OPPORTUNITIES OF MONETISING NATURAL GAS RESERVES USING SMALL TO MEDIUM SCALE LNG TECHNOLOGIES

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1 Introduction

Background

The baseload liquefied natural gas (LNG) industry now has over 40 years of history since the start up of Camel plant in Algeria in 1964. From the beginning of its development, it has been focused on the exploitation of large natural gas fields and the construction of "as large as possible" LNG baseload plants in order to take advantage of the economies of scale.

For this reason, all the stakeholders involved in LNG projects concentrated their efforts in world-scale plants. Liquefaction processes were reduced to two main schemes: cascade process (and its optimized version) and mixed refrigerant with propane precooling and two licensors have dominated the market for years. As a consequence, only a reduced group of engineering firms were able to develop these large projects thus reducing competition and increasing costs.

In addition, while major Oil and Gas companies focused their research on large natural gas reserves, thousands of gas fields with less than 5 tcf were waiting to be exploited. The LNG market was reducing its opportunities in monetising gas.

Currently, the development of world-scale LNG projects is suffering the consequences of the high costs increase in construction, materials, and engineering services, and LNG price decrease. Most of proposed projects have been delayed and some cancelled. Nevertheless, a few are still underway. Traditional licensors have improved their processes and other engineering firms have appeared in the LNG market capable of facing LNG projects either in joint ventures or alone.

All of the above issues notwithstanding, new opportunities still remain for those industry participants who are adapting to the market trends. In the last few years a group of companies have discovered that the exploitation of small gas reserves to produce LNG could be an interesting way of monetising gas for a variety of purposes.

These companies and their targets are very diverse: the supply to local markets, the integration of LNG and power plants projects or just to introduce themselves in the LNG local or world trade. The origin of gas reserves is wide as well. It includes non conventional sources, like coal-gas methane, gas flared or stranded gas not exploited for economic reasons.

Mid scale LNG plant projects can be split into those located onshore and offshore. Although technical requirements are different in each case, simplicity and standardisation are main targets in both. Thanks to the standardisation of these processes, more engineering firms can now face mid scale LNG projects through joint ventures or strategic alliances with owners or suppliers.

The liquefaction schemes and the selection criteria used in this niche will be reviewed in detail in this paper.

Current situation in small to medium scale LNG niche

At present, the total capacity of operational small to medium scale baseload LNG plants is just more than 1 Million Tonnes per Annum (MTPA), but a total capacity of more than 6 MTPA is under construction. Furthermore, announcements for another 9.5 MTPA of small to medium scale liquefaction has been made.

At this moment, there are more than fifty small to medium scale LNG plants in operation and projects with capacities less than 2 MTPA. Most of them are located in China and Australia. Other liquefaction units are being built or planned in Indonesia, Papua New Guinea, Iran, USA, Norway, Peru and Brazil.

There are several projects ongoing of baseload LNG plants with capacities ranging from 0.3 to 2 MTPA. Projects status and locations are shown in Table 1.

Table 1. Small to medium scale baseload LNG plants (0.3 to 2 MTPA)

Location	Name	Status	Capacity (MTPA)
Australia	Fisherman's Landing LNG	Front-End Engineering	1.5
Australia	Galveston LNG	Proposed	1.3
Australia	SUN LNG	Front-End Engineering	0.5
China	DaZhou LNG	Under Construction	0.5
China	Ordos LNG 2	Unknown	0.3
China	Shan Shan	Plant Operational	0.4
China	Shanxi LCBM 2	Unknown	0.3
China	Xinjiang Guanghui New Energy Company Syngas & LNG Plant	Proposed	0.4
East Timor	Flex LNG Australasia FPSO	Proposed	1.5
Indonesia	Donggi Senoro LNG	Proposed	2
Indonesia	Sengkang LNG	Under Construction	2 (4 x 0.5)
Iran	Qeshm – LNG Limited	Proposed	0.9
Nigeria	Flex LNG/Mitsubishi/Peak Petroleum Nigeria FPSO	Under Construction	1.5
Norway	Nordic LNG	Under Construction	0.3
Papua New Guinea	Flex LNG/Rift Oil LNG FPSO	Proposed	1.5
Papua New Guinea	PNG – LNG Limited	Proposed	2.6 (2 x 1.3)

As it can be seen from the table, most of the plants are located in the Australasia region. Both Australia and Norway are taking advantage of their experience with domestic plants and truck distribution to move into marine export trade. Two companies lead the process: Norway's Gasnor and Australia's Energy World Corporation Limited, an integrated energy company.

Shan Shan LNG, located in China, has been the pioneer in mid scale LNG. The plant is in operation since 2004. It is operated in a baseload mode and all the LNG produced is distributed by truck.

Four plants are under construction and two are in FEED phase. Among the projects in construction, the case of Sengkang LNG plant in Indonesia is worth being mentioned. Estimations have been done and the project cost seems to be much lower than the actual rates used for traditional baseload plants. The project consists of modular LNG trains with common utilities and storage facilities. The status of the works is that major equipment has been purchased and the majority of it has been manufactured and is ready for shipping.

Regarding FLNG, a very active company is FLEX LNG, with various projects. They have signed a Head of Agreement with Rift Oil for a project in Papua New Guinea and another one with Mitsubishi and Peak Petroleum for a project in Nigeria. The company has ordered four vessels (LNG Producers) to a shipyard in Korea to accommodate their floating liquefaction units and they have completed a FEED for the generic LNG Producer concept.

2 General requirements for the liquefaction process selection

Differences with large scale LNG plants

The large baseload LNG plants aim to take advantage of the economies of scale. In general, the main design criterion of these plants is the minimisation of capital cost, whereas the minimisation of energy consumption is left as a second objective. These two objectives can also go together; thus, in some cases, an optimisation of the efficiency of the plant may involve a reduction in the investment of equipment. On the other hand, a higher efficiency usually results in an increase in LNG production, so this is an important factor that has an impact on the plant economics.

This reasoning is not applied in the same way when the small to medium scale LNG niche is considered. In this case, it is not the efficiency, but other factors such as simplicity (low equipment count), modularisation, and ease of maintenance, operation and installation are the ones that play the most important role when selecting a liquefaction technology. The direct consequence of these different selection criteria is that the liquefaction technologies for small to medium scale applications are not the same as the ones that are used in large baseload LNG plants.

Onshore vs. Offshore

In recent years, offshore LNG has been a hot topic in the LNG industry and many companies are nowadays interested in the opportunities that this concept offers to monetise offshore gas reserves. Particularly, Floating LNG (FLNG) is the concept that appears to have more interest for the industry. FLNG implies the construction of a natural gas liquefaction facility on a floating structure.

The offshore location of this type of plant involves many challenges due to the constraints imposed by the marine environment. The reduced spaces on the floating structures force to optimise the layout of the plants. Thus, the priorities that the small to medium scale LNG plants have in comparison to large scale LNG plants are reinforced and the main parameters to be taken into account when designing a FLNG plant will be safety, compactness, low equipment count, modularisation, ease of maintenance, reliability, ease of operation, tolerance to a variety of process conditions and process robustness. Besides, another important challenge, specific of FLNG projects, is the influence of vessel motions on process equipment.

3 State of the art of the small to medium scale liquefaction technologies

The state of the art of the small to medium scale liquefaction technologies can be divided into two main groups of technologies:

- Mixed refrigerant (MR) technologies: These are “condensing-type” processes, where the refrigerant used for the liquefaction makes use of its latent heat of vaporisation to cool the natural gas.

- Expansion-based technologies: these are processes where the refrigerant is always in gas phase and only makes use of its sensible heat to cool the natural gas.

The Table 2 summarises the main technologies suitable for the small to medium scale LNG niche.

Table 2. State of the art of small to medium scale liquefaction technologies

		Process	**Company**
Mixed refrigerant technologies	SMR Technologies	PRICO AP-M LiMuM SCMR Single MR	Black & Veatch APCI Linde Kryopak Chart
	Precooling + SMR	PCMR OSMR	Kryopak LNG Limited
Expansion-based technologies		N_2 expansion cycles EXP Niche LNG OCX	Various licensors Kryopak CB&I Lummus Mustang

The following section explains the main characteristics of the most representative processes mentioned in Table 2.

a. Mixed refrigerant technologies

Single Mixed Refrigerant (SMR)

PRICO® (Poly Refrigerated Integrated Cycle Operation) (Figure 1): PRICO process is licensed by Black & Veatch Pritchard Corporation. It consists of one cycle of mixed refrigerant, where the refrigerant is composed of a mixture of methane, ethane, propane, butane, nitrogen and (sometimes) isopentane. The Main Cryogenic Heat Exchanger (MCHE) used in this process are Brazed Aluminium Heat Exchanger (BAHX) inside cold boxes. Some advantages claimed by the licensor are the operating flexibility, modular design and reduced refrigerant inventory. As a reference, 25% of the peak-shaving plants of United States use this process.

AP-M™ (Figure 2): The AP-M process is licensed by APCI (Air Products & Chemicals Inc.) and it is a single mixed refrigerant process with dual pressure Spiral Wound Heat Exchangers (SWHE). In this process the mixed refrigerant is vaporised at two different levels of pressure. The dual pressure cycle is more efficient than the single pressure cycle, resulting in smaller heat exchangers and compressor. The coil wound heat exchanger can be fully modularised. This version of the SMR process has no references in the industry.

LiMuM® (Linde Multistage Mixed Refrigerant) (Figure 3): The LiMuM process is licensed by Linde and consists of a SWHE and one 3-stage single mixed refrigerant loop for the precooling, liquefaction and subcooling of the natural gas. This process allows obtaining high capacities (up to 2.5 MTPA) following the 2x50% configuration that can be used in the refrigerant compressor (barrel type). An industrial reference of this process is the Shan Shan LNG plant (China), with a capacity of 0.43 MTPA.

Single MR (Chart): Chart Energy & Chemicals is a process designer and manufacturer of engineered solutions that holds a lot of experience designing BAHX. They propose a single mixed refrigerant process for the small to medium scale LNG niche, based on open art technology and using a BAHX heat exchanger as MCHE. They are actively working in the Sengkang LNG project (Indonesia), whose first phase consists of 4 modules of 0.5 MTPA each.

Precooling + SMR

PCMR® (Pre-cooled Mixed Refrigerant): PCMR is a process offered by Kryopak, which consists of a precooling stage (ammonia or propane cycle) followed by a single mixed refrigerant cycle, where the mixed refrigerant is a mixture of nitrogen, methane, ethane, propane and butanes. The heat exchangers are of the BAHX type. This process has some industrial references in plants with a capacity less than 0.1 MTPA (e.g. Karratha LNG project, of 0.07 MTPA).

OSMR™ (Optimised Single Mixed Refrigerant) (Figure 4): This process, offered by LNG Limited, is a single mixed refrigerant process complemented with a standard package ammonia absorption process. Within the SMR cycle, the main compressor comprises a single stage unit and the cold box optimises the passes of the streams (3 main streams plus 2 minor streams). The utilization of an ammonia process allows an improvement of the efficiency of the process and an increase of the LNG output compared to traditional SMR processes. It also allows a reduction in the cold box size. This process is being applied for the Gladstone LNG Project - Fisherman's Landing, in Australia, whose first phase has a plant capacity of 1.5 MTPA (target of first LNG export shipment: December 2012).

b. Expansion-based technologies

N_2 expansion cycles: there are various processes based on the use of nitrogen as the refrigerant to liquefy the natural gas. Some of these processes use a single cycle, others use a dual expansion cycle and in other cases a precooling cycle is added to improve the overall efficiency. APCI, Hamworthy, BHP Petroleum Pty Ltd, Mustang Engineering and Kanfa Aragon are some of the companies that offer N_2 expansion cycles. Figure 5 shows the NDX-1 process, proposed by Mustang, which is based on a dual cycle. N_2 expansion cycles hold an extensive experience at low LNG plant capacities, in peak-shaving plants and also in reliquefaction units located in very large LNG carriers; today they are being considered by many companies as the option for FLNG, due to the inherent safety that the non flammability of the N_2 offers to the process.

Niche LNG℠: this process, offered by CB&I Lummus, consists of two independent cycles: one cycle uses methane as refrigerant (it can also be used the same gas to be liquefied after the heavies have been removed), while the other uses nitrogen (Figure 6). The methane cycle provides cooling at moderate and warm levels while the nitrogen cycle provides refrigeration at the lowest temperature level. The MCHE is of the BAHX type. There are no operating references for this process, but it is being actively promoted for FLNG.

OCX processes: these processes, offered by Mustang, are based on the use of the inlet gas as a refrigerant in an open refrigerant cycle with turboexpanders. There are several processes: OCX-2 (Open Cycle Expander Refrigeration, second generation) is the basic one (Figure 7); OCX-R adds a closed loop propane refrigerant to the OCX-2 configuration and OCX-Angle incorporates LPG recovery. These processes are also being proposed for FLNG. All these processes, together with NDX-1, are part of the LNG Smart® Liquefaction Processes offered by Mustang.

4 Comparison of the small to medium scale liquefaction technologies

Each group of technologies shown in the previous section has distinguishing features that make it more suitable to certain small to medium LNG applications than the other group. Following, the main pros and cons of each category of processes are discussed.

The main advantages of mixed refrigerant technologies are the high efficiencies that can be achieved and the big capacity that a single liquefaction train can handle. Their existing industrial references in a wider range of capacity than the expander-based technologies, confer them another important strength. On the other hand, the main drawbacks of these processes are referred to the presence of flammable refrigerants in the plant; this presence forces to have large storage and many more pieces of equipment to handle the refrigerant (separators, manifolds, instruments and controls to adjust the refrigerant charge and composition, etc.). This usually makes the plant more complicated to operate, demands extensive plot space and places constraints on the layout to ensure process safety. Finally, as a liquid phase is present for achieving the liquefaction of natural gas, the effects of motion (when a FLNG project is being considered) are a concern, since they can cause a maldistribution of fluid phases, and consequently, a poor plant performance.

The advantages of expansion-based technologies are mainly referred to the simplicity of the processes. These technologies do not require large storage and management system for the refrigerant, decreasing the demand of plot space (and also the weight) and allowing an easier operation and start-up. The smaller plot requirements make the design of cold boxes easier and facilitate plant modularisation. Besides, these technologies offer the potential for using non flammable refrigerants (nitrogen), which gives a higher inherent safety to the process and reduces the constraints on the layout. Something relevant for the FLNG projects is the insensitivity of these processes to motion effects, as the refrigerant remains always in gas phase, so no maldistribution problems arise. On the other hand, these technologies have several disadvantages; they primarily refer to the relatively low capacity that can be achieved with a single train and the lower efficiency of these types of processes; they also require higher refrigerant flow rates and, consequently, higher refrigeration power leading to higher operating costs. Moreover, all the industrial references of these technologies are limited to very low plant capacities, so the scaling up to higher capacities remains as an uncertainty.

Table 3 summarises the main advantages and disadvantages of each group of technologies.

Table 3. Advantages and disadvantages of mixed refrigerant vs. expansion-based technologies

	Advantages	**Disadvantages**
Mixed refrigerant technologies	- Single train capacities up to 1.8 MTPA	- Flammable refrigerant
	- Higher efficiency	- Large flammable refrigerant inventories involve overpressure potential and extensive flare requirements
	- Minimum utilisation of rotating equipment	- Higher plot space requirements for refrigerant storage and management
	- Flexibility to changes in feed gas composition and ambient conditions	- Complex operation and high equipment count
	- Industrial references at the capacity range of 0.5-1.5 MTPA	- Adverse effect of motion to the process performance (FLNG)
Expansion based technologies	- Simplicity, low equipment count	- Single train capacity limited to 0.8 MTPA (approximately)
	- Compactness and light weight	- Higher refrigerant flow rates
	- Easier modularisation	- Lower efficiency
	- Potential for using non flammable refrigerants (higher safety)	- High presence of rotating equipment
	- Ease of operation and start-up	- No industrial references at the capacity range 0.5-1.5 MTPA
	- Insensitivity to motion effects (FLNG)	

5 Technology Selection Methodology

Case study assumptions

As mentioned, the small to medium scale LNG niche has an interesting potential that is worth analysing. For that reason, and in order to evaluate the opportunities of these types of plants, a generic case has been studied within Repsol. This case focuses on an onshore LNG plant with a capacity ranging between 0.5 and 1 MTPA.

Methodology and results

Process selection is critical to LNG economics, so it is a key activity that starts at an early stage in the life of an LNG project and is typically addressed at the feasibility study and pre-FEED definition stages.

Next, the methodology for liquefaction technology selection that was used in the analysis of the case study is presented. It is based on the technology evaluation methodology explained in reference [1].

Taking into account the early stage of the analysis, the initial objective was to obtain a short list of the technologies that could be suitable for a project with the characteristics of the case study. All the technologies mentioned in this paper, among others, were included in the assessment.

For achieving a ranking of technologies, a systematic technique for decision making was applied. For this purpose, a decision table was built, more specifically a “0 to 5” value table. The steps to obtain such a table are explained below.

First of all, the main attributes that should be measured when assessing the different technologies were selected. Thus, the parameters that can be considered critical for a small to medium scale onshore LNG plant are the following:

- Capacity range of applicability of the technology
- Simplicity (low equipment count)
- Modularisation
- Ease of operation
- Flexibility of the operation with change in feed gas composition, ambient temperature, etc.
- Energy consumption
- Industrial references

The quantification of each parameter involves two main stages: rating and weighting.

For the rating stage, several scales can be used. It is very common to apply 1 to 10 scale but in this case, for simplicity reasons, a scale from 0 to 5 was applied, where 0 was the minimum and 5 the maximum mark that could be assigned to each parameter. Considering the preliminary stage of the analysis, public information was used for assigning the values to the different parameters under study.

Weighting stage involves three steps: preparing a range table, ranking the values in importance order and weighting the values.

A range table includes all the parameters that are being evaluated and two separate columns: the left column represents the high ends of the ranges (rated “5”) on all the values, and the right column represents the low ends of the ranges (rated “0”). As an example, the range used for the parameter “energy consumption” was 275 kWh/t (high end, rated “5”) and 800 kWh/t (low end, rated “0”).

Since it is unlikely that any alternative is all 0’s or all 5’s, each column represents a hypothetical alternative. The next step is to rank the attributes in terms of importance; for this step, the priorities established for a project of these characteristics were taken into account. It is worth saying that some parameters can share the same position in the ranking. Table 4 shows the appearance of a range table with rankings, where it can be observed that two parameters (3 and 4) share the third position in the ranking.

Table 4. Range table (with rankings)

Parameters	**Ranking**	**5**	**0**
Parameter 1	B		
Parameter 2	A		
Parameter 3	C		
Parameter 4	C		
...	...	...	...

The final step in thinking about parameters importance is to assign numerical weights to them. There are different methods for doing this; a superior method is based on *tradeoff judgements* and two forms of this method can be applied: value ruler and probability ruler (see reference [2] for more information). However, a simpler method called *point-allocation method* was applied in this case. It consists of distributing 100 points over the different parameters in such a way that the relative numbers of points reflect relative importance. It is important to remark that the importance weights do not reflect the importance of the attributes on their own, but the importance of full-range (0 to 5) changes on the attributes.

A global mark for each technology was finally obtained from the weighted sum of the different rated parameters, normalised to express the result as a percentage; this was included in a summary table like Table 5. This table was very useful to have a quick picture of the strengths and weaknesses of each liquefaction process, as well as to compare the different evaluated options.

Table 5. Comparative table for technology assessment

Parameters	Weighting factor	Parameter evaluation		
		Technology 1	**Technology 2**	**...**
Parameter 1	WF1	0-5	0-5	0-5
Parameter 2	WF2	0-5	0-5	0-5
Parameter 3	WF3	0-5	0-5	0-5
Parameter 4	WF4	0-5	0-5	0-5
...	...	0-5	0-5	0-5
Global mark (%)		***0-100%***	***0-100%***	***0-100%***

Next, an example of the assessment results is shown in Table 6 (technology identities are not shown for confidentiality reasons).

Table 6. Example of technology assessment results

Parameters	Parameter evaluation (%)		
	Technology 1	**...**	**Technology n**
Parameter 1	5	...	4
Parameter 2	3	...	2
Parameter 3	4	...	5
Parameter 4	4	...	3
...		...	
Global mark (%)	***78 %***	***...***	***59 %***

The results obtained in this analysis were valuable to know the best alternatives to the case study considered. However, the obtained ranking cannot be extrapolated to any case within the small to medium scale LNG niche.

As a general rule, it can be said that every project has its own priorities and the selection criteria may change when the bases of design of the project change. Likewise, the weighting factors assigned to the main parameters analysed in the selection process will vary in every different project evaluated.

6 Conclusions

The LNG industry is pointing at a new trend focused on a smaller size of liquefaction plants in comparison with the traditional size of baseload LNG plants. Although the small to medium scale LNG niche has been traditionally focused on the domestic market, a bigger presence of this niche in the LNG export market is foreseen within the next years. Many new plants are under construction and planned for the short term.

From a technological point of view, a review of the available liquefaction processes in the market highlights that there are feasible technologies that can be applied to the small to medium scale LNG niche. Two main groups of technologies are present in the state of the art and each group has different features that make some processes more suitable than others to satisfy some of the relevant criteria applicable to this niche.

The selection of the most appropriate technology is very case-specific. The most relevant parameters to be considered in the selection will depend on the particular conditions of a project. Specifically, the location offshore or onshore of a plant can greatly affect this process. The techniques for “decision making” can be very helpful for doing a preliminary technology assessment.

7 Appendix

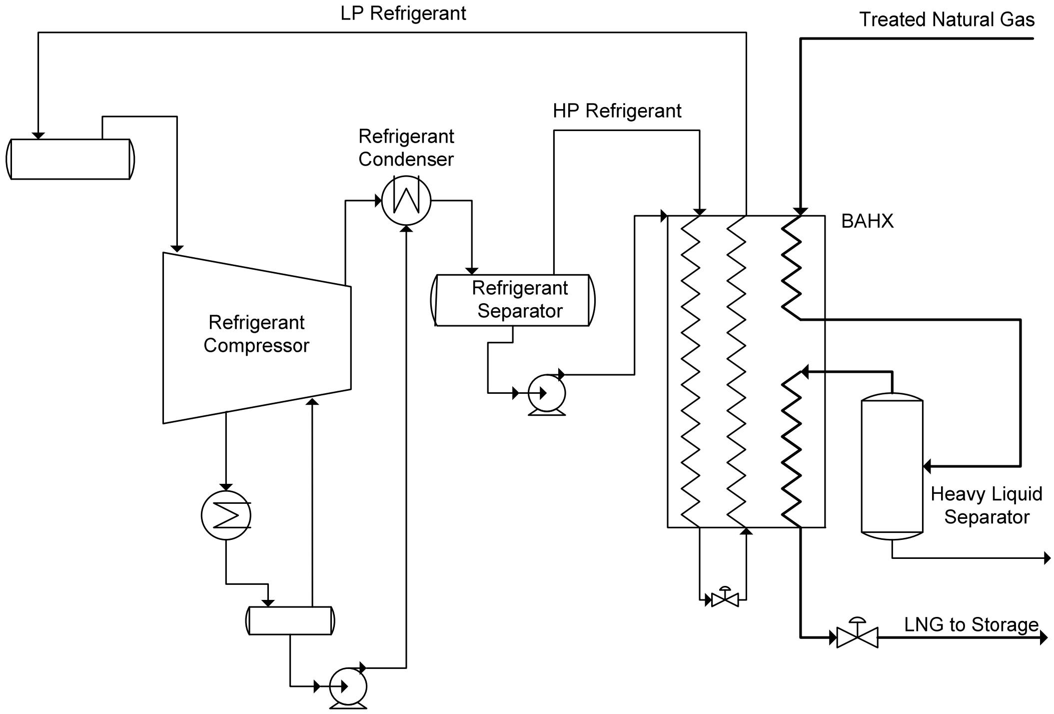

Figure 1. PRICO Process (Black & Veatch Pritchard Corporation)

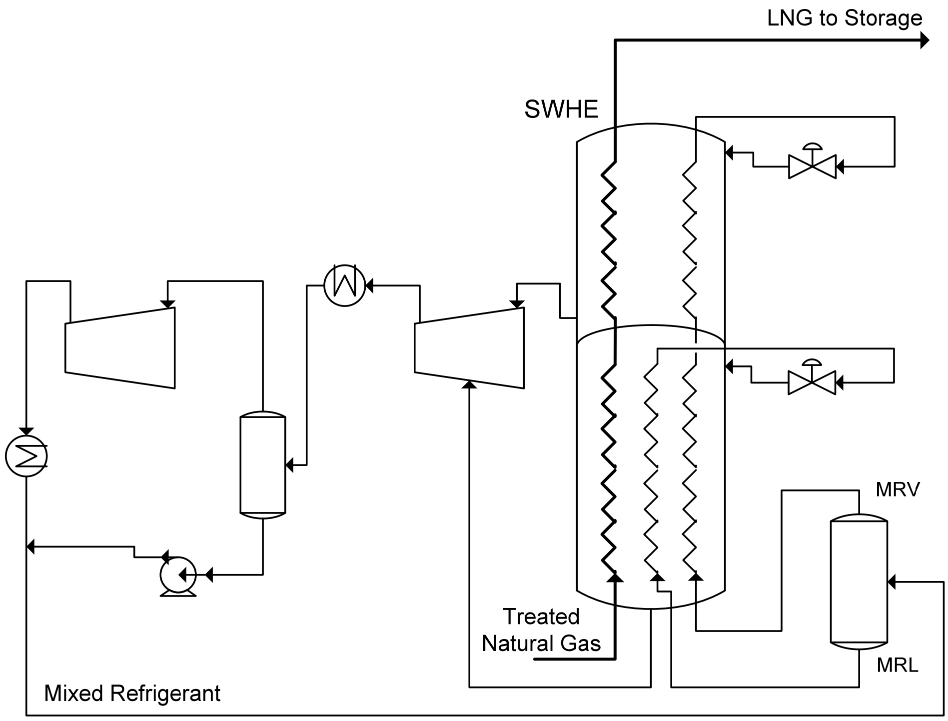

Figure 2. AP-M Process (APCI)

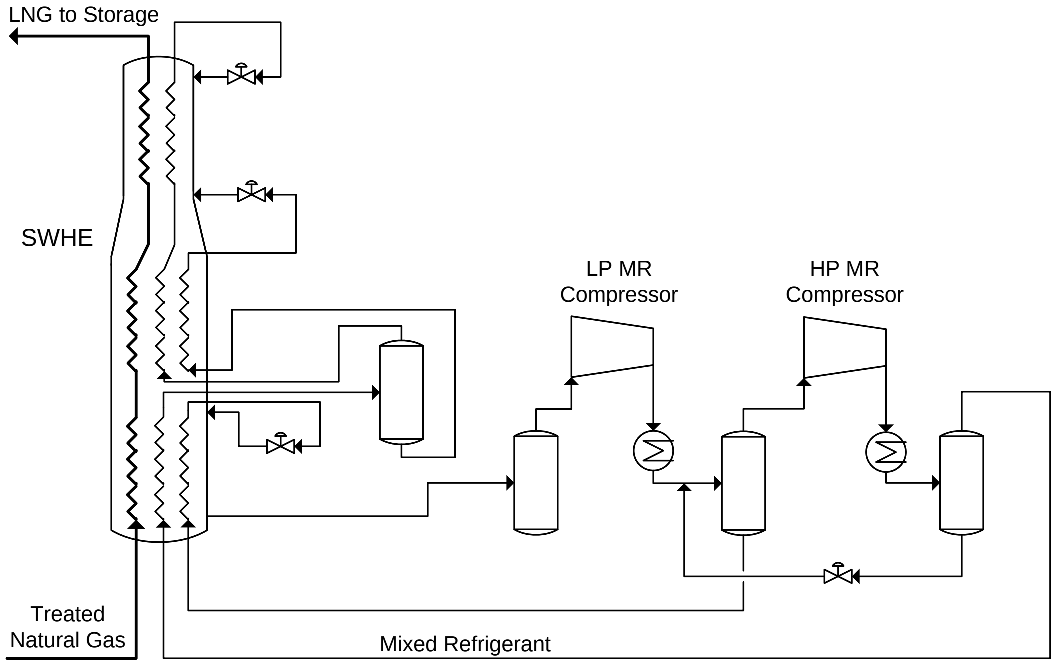

Figure 3. LiMuM Process (Linde)

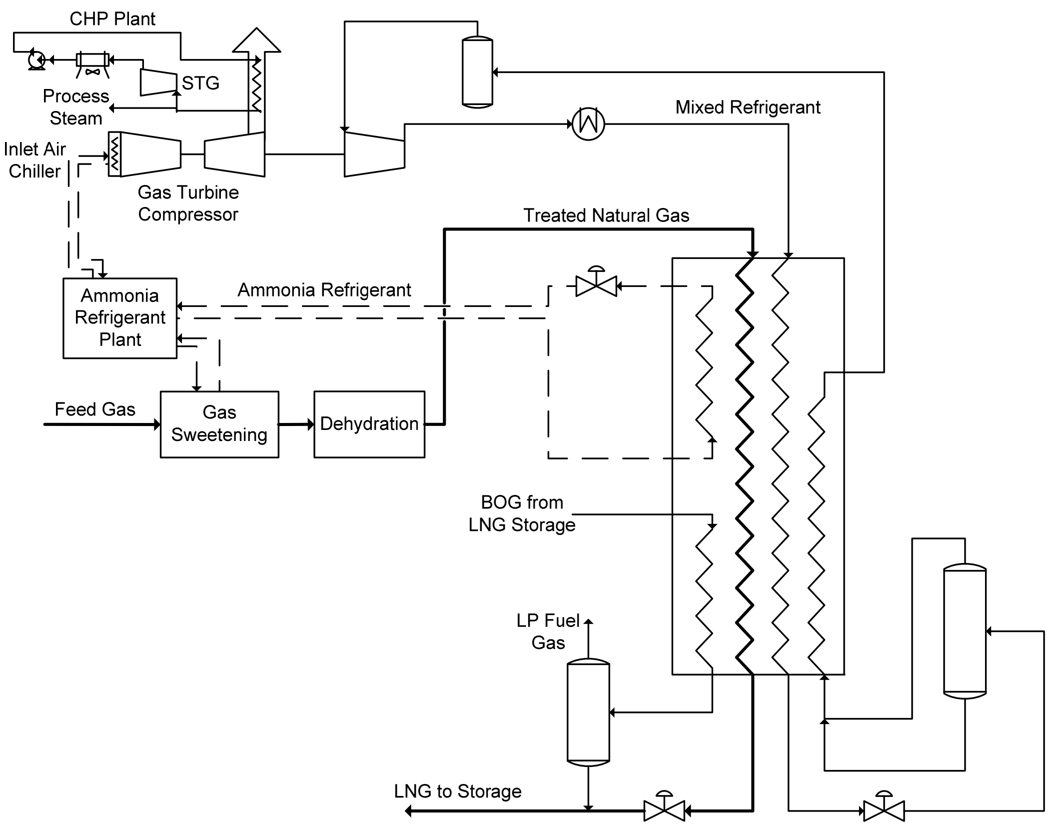

Figure 4. OSMR Process (LNG Limited)

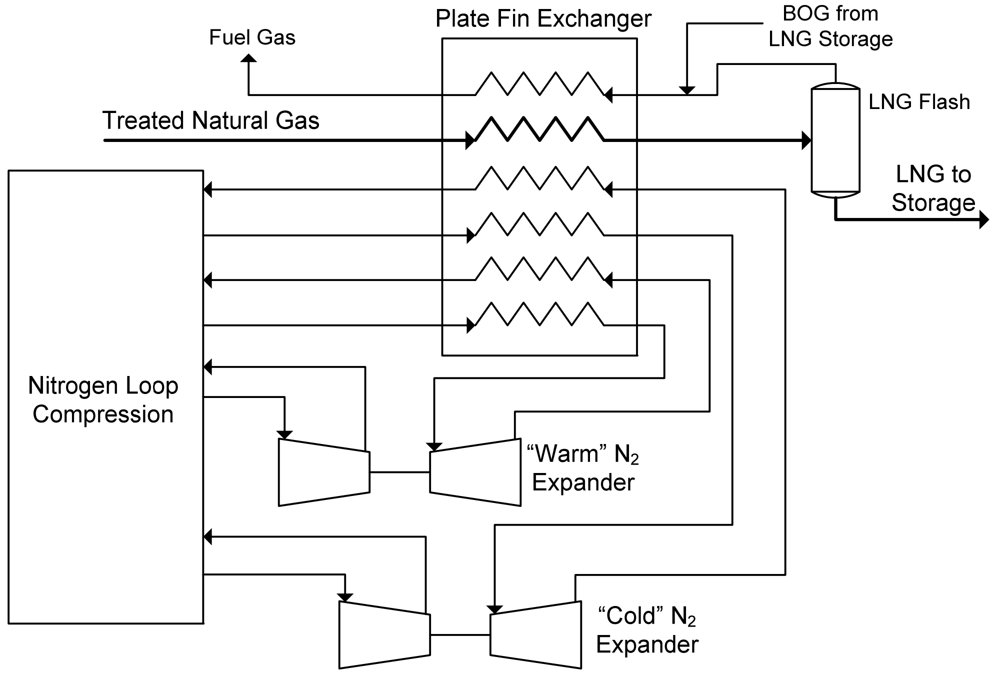

Figure 5. NDX-1 Process (Mustang)

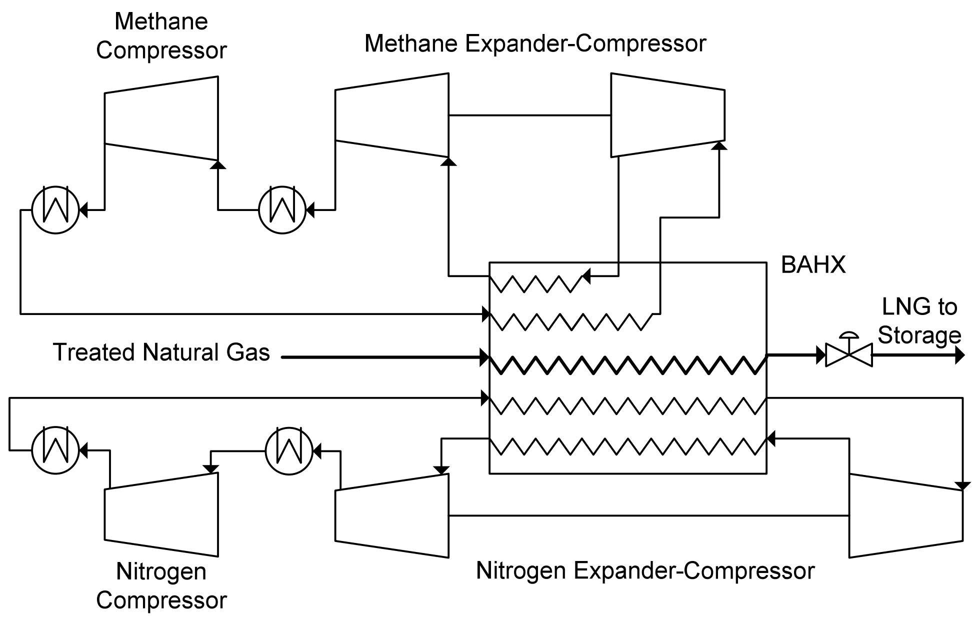

Figure 6. Niche LNG Process (CB&I Lummus)

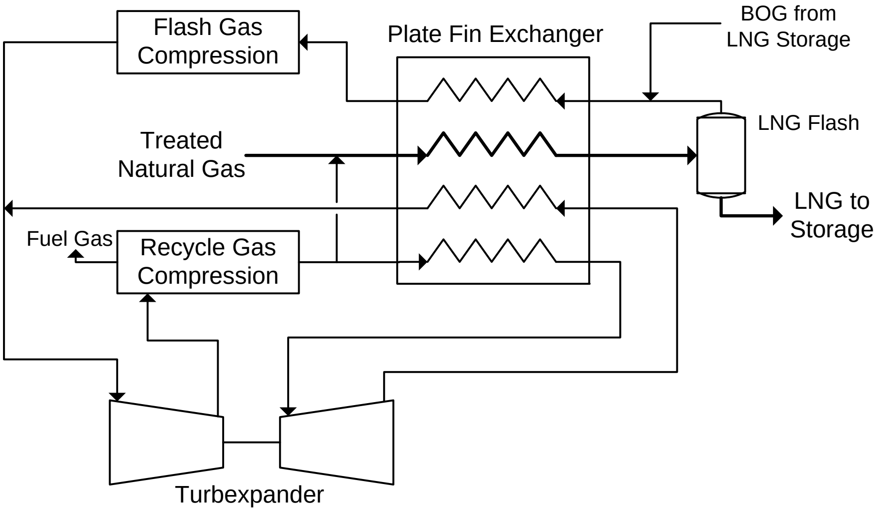

Figure 7. OCX-2 Process (Mustang)

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