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Overview of LNG Technologies

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May 2021

This is the fifth article in a series by OTC specialists and partners on natural gas (NG) and liquefied natural gas (LNG).

The series comprises the following articles which are scheduled for publication on the dates listed:

1. Overview of the LNG industry – September 2020
2. Traditional gas transport modes – November 2020
3. Safe and clean storage of natural gas – January 2021
4. Alternative modes of natural gas transport – March 2021
5. LNG technologies – May 2021
6. Comparison of inland gas and imported LNG – June 2021
7. Outlets for NG and LNG – August 2021
8. Gas for power generation – September 2021
9. Small scale versus large scale LNG – November 2021
10. Gas utilisation in transport – December 2021

These articles are published over a period of 16 months and will be interspersed with articles related to aspects of project management and renewable energy.

Introduction

Natural gas (NG) has become an increasingly important energy resource and is an important feedstock for the chemical industry. Today approximately 30% of the world's energy needs are met with this gas, mostly supplied in gaseous form by pipeline. To liquefy natural gas, it must be cooled to cryogenic temperatures of -160˚C. As a liquid, natural gas occupies only 1/600 of the volume of natural gas in gaseous form at atmospheric pressure, making liquefied natural gas (LNG) more economical and practical to store. NG is typically transported in liquid form when vast distances, geological conditions or political dynamics make pipeline construction impractical.

As global LNG trade continues to increase, cost effectiveness and flexibility of technologies for LNG projects is driven by plant capacity, feedstock type and availability, plant location, swings in LNG market demand, etc. Considerable diversification of liquefaction processes has been seen recently and the ultimate choice of which technology to select will be dependent on project-specific variables.

This article explores the most commonly used technologies for the different plant capacity ranges.

Background

LNG plants are classified into baseload, mid-scale, peak-shaving, and small- or micro-scale plants. Baseload plants usually export their product (by sea), are in the capacity range 1 to 7 million tpa and often consist of multiple trains. Midscale is normally for domestic consumption and covers the range 0.1 to 1 million tpa. Peak-shaving and small-scale plants of up to 100 000 tpa provide extra capacity during peak demand periods, emergency fuel backup and vehicle fuel.

As the worldwide availability of CO_2 lean NG decreases, smaller, unconventional gas sources with high CO_2 concentrations and heavy hydrocarbon (HHC) content must be used. Hence demand for small-scale LNG plants (from 1 000 to 100 000 tpa) is showing strong growth due to small, stranded gas resources such as flare gas or coal bed methane in remote locations. Small- or micro-scale plants are also used to convert biogas from anaerobic digesters, farm wastes and municipal wastes into LNG.

The composition of NG can vary widely from 50% methane (with 40% CO_2, H_2O, H_2S, and N_2) to an almost pure methane stream with few impurities. Hence, the conversion of these gases requires two main processing steps, namely gas purification to remove impurities that interfere with the liquefaction process or are undesirable in the final LNG product, followed by the liquefaction or LNG plant.

Gas purification technologies

For NG to be suitable for liquefaction requires the hydrogen sulphide content to be less than 4 ppmv, total sulphur less than 30 ppmv, carbon dioxide less than 50 ppmv, water content below 0,1 ppmv and mercury levels below 0,01 mg/m^3_n.

The primary objective of the gas purification plant is to remove unwanted contaminants such as carbon dioxide (CO_2), hydrogen sulphide (H_2S), water (H_2O), nitrogen (N_2), heavy hydrocarbons (C_3+), and aromatics. There are several technologies that can be used (or combinations thereof), each with advantages and disadvantages as shown in Table 1. All are based on one of the four processes of absorption, adsorption, membrane separation, or cryogenic separation.

Table 1: Gas purification technologies (Adapted from Shimekit & Mukhtar, 2012)

Process	Examples	Advantages	Disadvantages
Absorption	• Rectisol (methanol) • Selexol (polyethylene glycol) • Water scrubbing • Amine scrubbing	• Widely used technology for efficient (50-100) % removal of acid gases (CO_2 and H_2S).	• High partial pressure is needed when using physical solvents • Low partial pressure is needed when using chemical solvents.
Adsorption	• Pressure swing adsorption (PSA) • Thermal swing adsorption (TSA) • Displacement desorption	• High purity of products can be achieved • Ease of adsorbent relocation to remote fields when equipment size becomes a concern	• Recovery of products is lower than for absorption • Adsorbents are engineered for specific contaminants
Membrane	• Molecular sieves • Polymeric membranes • Inorganic membranes • Mixed matrix membranes	• Low capital investment and operational cost • Stability at high pressure • High recovery of products • Weight and space efficiency • Low environmental impact	• Recompression of permeate is required • Final products are typically only moderately pure
Cryogenic	• Low temperature distillation	• Relatively higher recovery compared to other processes • Relatively high purity products	• Highly energy intensive for regeneration • Not economical to scale down to small size. • Highly integrated process schemes

Amine scrubbing has been the traditional technology for removal of CO_2 and H_2S and is available in a wide range of capacities. The smaller capacity plants can be delivered in a compact skid.

Membrane technology is often selected as the purification technology for smaller biogas to LNG plants. It is a passive technology and requires minimal supervision. Systems are constructed in modules (several modules per skid), and this provides flexibility by increasing or decreasing the number of modules online. Multiple stage systems can produce 99% pure methane, with a single stage achieving 88 to 93% purity. Membrane technology is a low capital option and membranes have a usable lifetime of 8 to 10 years. Due to the need for minimal supervision and no requirement for solvents or chemicals, membrane technology is a good, low capital option for remote locations.

The disadvantage of membrane separation technology is the energy and capital required for compression of the permeate. However, the liquefaction process downstream requires high pressures too, so it does not really present a disadvantage in this combination. Membranes do need to be stable with limited degradation at high CO_2 and HHC partial pressures. It is often wise to test membranes from different suppliers in the laboratory using a sample of feed gas before selecting a supplier.

NG with a relatively low CO_2 content (less than 1%) can be pre-treated using carbon molecular sieves, constructed as compact skid units and available from several vendors.

Gas Liquefaction (LNG) Technologies

Opening remarks

Purified gas, which is made up mainly of methane and contains less than 0,1 mol% of heavier hydrocarbons, is cooled in the cryogenic section to -160˚C and is completely liquefied. For feed gas containing N_2 levels greater than 1 mol%, N_2 will be removed in the LNG plant to prevent rollover during transport. The nitrogen is removed by adjusting the amount of end flash gas that is produced.

Two basic refrigeration cycles have been used in LNG liquefaction schemes, namely:

- **Expander cycles:** Expander cycles rely on the fact that when high pressure gas expands, it cools. In an LNG plant, the expanded refrigerant is used to cool and liquefy the feed NG in a heat exchanger. Historically, nitrogen has been the favoured refrigerant medium for LNG expander cycles.
- **Vapour-Compression cycles:** These processes rely on liquids absorbing heat when changed from a liquid to a gas. In LNG plants, liquid refrigerants are evaporated by the feed NG, cooling and liquefying the NG in the process. Historically, mixed refrigerants comprising a mixture of hydrocarbons or multiple single component hydrocarbon refrigerants have been used to liquefy NG.

Each of these refrigeration cycles is explained in more detail in the sections that follow, and representative examples are provided where applicable.

Expander Cycles

Nitrogen Expander Processes

Nitrogen expander processes for the liquefaction of NG are available with single, double, or triple expander cycles, as illustrated in Figure 1.

Because the nitrogen expander process is relatively inefficient, its use has generally been confined to small-capacity LNG plants. Additional expanders are added to improve the liquefaction cycle efficiency, but even with the complexity of three expanders, the process is less efficient than mixed refrigerant schemes.

In this scheme, nitrogen is circulated in a closed loop by the compressor through the expanders where the nitrogen is chilled through the expansion process. The chilled nitrogen cools and liquefies the incoming gas feed in the main heat exchanger. LNG is produced at -161^{o}C.

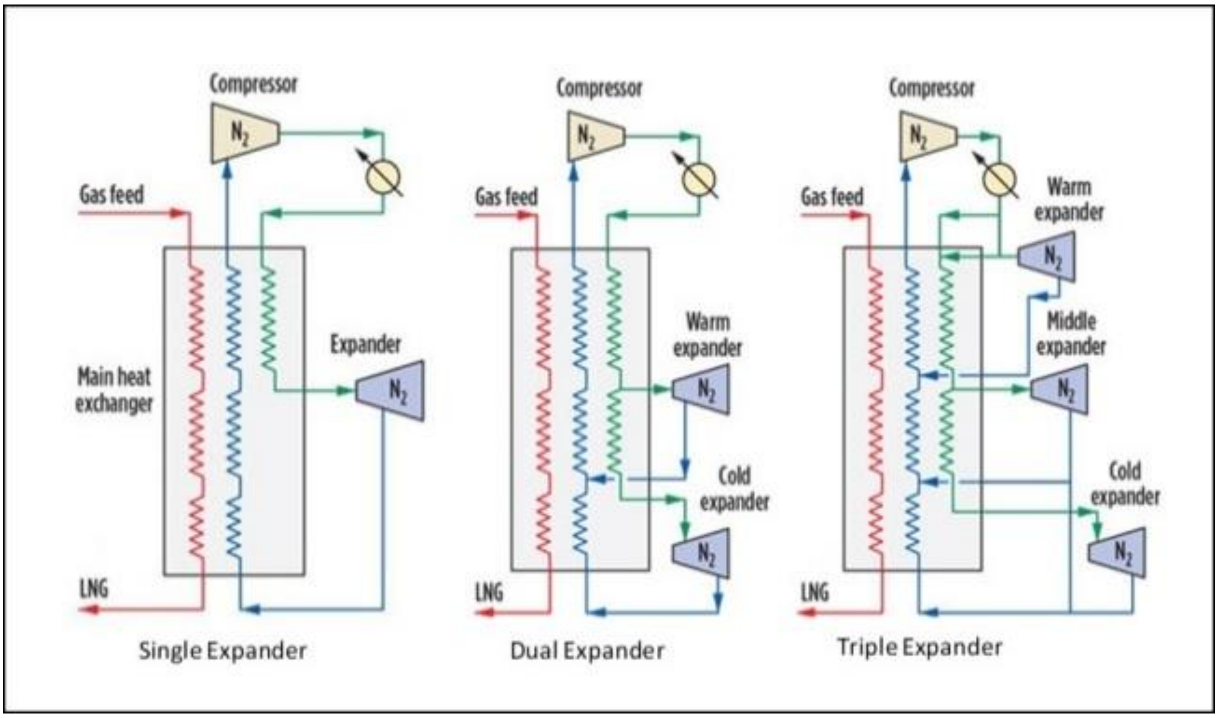

Figure 1: Nitrogen expander processes for LNG production (Bukowski et al, 2018)

There are numerous technology suppliers for nitrogen expander schemes, some with their own nuances to improve plant efficiency. The maximum economic single-train capacity of a nitrogen expander process is generally considered to be 1 million tpa.

Methane Expander Processes

Methane, in the form of the natural gas feed has been widely used as the refrigerant medium in peak shaving LNG plants. These plants are generally built to expand high pressure grid gas through an expander in a manner similar to nitrogen schemes. They rely on there being a market for the reduced pressure gas downstream of the expander. Peak shavers have generally been built to build up LNG supplies over low-demand summer months for use in peak winter demand periods. They are typically low capacity plants.

More recently Lummus Technology (Niche LNG), Air Products (APC1), Gasconsult (ZR-LNG), Saipem (Liqueflex) and Samsung (Sense IV) have developed more advanced methane cycle expander processes. The Lummus Niche LNG technology uses independent nitrogen and methane expander cycles. An obvious disadvantage is the complexity and cost of such a scheme. The Saipem Liqueflex and Samsung Sense IV processes also utilise a combination of methane and nitrogen cycles. The Lummus Niche LNG technology is shown in Figure 2 as an example of these technologies.

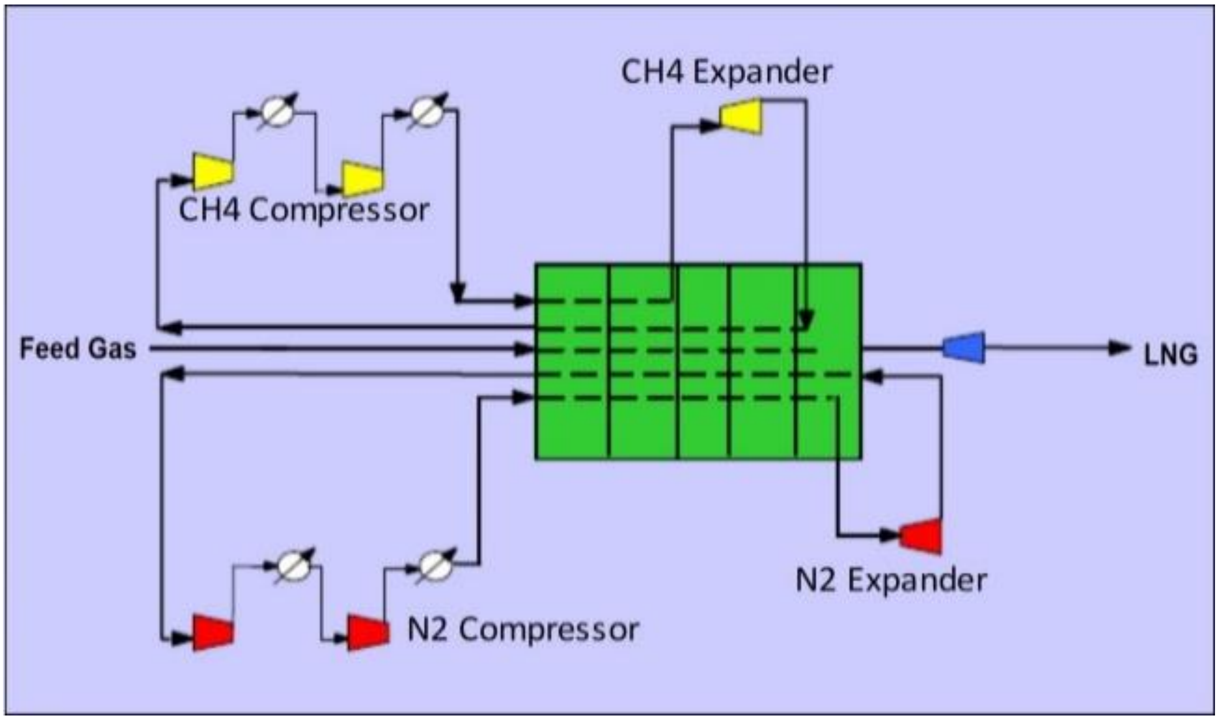

Figure 2: Lummus Niche LNG technology (Adapted from Foglietta, 2002)

The Air Products APC1 process uses a mixed refrigerant of methane and nitrogen in a closed loop expander system, as shown in Figure 3.

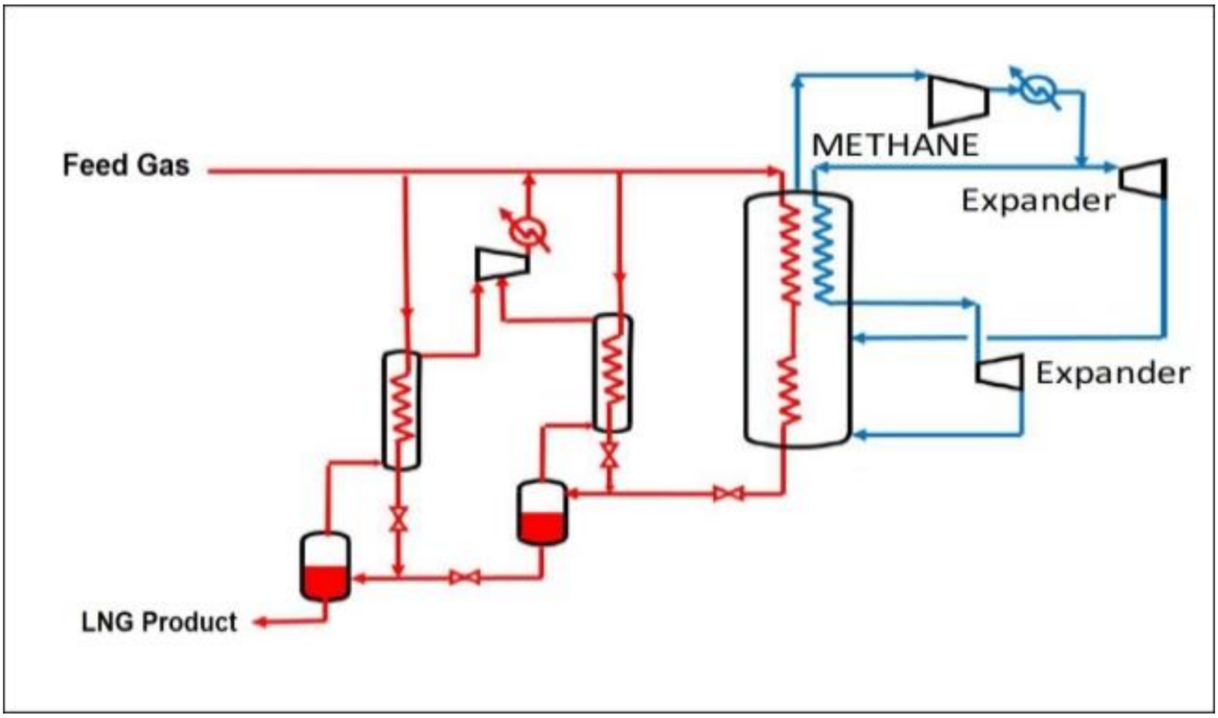

Figure 3: Air Products APC1 LNG technology (Bukowski et al, 2018)

Gasconsult’s Zero Refrigerant LNG (ZR-LNG) technology uses an open methane cycle. Its efficiency is superior to single mixed refrigerant schemes and uses 10% less power than APC1. The Niche, Saipem and Samsung processes employ a combination of methane and nitrogen cycles and are therefore more complex than APC1 and ZR-LNG. They achieve an energy efficiency comparable to the triple expander nitrogen process shown in Figure 1. A block flow diagram of the ZR-LNG technology is shown in Figure 4.

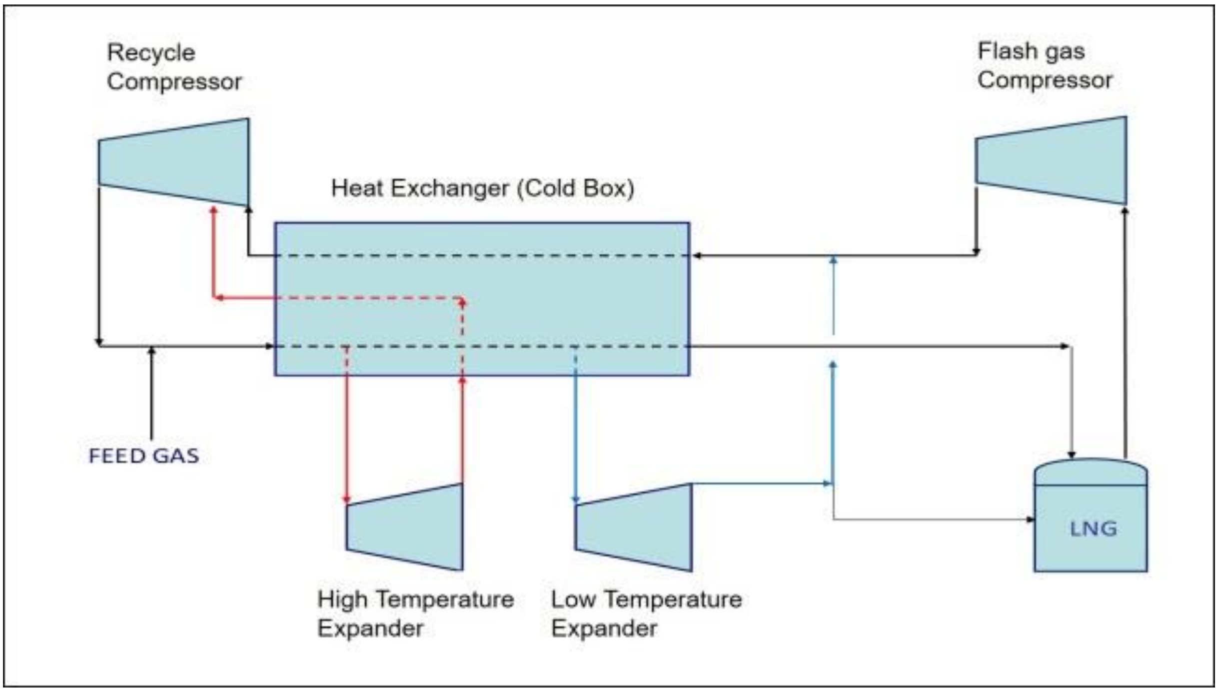

Figure 4: Gasconsult's Zero Refrigerant LNG (ZR-LNG) technology

Methane expander cycles have a fundamental advantage over nitrogen expander cycles. The specific heat of methane is higher than nitrogen. This reduces the circulating gas flows in the methane system, reducing the power demand and pipe sizes. ZR-LNG has a further advantage in that it has patented a feature to undertake some of the liquefaction in its low temperature expander. This is more efficient than liquefaction in the main heat exchanger as is required by the competing methane cycles. This explains its 10% lower power demand than the APC1 process. It also reduces the size of the main exchanger.

Vapour-Compression Cycles

Multi-Refrigerant Schemes

Bulk LNG production has been dominated in recent times by technology from Air Products, Shell, ConocoPhillips, and Linde. The Air Products (C3MR and DMR) and Shell (DMR) processes typically cool and liquefy the natural gas feed in two refrigeration cycles. C3MR employs propane and mixed-refrigerant cycles, while DMR uses two mixed-refrigerant cycles. Single train capacities of these schemes are typically 5 million tpa. An example of a dual multi-refrigerant (DMR) flow scheme is shown in Figure 5.

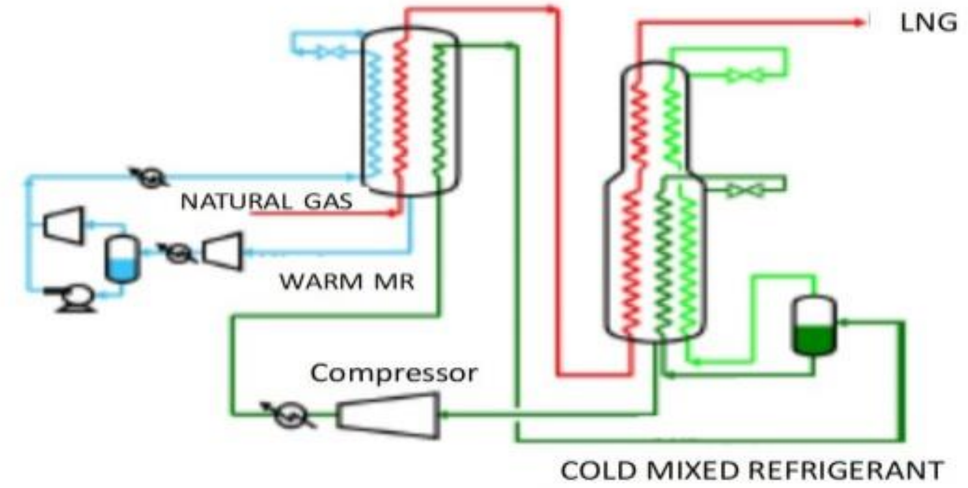

Figure 5: Air Product's DMR mixed-refrigerant technology (Bukowski et al, 2018)

The Linde Mixed Fluid Cascade (MFC) process was jointly developed with Statoil and comprises three refrigeration cycles. The pre-cooling cycle may be by propane or mixed-refrigerant, depending on application. The intermediate and sub-cooling cycles use mixed-refrigerants.

The ConocoPhillips Optimised Cascade process has three refrigerant cycles using pure components of propane, ethylene, and methane. The ConocoPhillips Optimised Cascade process is shown in Figure 6.

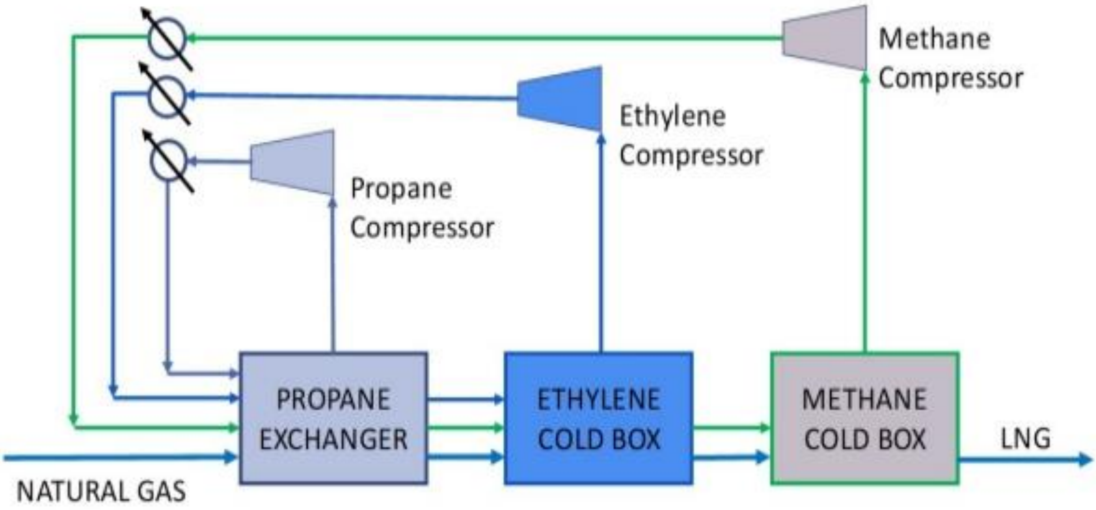

Figure 6: The ConocoPhillips Optimised Cascade technology

Single Mixed-Refrigerant Schemes

The single mixed-refrigerant (SMR) cycle uses only one circuit for precooling, liquefaction, and subcooling in a single coil-wound heat exchanger. This provides the benefit of reduced equipment count but comes at the cost of lower power efficiency than precooled multi-refrigerant schemes. However, it is simpler and has thus found widespread application at mid-scale capacities. Leading technology providers are Linde, Black & Veatch, and Air Products. Maximum economic single train capacity is generally considered to be 1,5 million tpa. A schematic of the SMR technologies is shown in Figure 7.

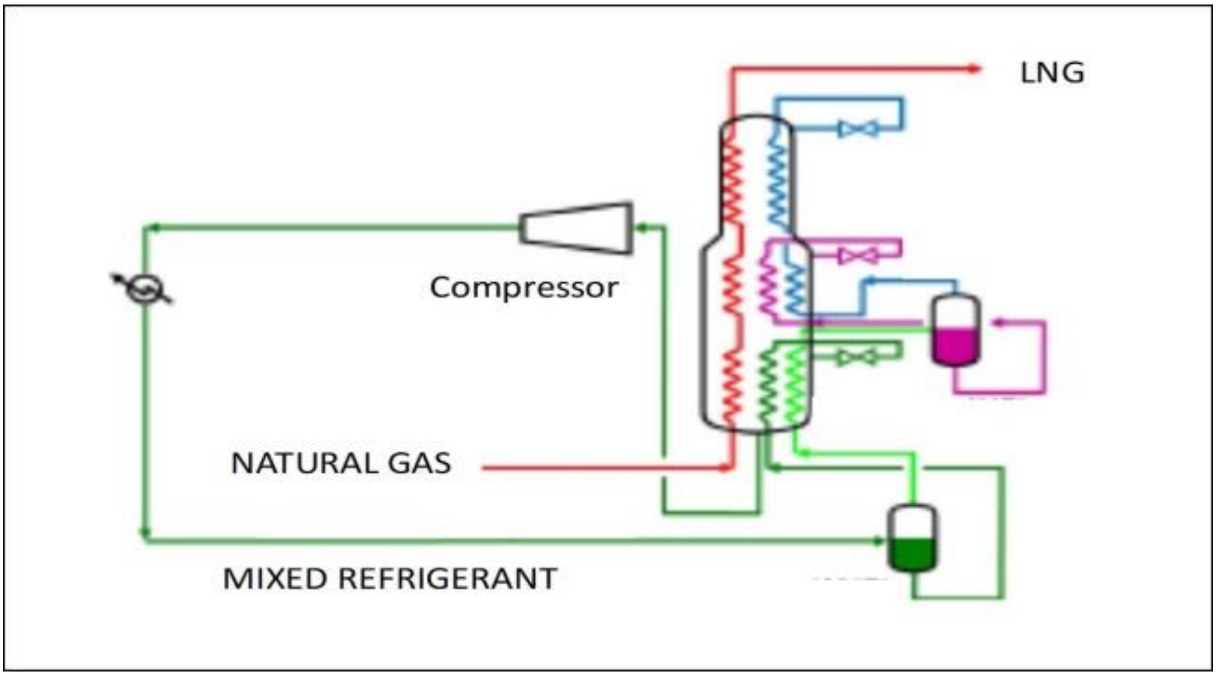

Figure 7: Schematic of the SMR technologies (Bukowski et al, 2018)

Design Issues

For bulk and mid-scale production capacities, plants are designed around the selected compressor driver, around which is assembled a matched set of process equipment. The design imperative is to maximise LNG production from the selected compression equipment. All things being equal, the cycle with the highest energy efficiency will achieve this. This accounts for the higher complexity and higher equipment count in bulk production facilities. The higher the planned LNG production, the more significant is this factor.

Typical cycle efficiencies, train capacities and equipment count for the various LNG production technologies are shown in Table 2. If refrigerants for the mixed-refrigerant schemes need to be extracted from the feed gas, the equipment count and capex for those processes will increase significantly. Similarly, nitrogen-based schemes may require a membrane-based system to recover nitrogen from the atmosphere.

Table 2: Comparison of the LNG production technologies

Process	Power demand	Typical Capacity per Train	Equipment Count (IBL + OBL)
	kWh/tonne	tpa	#
C3MR/DMR	280	3 - 7	46
Optimised Cascade	300	3 - 5	50
ZR-LNG	310	0,06 – 1,5	19
SMR	330 - 350	0,06 – 1,4	26
Triple N_2 Expander	360	0,10 – 1,3	20
Dual N_2 Expander	400 - 450	0,02 – 1,1	19

In broad terms, high capacity bulk production plants will opt for one of the multi-refrigerant vapour compression schemes. Lower capacity mid-scale plants, or smaller gas reserves, cannot sustain the high capex associated with these technologies and will opt for SMR or expander based processes. Small-scale plants are usually expander-process based.

Closing Remarks

Selection of an appropriate LNG technology should be based on technical, economic, market, and environmental factors, as well as location and availability of existing infrastructure. Feedstock quantity and quality will also be an important consideration for type of technology to be used. One of the key drivers for a new large-scale project is the ability to operate across a wide range of capacities to meet swings in market demand. For smaller scale plants, construction in smaller modules provides the benefit of duplication of a standard design as well as flexibility in capacity. Additional trains can be added as a second and third project phase.

Each technology discussed in this article can be competitive within certain conditions and range of train sizes. The selection of technology will be project specific and dependent on several factors.

Innovation is key to realising new opportunities with new suppliers, markets, and technologies, and finding an optimum solution regarding cost, site specifications, and constructability.

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