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The Advantages and Prospects of Liquefied Natural Gas (LGN)

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Abstract

As the usage of LNG (Liquefied Natural Gas) continues to grow, the natural gas value remains high, and large capacities of LNG plants which lead to lower cost per unit of LNG produced avail the LNG projects under construction or in plan. The refrigeration and liquefaction process is the key element of LNG project and it can consume about 35% of the capital expenditure and up to 50% of the subsequent operating cost. Technology advances have lowered the cost for liquefaction and regasifying, shipping and storing LNG. This report presents the main technologies available for natural gas liquefaction based on onshore and base-load cases. An overview of LNG processes including the refrigeration theory and pretreatment process involved is explained as well in details. Parameters between alternative technologies for the operating units are compared for economically choosing process routines. All existing LNG plants are located onshore, and the reasons for potential development reasons for offshore plants are also discussed in this report.

Key words: LNG; Operating cost; Economically choosing; Alternative technologies

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INTRODUCTION

A. Definition of LNG

LNG stands for Liquefied Natural Gas that has been cooled to around minus 160ºC at atmospheric pressure. It is odorless, colorless, non-corrosive, and non-toxic. When vaporized, it burns only in concentrations of 5% to 15% when mixed with air. Neither LNG, nor its vapor, can explode in an unconfined environment. The density of LNG is roughly 0.41 to 0.5 kg/L, depending on temperature, pressure and composition. The transformation in state results in significant volume reduction ($1m^3$ LNG = $600m^3$ NG). The heat content of LNG can range between 1,000 and 1,162 BTU per cubic foot ($11.5 kWh/m^3$) (Wiki).

B. Background of LNG and Worldwide Market of LNG

Liquefying natural gas was first achieved back in the 19^{th} century, by British scientist Michael Faraday and German engineer Karl Von Linde, but the LNG industry as we now know it did not take off until 1960s. On October 12, 1964, the "METHANE PRINCESS", six days out of Arzew in Algeria, arrived at Canvey Island in the Thames Estuary with a cargo of liquefied natural gas. The liquefaction plant in Arzew, Algeria, was the first liquefaction plant in the world (William, 1995). Since its commercial start 40 years ago, the LNG business has expanded dramatically. Most of the growth has been in Asia-Pacific, driven first by demand in Japan, then South Korea, and newly emergent China and India. US by far is the largest LNG consumer worldwide (Christian, Begazo, & Erica, 2007). For North America, unconstrained demand would have the potential to grow to 88 BCF/d by 2010. Considering all new projects under negotiation, LNG transportation will steadily increase. The worldwide LNG projects are as shown in Figure 1.

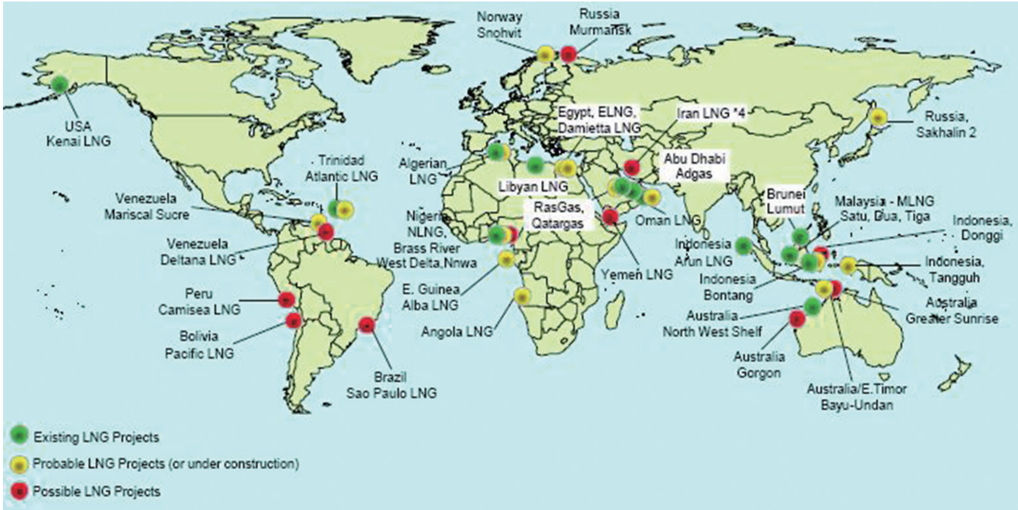

Figure 1
Global Projects of LNG

The international LNG trade is undergoing an unprecedented period of growth. LNG accounts for only 6.0% of the total gas consumption, but some 25% of the internationally traded gas. Asia remains an important player in the world LNG market, both as an importer and exporter. Japan is the world's largest LNG importer with 53% of the total production capacity. Indonesia is the largest exporting nation with 27% of all exports (Maclean, Lave, & Hendrickson, 2000).

1. LNG CHAIN

1.1 LNG Value Chain

LNG plant is the key element of the LNG value chain (Figure 2) which mainly consists of exploration and production, liquefaction, shipping, storage and regasification (Mokhatab & Economides, 2006). Liquefaction section is a key element of LNG plant in which the phase is the most costly and it requires financial investment which takes up to 45% of the overall cost. This explains the present trend towards every possible improvement in liquefaction techniques. Capital charges may vary depending on the rate of depreciation, interest charges, taxes and profit.

Figure 2
LNG Value Chain

1.2 LNG Plant Overall Flow Scheme

A typical LNG plant overall flow scheme is shown in Figure 3, although no LNG project can be called "typical" due to the many factors that can influence the components of a plant involved (Shukri & Foster, 2005).

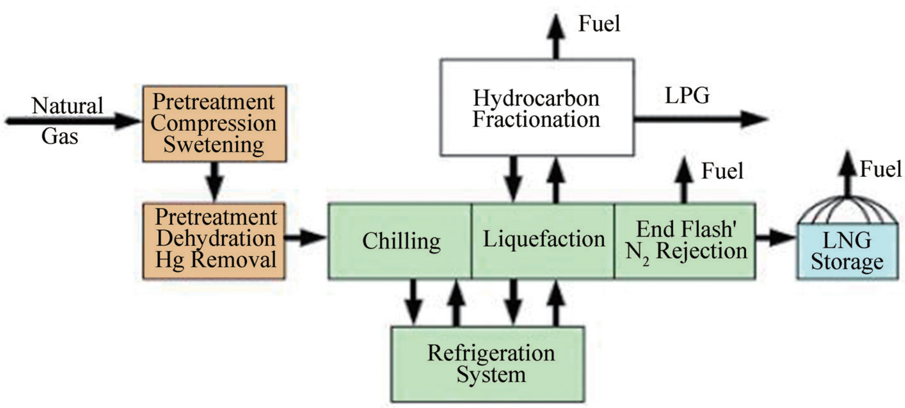

Figure 3
Typical LNG Plant Overall Flow Diagram

Based on the usage and the size, there are basically two types of LNG liquefaction plants which are generally classified in two types, base-load and peaking shaving. The discussion on the location of the plant and liquefaction scale in this report is directed towards onshore case and base-load plants respectively.

The feed gas is transported at high pressure level which is approximately 90 bar from upstream gas fields via trunk lines and associated condensate will be removed. The typical temperature of the feed gas is in the order of 40°C and the pressure is in the range of 35 bar to 13 bar preferably. Similarly, other heavier HC components follow the same mechanism. The boiling points of possible components of raw natural gas under atmosphere pressure are listed in Table 1.

Table 1
NG Components Boiling Point

Name	Formula	Boiling Point (℃)
Methane	CH_4	-162
Ethane	C_2H_6	-88.6
Propane	C_3H_6	-42
Butane	C_4H_{10}	-0.5
Pentane	C_5H_{12}	+36
Hydrogen Sulfide	H_2S	-82.3
Helium	He	-286.93
Nitrogen	N_2	-195.8
Carbon dioxide	CO_2	-78.5

Here we take the most multiple components into consideration. The gas is metered and pressure-controlled to the designed inlet plant pressure. In pretreatment process, natural gas generally requires removal of impurities prior to liquefaction in order to meet product specifications, avoid blockages and to prevent damage to process equipment. In the first stage, sulfur compounds can be removed from the raw gas by sulfur recovery unit. CO_2 can either be removed by amine or membrane if still exists after transportation in trunk line. The second stage is dehydration to get rid of water. The third stage is the mercury removal which is usually achieved by adsorption on activated carbon bed. NG is then sent to the pre-chilling process, in which typically a propane refrigerant is used, the purpose of which is to minimize the whole process energy consumption and where propane, butane heavier HC are separated and then are fractionated to recover the ethane which can be re-injected into the gas stream to be liquefied. LPG is referred as liquefied petroleum gas whose main components are propane and butane for commercial use, and heavier compounds that can be the components of gasoline products for export. The process by which natural gas is converted into liquid natural gas is known as liquefaction. It is further cooled in the sub-cooling section to around -160°C and is completely liquefied. In final LNG product stored in the tank, the boiled off which can be used as fuel and is rich of nitrogen which can be re-injected or be used elsewhere. LNG components are shown below.

Table 2
LNG Components

Composition		Range	
		Low (%)	High (%)
Methane	C1	83	99.8
Ethane	C2	0	14.0
Propane	C3	0	4.0
Butane	C4	0	2.5
Nitrogen	C5	0	1.3

Most of the feed gases are with low concentration of CO_2, mercury and water as impurities. This type of gas just requires minimum treatment, so pretreatment unit consists of CO_2 removal unit, molecular sieves for drying and a carbon bed for mercury removal. The final LNG can be transported by specially designed cryogenic sea vessels (LNG vessels) or cryogenic road tankers at atmosphere pressure. Once the LNG reaches a terminal, it is turned back into gas and then delivered to customers. A more detailed description is shown in Figure 4 in the next page.

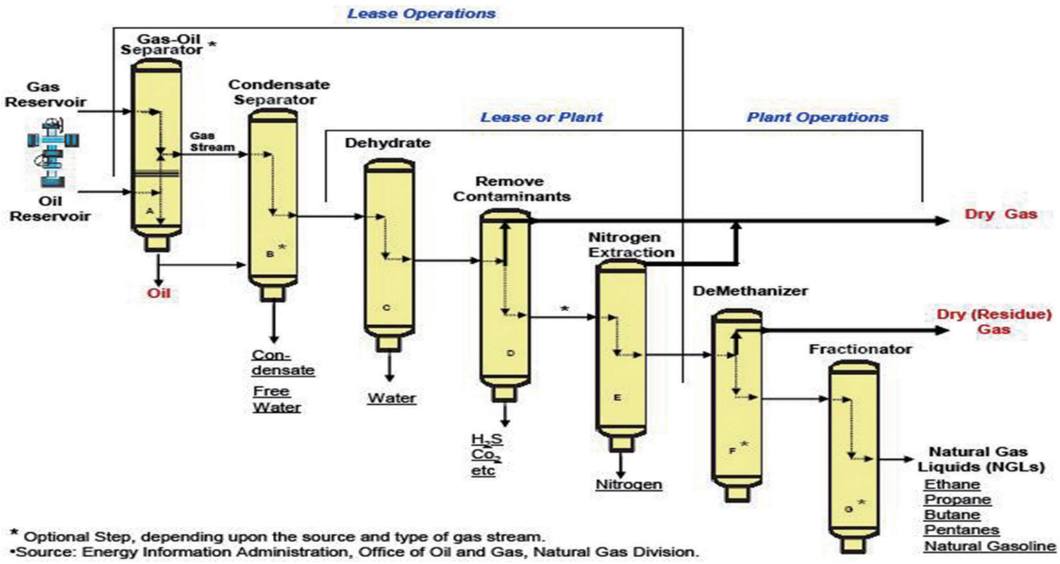

Figure 4
Generalized Natural Gas Schematic

2. LIQUEFACTION TECHNOLOGIES

2.1 LNG Plant Components

Natural Gas Liquefaction is the process in which natural gas is converted from the gaseous phase to the liquid phase. LNG plant often consists of one or more LNG trains, each of which is an independent unit for gas liquefaction. They treat and liquefy NG and then send LNG to storage tanks. Each train usually consists of several key equipment items including the compressors which are used to circulate the refrigerants, the compressor drivers, and the heat exchangers which are used to cool, liquefy the gas and exchange heat between refrigerants. The capacity of a liquefaction train is primarily determined by the liquefaction process, the refrigerant used, and the largest available size of the compressor driver and the heat exchangers that cool the natural gas.

2.2 Refrigeration Cycle

Liquefaction technology is based on a refrigeration cycle referred to the removal and relocation of heat, as shown in Figure 6.

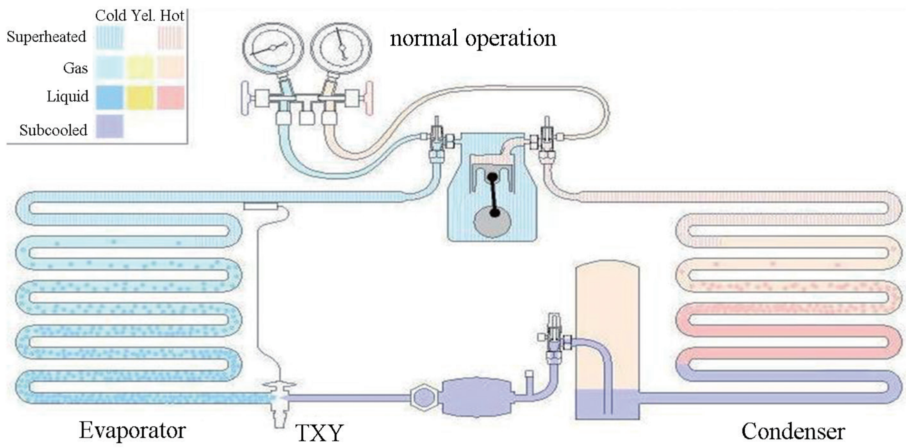

Figure 6
Refrigeration Cycle

As we see from this refrigeration loop, a refrigerant by means of successive expansion and compression transports heat from a lower to a higher temperature. The compressor is a vapor compression pump which uses pistons or some other methods to compress the refrigerant gas and send it on its way to the condenser. The condenser is a heat exchanger which removes heat from the hot compressed gas and allows it to condense into a liquid, working as a heat rejector. The liquid refrigerant is then routed to the metering device. This device restricts the flow by forcing the refrigerant to go through a small hole which causes a pressure drop that lowers the boiling point of the refrigerant and makes it easier to evaporate. When a liquid evaporates, it will absorb heat from the surrounding area. This is how refrigeration works. The component where the evaporation takes place is called the evaporator. The refrigerant is then routed back to the compressor to complete the cycle. The refrigerant is used over and over again absorbing heat from one area and relocating it to another. Here we take propane as the refrigerant because it is available in large quantities worldwide and it is one of the cheapest refrigerants. The procedure is explained using the P-H (Pressure-Enthalpy) diagram of propane shown in Figure 7.

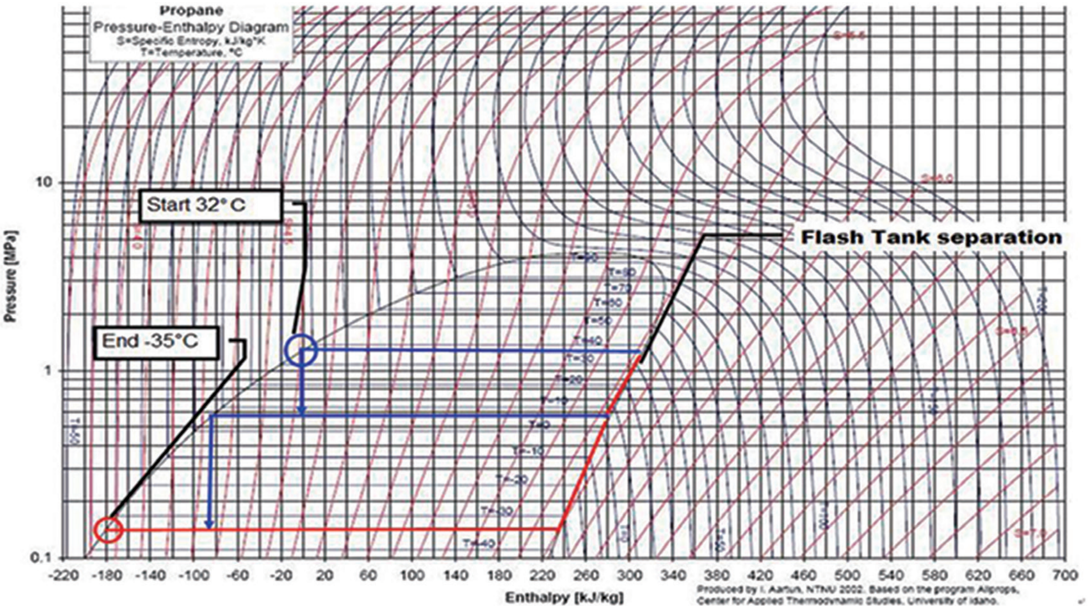

Figure 7
Propane Loop P-H Diagram

The compressor compresses propane to a pressure of 45-48 bar, afterwards the compressed propane exchanges heat with cooling water through which heat is removed and propane condenses to a liquid. The liquid propane is passed through a valve before entering the heat exchanger where it evaporates and absorbs heat released by process natural gas. We start at 32°C or at a lower temperature and about 1.35MPa, flashing across a valve to the new pressure (0.74MPa), ending at the boiling point of propane. Propane vapors return to the compressor to complete the cycle (Barclay, Denton, & Foster 2006).

2.3 Natural Gas/Refrigerant Cooling Curves

The basic principles for cooling and liquefying the gas using refrigerants involve matching as closely as possible the cooling/heating curves of the process gas and the refrigerant. These principles result in a more efficient thermodynamic process requiring less power per unit of LNG produced and they apply to all liquefaction processes. Typical cooling curves are shown in Figure 8 as follows.

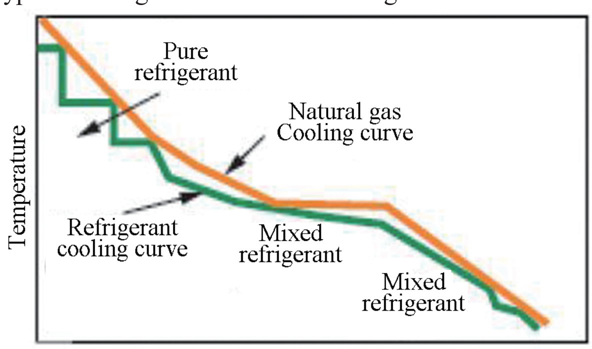

Figure 8
Typical Natural Gas/Refrigerant Cooling Curves

Based on the cooling curve of a typical liquefaction process, three zones characterized by having different slopes can be noted in the process of the gas being liquefied. A pre-cooling zone, followed by a liquefaction zone, and completed by a sub-cooling zone. All LNG processes are designed trying to closely match the coming curve of at different zones of the liquefaction process in order to achieve high refrigeration efficiency and low energy consumption (Arteconi & Polonara, 2013).

2.4 Liquefaction Processes

With the development of technologies, liquefaction processes have been developed with the differences mainly focusing on the type of refrigeration cycles having been utilized. By far there are three main types of liquefaction cycles (cascade, mixed refrigerant, and expansion cycles). Each has its own merits. At the same time there are also common features between them. For example, in both the mixed-refrigerant cycle and expander cycles, the feed gas maybe pre-cooled by a conventional propane vapor compression cycle. This is also a feature of the cascade cycle. Most commercially available processes are based on these cycles or a combination of these cycles. The processes used in current LNG plants or applied in LNG projects in progress are introduced below (Vatani, Mehrpooya, & Tirandazi, 2013).

2.5 Liquefaction Method

Propane Pre-cooled Mixed Refrigerant (PPMR)/C3 MR Process

The Propane Pre-cooled Mixed Refrigerant process-developed by APCI - started to dominate the industry from the late seventies on, accounting for a very significant proportion of the world base-load LNG production capacity. Train capacities of up to 4.5 MTPA were built or are under construction. Furthermore, APCI has developed improved design which can reach a capacity as high as 8 MTPA. The MCR process will be explained in greatest detail. Many of the principles apply to other processes, and the main differences will be highlighted (Goto, 2002).

The overall flow scheme as shown in Figure 9 consists of two main refrigerant cycles.

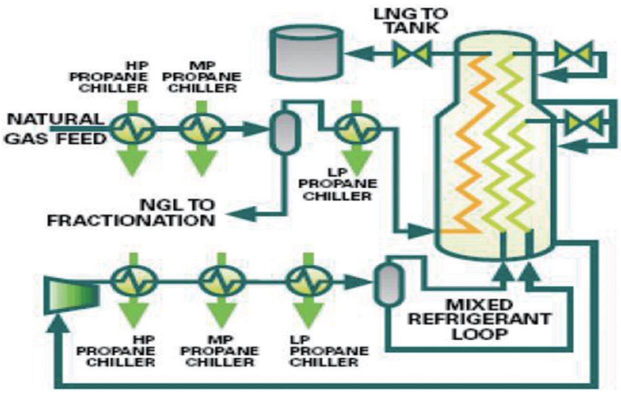

Figure 9
Typical APCI Propane Pre-Cooled Mixed Refrigerant Process

The pre-cooling cycle uses a pure component, propane. The liquefaction and sub-cooling cycle uses a mixed refrigerant (MR) which is composed of nitrogen, methane, ethane and propane (Kuz'menko, Dovbish, & Darbinyan, 2003). The pre-cooling cycle uses propane at three or four pressure levels to cool the natural gas feed to -35°C, at which the heavier components in the feed gas condensate out and are sent to fractionation (Zietsman, Ehsanul Bari, & Aaron, 2008) . The cooling is achieved in kettle type exchangers (shown in Figure 10) which permit very close temperature approach between the condensing and boiling streams with propane refrigerant boiling and evaporating in a pool on the shell side, and with the processed streams flowing in immersed tube passes where the MR refrigerant is partially condensed by the propane chiller before entering the cold box (Beale, 2003).

Figure 10
Kettle Heat Exchanger

A centrifugal compressor with side streams recovers the evaporated C3 streams and compresses the vapor to 15-25 bar. The NG is then sent to the main cryogenic heat exchanger (MCHE), which is composed of a large number of small diameter spiral wound tube bundles (as shown in Figure 11).

The separate liquid and vapor streams are then chilled further before being flashed across the Joule-Thompson valves which provide the cooling for the final gas liquefaction (Bubger & Loerbroks, 1998).

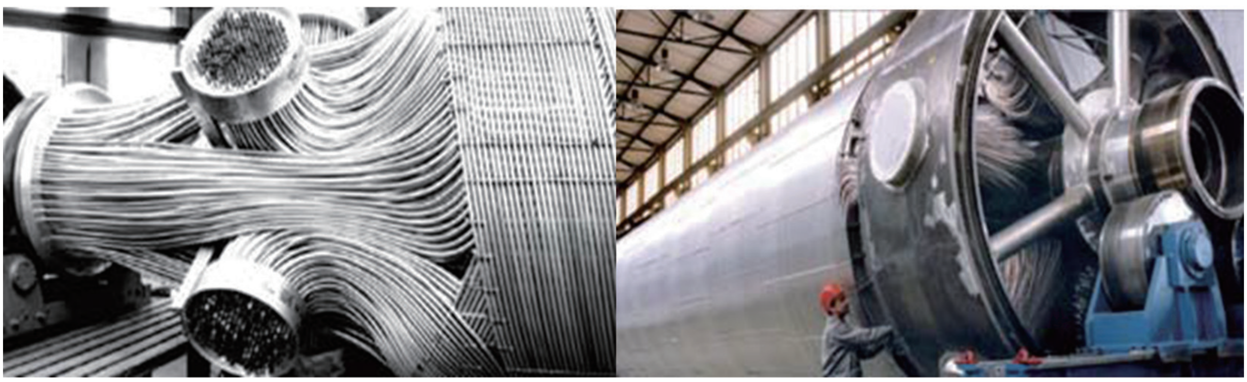

Figure 11
Spiral Wound Heat Exchanger

CONCLUSION

More and more natural gas is liquefied at its production region and shipped in form of LNG to the consumption region. Large train capacities up to 11 MTPA are being developed, and LNG is experiencing unprecedented growth than ever before. This report explains what LNG is and presents the LNG chain in general. Different processes available to economically liquefy natural gas are discussed. According to the analysis of different technologies for liquefaction, basic steps of liquefaction processes are remove of impurities and recovery of NPGs, refrigeration of the gas until it liquefies, and movement of LNG to storage and ultimately to tanker.

The principle of closed-loop liquefaction cycles relies on cooling the natural gas using one of more refrigeration cycles depending on the technology. Historically, liquefaction cycle selection is easy to make because of existing patent processes available offering different advantages over each other according to various factors. For each technology, some parameters like compressors, heat exchangers, and refrigerants and train sizes are compared to highlight the pros and cons for reference of further economic improvements or developments. Yet to date, all liquefaction facilities have been built onshore with close proximity to a safe harbor. However, liquefaction is currently being developed for offshore application with reduced weight, minimizing energy transfer and a high degree of process safety. More companies are considering feasibility studies for future projects for this prospective industry.

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