potential leakage to the environment.

Conclusion

The design of liquefaction facilities for low or zero-carbon emissions is within the capabilities of today's technology. Air Products is well positioned to develop these solutions. Recent LNG plants leveraging Air Products LNG technology have adopted some of these strategies to reduce emissions while also providing financial benefits to operations by minimising loss of costly refrigerant and feed gas.[13] Adopting more of these techniques will enable the process of turning natural gas into LNG to achieve low or zero-carbon emissions while maintaining LNG as the preferred fuel for the energy transition and into a greener future. **LNG**

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