Production of LNG using Dual Independent Expander Refrigeration Cycles

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Abstract

In recent years the LNG business has begun an exciting development. Recent projections indicate that the LNG business could grow 8 % every year until year 2010, including some growing spot market opportunities. But the LNG business is not structured today for opportunism. LNG projects undergo serious financial and technical studies before they become real projects.

New technologies, especially those which add operational flexibility, cost reduction, expeditious construction and deployment are starting to capture the attention of those interested in developing an alternative path for delivering LNG to markets.

LNG turboexpander technologies are challenging the current LNG paradigm. This paper describes a new process (in patent prosecution process) and its benefits.

Introduction

This paper describes a process for the production of liquefied natural gas. This process produces quality LNG by means of refrigeration generated by the isoentropic expansion of gases used as refrigerant agents. By this means, no conventional mechanical refrigeration is used, simplifying the process accordingly.

The refrigeration duty required to liquefy the gas stream is provided by two independent closed compression - expansion circuits. These two circuits use two different fluids as refrigeration agents, one being methane, or the same gas type to be liquefied, and the second being nitrogen. Refrigeration agents are always in gas phase.

Both refrigeration cycles work jointly with the purpose of producing refrigeration to satisfy their refrigeration demand and that imposed by the LNG requirements.

The advantages and benefits of this process are:

- Its simplicity when compared with the existing prior art processes,

- adaptablity to different quality of feedstocks by changing the relation of refrigerants.

- Nitrogen and methane refrigerants are always in gas phase which eliminates the requirement of refrigerant inventory and separators for their handling, with the corresponding impact in safety on the facility,

- Heat transfer occurs in gas phase and dense phase simplifying the construction of the exchangers, and resulting in a smaller size of the combined heat exchanger.

Because of its simplicity this process represents a unique opportunity to exploit offshore reservoirs with floating production systems or selected onshore projects.

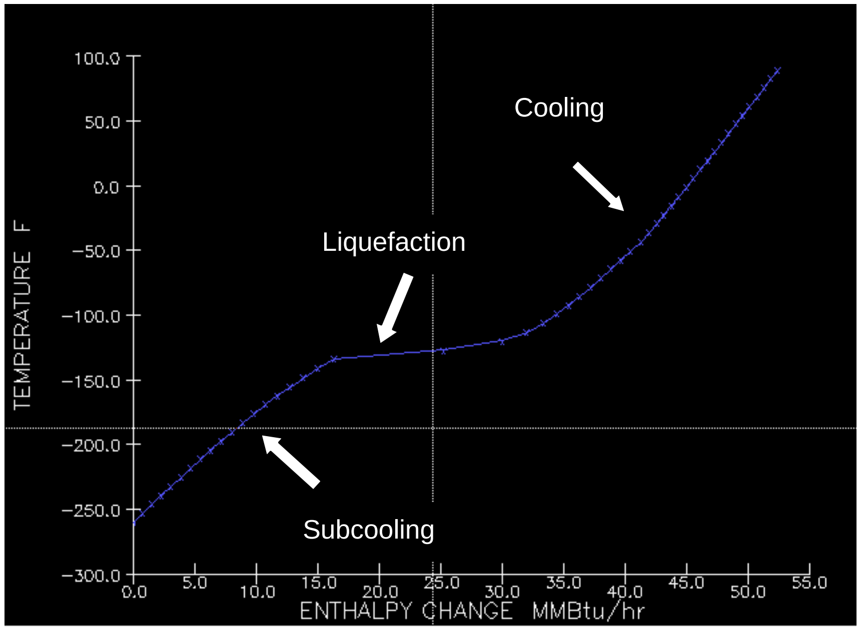
Process Fundamentals

This is not the first time that expanders have been suggested for this application. Linde, Kapitza and Claude have proposed expansion machines for gas liquefaction systems. Substantial intellectual property has been developed on this matter. (*see references 1,2,3, and 4.)*.

Basically, in the expander-based process, a stream of gas at high pressure is expanded isentropically to a lower pressure. In this process work and refrigeration are extracted from the expansion process. This refrigeration is then used to aid the liquefaction process. The work extracted is then utilized to partially recompress the refrigerant gas.

Observing a Q/T diagram three zones could be noted in the evolution of the gas being liquefied. A first cooling zone, followed by a liquefaction zone, and completed by a sub-cooling zone. All these zones are characterized by having different curve slopes, or specific heats, along the process. By recycling gas, the slope of the Q/T curves is artificially changed, obtaining profiles close to the gas refrigerant been used. The amount of flow used in the recycles, the feed gas, and refrigerant pressure levels, as well as flow splits to alter the shape of the Q/T curves, are part of the design parameters used in achieving an optimum design. *(See figure 1.)*

Figure 1



Thermodynamically speaking these cycles are as efficient as the most advanced mixed refrigerant cycles. However, the efficiency of the first turboexpanders was very low, around 60 to 70%. Today, expander efficiencies are reaching more than 85%. This represents an emerging opportunity to insist on the utilization of this technology in the LNG business. *(See reference 5).*

Mixed refrigerant cycles try to closely approach the cooling curve of the gas being liquefied by using multi-component refrigerants that will match the cooling curve at the different stages of the liquefaction process. Most current base-load processes take place at medium pressure level, about 500 to 550 pounds.

In the LNG turboexpander process of *references 4 and 5*, the gas being liquefied is used as low temperature refrigeration, while propane refrigeration is used at moderate and warm levels. This process is able to reach very low specific energy levels, between 12.7 and 13.5 kW/ton day LNG (that is, the energy used to liquefy one pound of LNG). *(See figure 2).* In *figure 3*, a Q/T diagram of this process is shown.

Figure 2

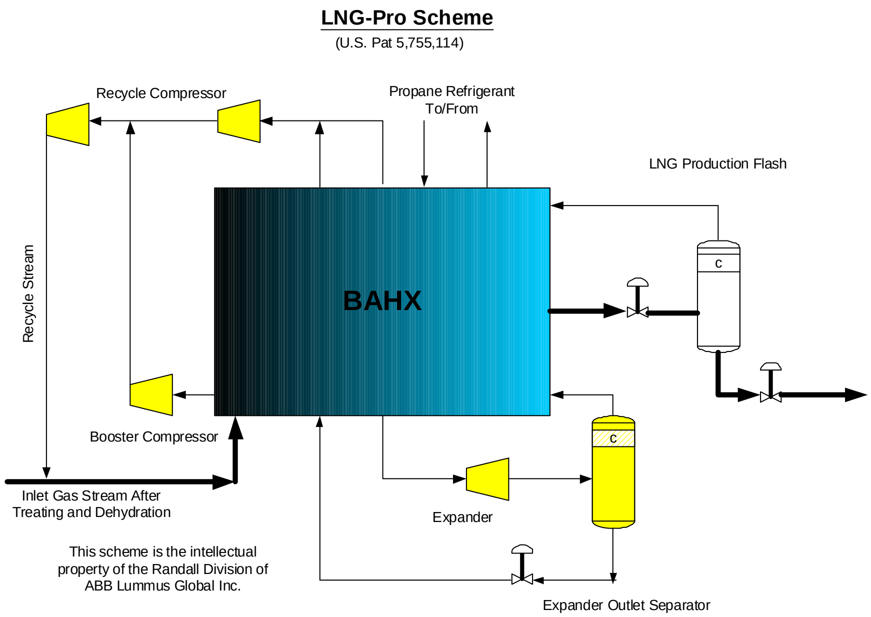
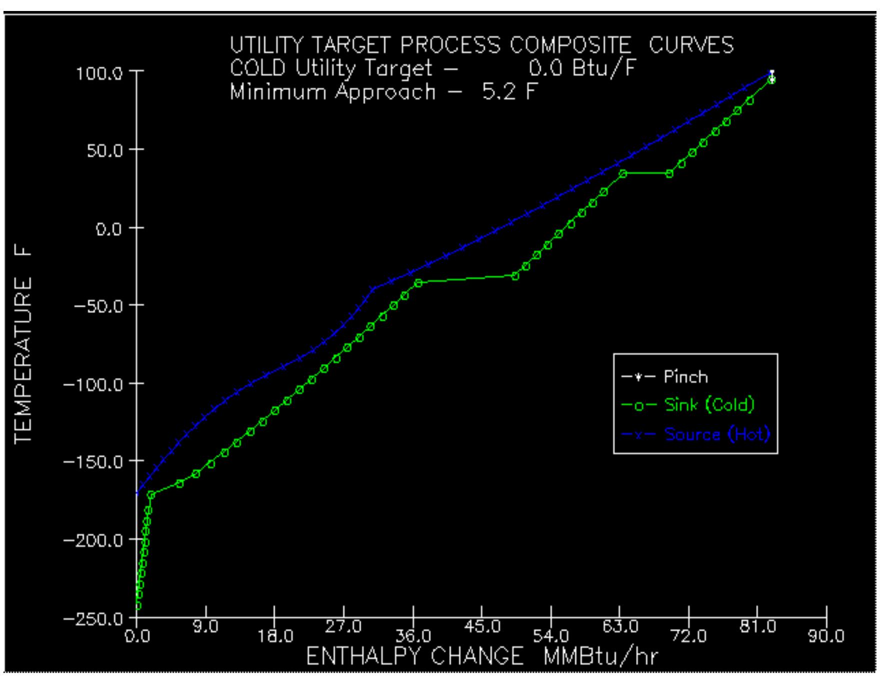


Figure 3



In the process discussed in this paper two independent turboexpander circuits are used. One circuit, using almost the same gas being liquefied (similar as in U.S. Pat. 5,755,114), satisfies the heat balance requirements of the mid section of the Q/T curve while the second circuit, using nitrogen, provides refrigeration at a lowest temperature level. *(See figures 4,5 and 6)*

Figure 4

Production of LNG Using Dual Independent Expander Refrigeration Cycles

Intellectual Property of ABB Lummus Global
Patent Pending

Embodiment 'A'

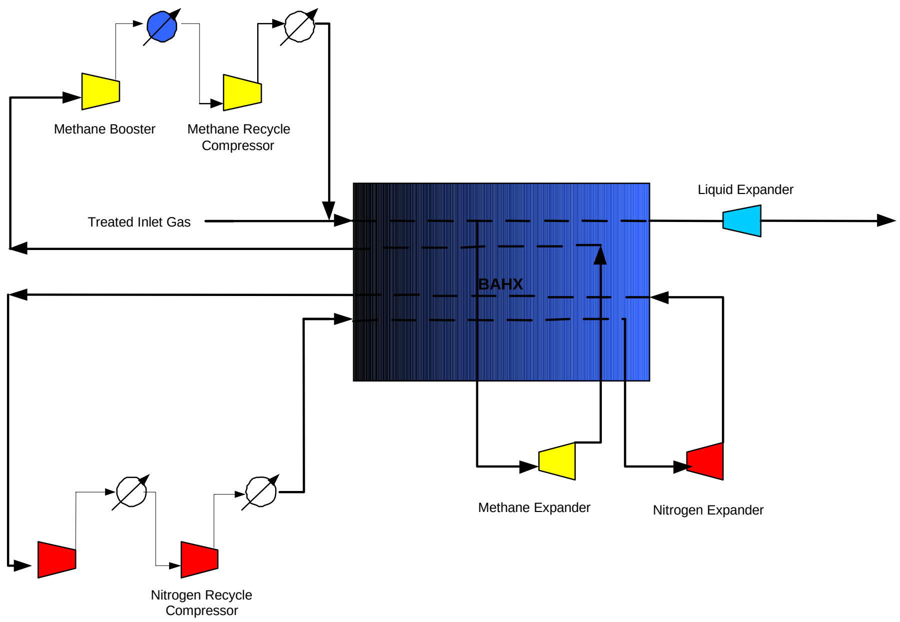


Figure 5

Intellectual Property of ABB Lummus Global
Patent Pending

Embodiment 'B'

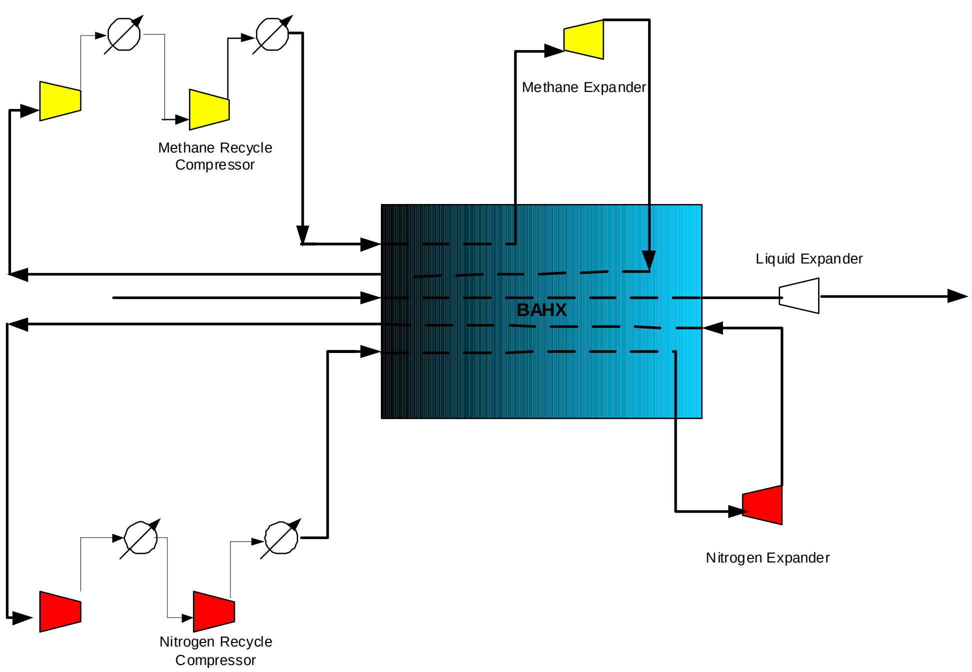
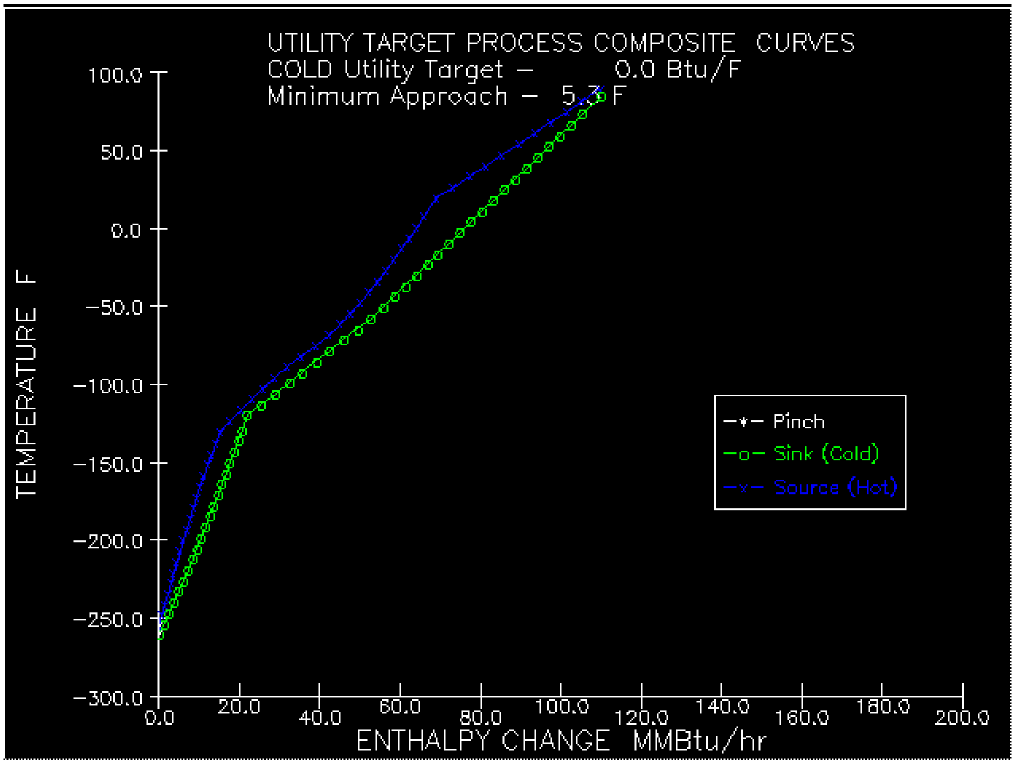


Figure 6



The above processes can use pre-cooling for base load applications. In this case, the recycling refrigerant gases are pre-cooled using multiple levels of propane refrigeration depending on the degree of optimization desired.

With this additional feature, this cycle is able to achieve a very low specific energy consumption of 13 kW/ton day LNG, comparable to the pre-cooled mixed refrigerants cycles widely used in the large base load plants.

Figure 7 depicts the Pre-Cooled Dual Expanders Cycle LNG Scheme. *Figure 8* shows the Q/T curves.

Figure 7

Intellectual Property of ABB Lummus Global
Patent Pending
Embodiment 'C' Propane Pre-Cooled

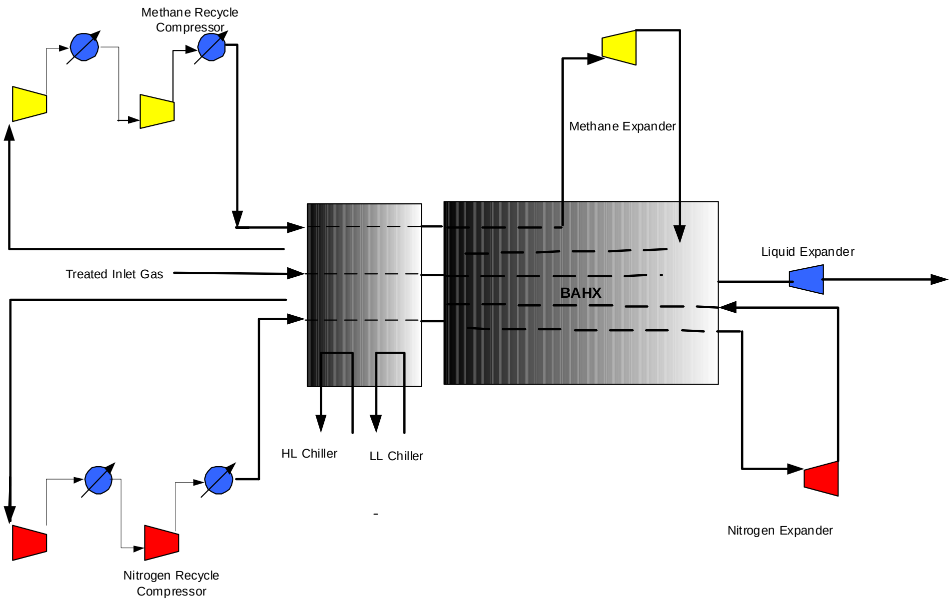
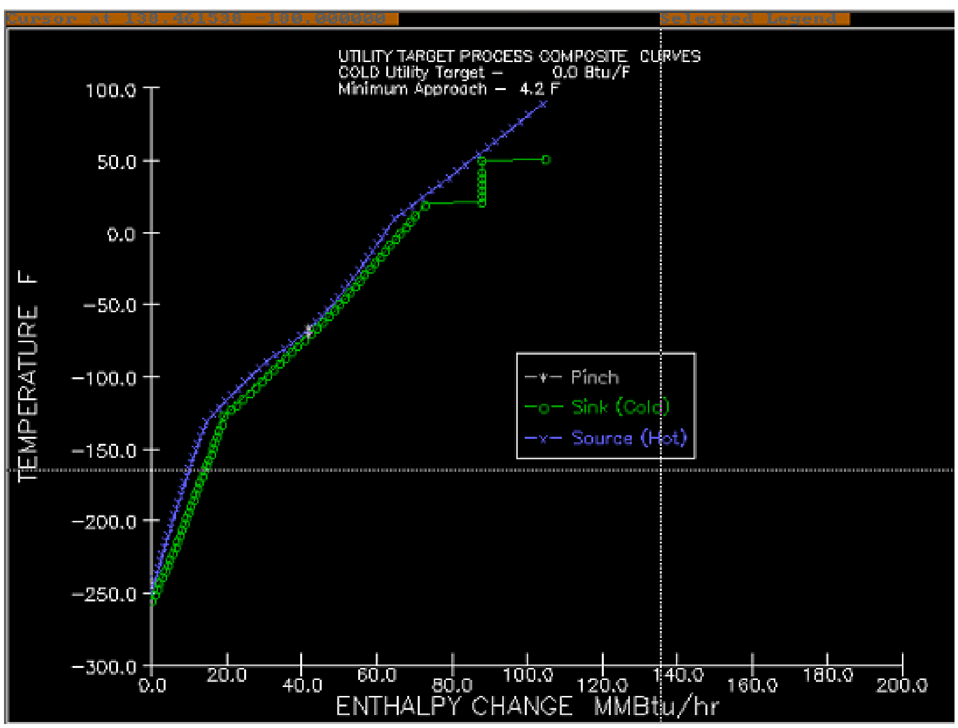


Figure 8



Process Description *(Refer to figures 9 and 10)*

In the following description the inlet gas treating and dehydration sections are obviated since they are common to all the liquefaction processes. For reference, *Table 1* indicates the most frequent feed gas specifications for LNG production.

Table 1

Typical Feed LNG Plant Specifications:

• Nitrogen	**<= 1%**
• Carbon Dioxide	**< 50 ppmv**
• Hydrogen Sulphide	**< 4 ppmv**
• Total S (H2S+COS+ organic Sulphur)	**< 20 ppmv**
• Water	**< 0.5 ppmv**
• Mercury	**< 0.01 microgram/Nm3**
• Butanes	**2% max**
• Pentanes+	**0.1% max**
• BTX	**ND**

The description follows the simple non pre-cooled process. For this case feed gas at 1000 psig is considered.

Treated and dehydrated gas enters the liquefaction box made up with plate-fin exchanger modules. If the gas contains an important quantity of heavy hydrocarbons, the gas is first cooled to a point where most of the pentanes and heavier fraction are separated (*Please note that this step is not shown in the diagrams)*. This additional step is achieved with a high pressure cold separator or a scrubbing column. Here, the condensed liquids are separated and the gas continues the cooling process in the liquefaction box. The dense phase gas exits the liquefaction box at -255 deg F, and is then expanded to 20 psia before going to the storage tank. Some vapor is formed during this expansion. A 2% to 4% vapor is common based on economical conditions. The liquefaction box outlet temperature dictates the boil off gas rate.

Two independent expander cycles provide the refrigeration requirements for the process. One circuit is rich in methane, and it can use the same gas to be liquefied after the heavies have been removed. The second circuit uses nitrogen as refrigerant fluid. The nitrogen refrigerant is produced with a small nitrogen generation package that also serves to make up the nitrogen that is lost through compressor seals.

Heavier liquids removed are sent to stabilization and further fractionation.

Methane Cycle

High pressure methane rich refrigerant (1000 psia, 90 deg F) is cooled from ambient temperature down to approximately 20 deg F. The gas is then isoentropically expanded in a rotating type expander to 200 psia, generating work. During this expansion the gas temperature descends to –120 deg F. The cold methane rich gas is then re-entered in the liquefaction box providing refrigeration. The gas is warmed to 85 deg F. The gas is then taken by the booster compressor driven by the methane cycle expander, where the pressure is boosted to about 315 psia. In this compression, the gas is heated up to 178 deg F. The gas is cooled before entering the methane recycle compressor that compresses the gas back to 1000 psia.

Nitrogen Cycle

High pressure nitrogen (1200 psia, 90 deg F) is cooled from ambient temperature down to approximately -130 deg F. The gas is then expanded to 200 psia in a turboexpander/compressor set. This expansion lowers the temperature to –260 deg F. The cold nitrogen gas is then re-entered in the liquefaction box, providing refrigeration. The gas is warmed to 85 deg F. The gas is then taken by the booster compressor driven by the nitrogen cycle expander, where the pressure is boosted to about 280 psia. In this compression, the gas is heated up to 165 deg F. The gas is cooled before entering the two stage nitrogen recycle compressor that compresses the gas back to 1200 psia.

The system requires a small nitrogen generation unit to provide nitrogen to fill the system and to maintain the natural losses through compressor seals.

In the arrangements shown, the booster compressor is placed in “post-boost” mode. Sometimes, depending on the pressure level selected, the booster could be placed in “pre-boost” mode that is after the recycle compressor. The final arrangement is selected to optimize compression ratios.

As indicated before, the gas re-circulation rate, as well as the pressure levels and temperatures, are a function of the gas to be liquefied.

As an example, for a medium size LNG production of about 0.5 MMtpy, which equates to about 75 MMscfd of gas, 263 MMscfd of methane rich gas and 172 MMscfd of nitrogen are required to re-circulate. This is a ratio of 5.8 in volume, or 7.3 ratio in mass.

The methane expander generates about 9650 BHP, while the nitrogen expander generates 4050 BHP during their respective expansions. Total recycle compression amounts to 33,675 BHP; this is about 16.1 kw/ton day.

Figures 9 and 10 show typical flow diagrams for the non pre-cooled scheme.

Figure 9 - Liquefaction

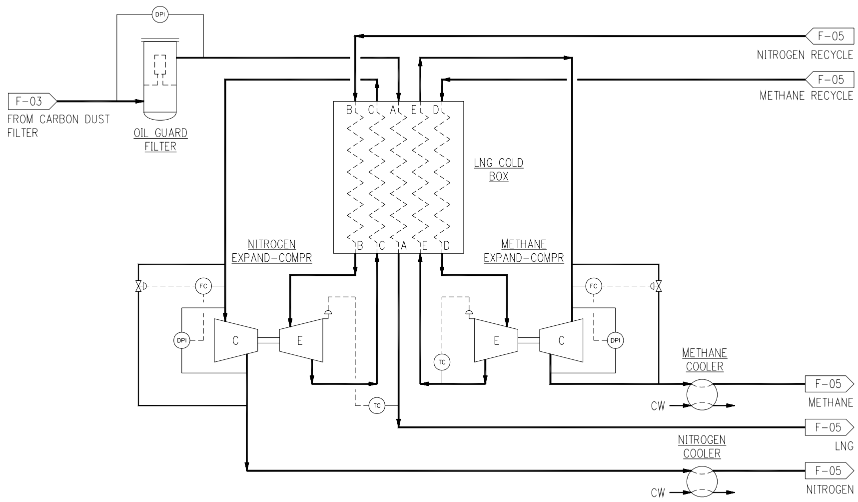
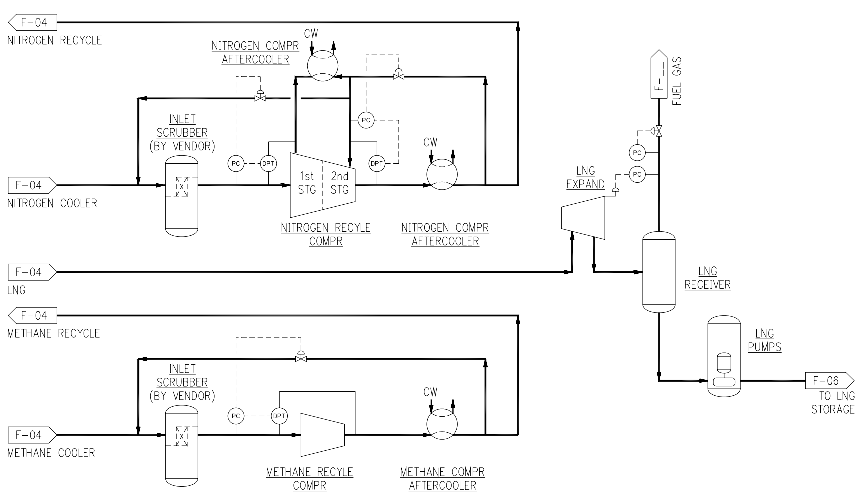


Figure 10 – Gas Recycle Compression



The LNG Business paradigm

We can consider the LNG business as a utility business. Every new project requires a meticulous series of financial and technical requirements. Several institutions service the financial requirements to make possible these projects. Even though new technology solutions are important, they are not the key issue. The biggest issue in an LNG project is not technical but financial. The "*project*" of an LNG project is to structure the financial agreements. After that, the project execution is all that remains to complete. Therefore, proven processes are the choice because they pose no financial risk to the shareholders.

The New Niche LNG Business - Potential Applications

There are indications that in LNG business at sustained pace, spot transactions soared 61% to 7.6 billion m3 in 2000, and accounted for 5.1% of all imports (spot sales are defined as transactions whose durations do not exceed 12 months). The LNG market is expected to double in size in the next ten years (*See references 6 and 7.*)

A number of factors are driving the spot trading small plants exceeding production volumes, debottlenecking of old plants, excess capacity in new plants, speculation, etc. Very soon, the spot trading volumes will lead to opportunistic projects. This could potentially lead to the beginning of a new LNG trading business.

A ton of LNG produced under an "*opportunistic basis*" does not need a stiff project structure as the typical base-load plants. A plant built on an "*opportunistic basis*" is based on trading risk. This technology is aiming to compete in this new emerging LNG business paradigm.

Several immediate potential applications include:

- *FPSO LNG*

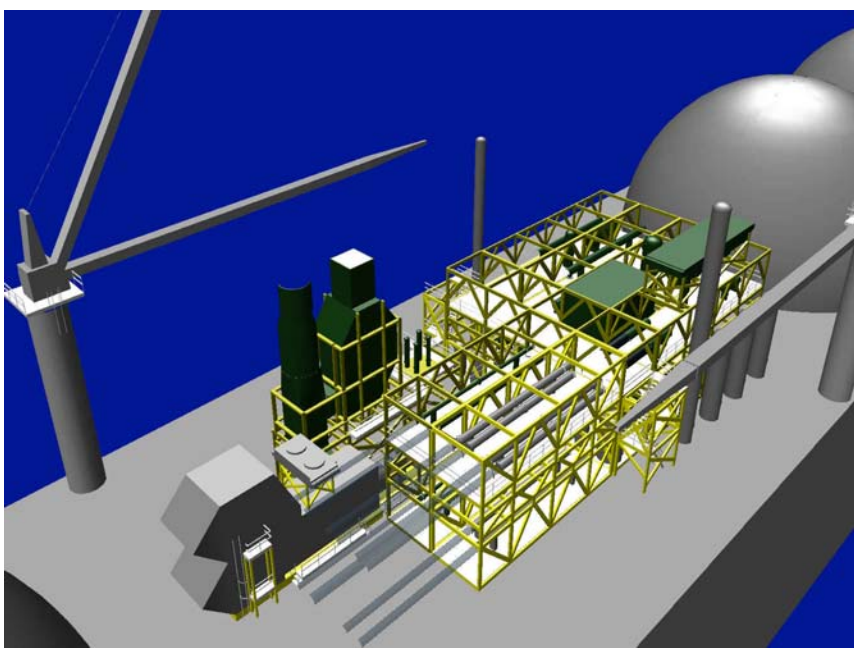
This process is perfectly suitable for production of LNG on an FPSO (*Floating, Production, Storage and Offloading)* vessel. *(See figures 11 and 12.)* The main advantages are:

- Process Simplicity
- Reduced Plot Area
- Modularization
- Safe and Simpler Operation
- Minimal Flare Requirements
- No Refrigerant Inventory
- No Motion Impact

- Equipment Reliability
- Effective Project Execution

Figure 11 *(Courtesy of Moss Maritime)*

Figure 12



- *Boil Off Suppression*

During the ship loading operations an important amount of vaporized LNG is sent to the flare system where it burns through the duration of the loading operation. In a world class base load plant processing 4 MMtpy of LNG, it is estimated that between 10 to 14 MMUS $ are "*burned*" per year. The amount of gas vented is equivalent to a rate of 100 MMscfd, during the 12 hours of loading.

The LNG turboexpander scheme could offer an interesting solution to abate the flaring of LNG, and could potentially offer additional LNG production.

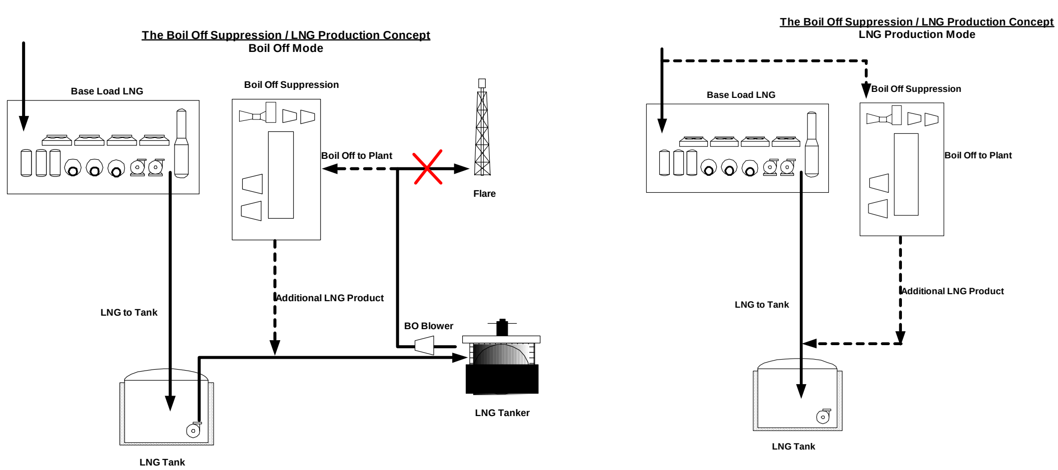
In fact, the plant module would operate in two modes (*See figure 13*):

- Boil Off Suppression Mode - during the ship loading operation, all the boil off is captured by the plant, re-liquefied and sent to the LNG loading line.

- LNG Production Mode - When the loading operation is about to complete, the plant smoothly switches to plant feed gas, producing additional LNG. Boil off rate of this LNG could be controlled or minimized.

The cost of this LNG module could be significantly optimized if the front end of the existing plant is able to process the additional feed gas (about 16% in a 4 MMtpy plant).

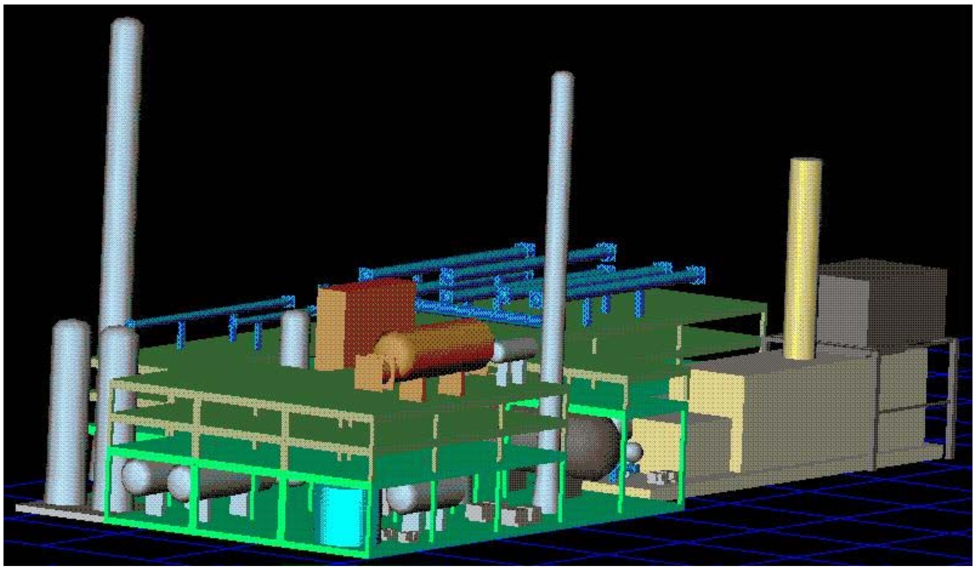
Figure 13



- *Base Load LNG Production*

Turboexpander LNG plants could offer existing production complexes the possibility of expansion in increments that would be not economically attractive using conventional technologies. Current market trends could justify expansion of existing base load facilities. *Figure 14* shows the turboexpander process for supplemental base load production.

Figure 14



<u>Utilities and Specific Energy Consumption</u>

Because of the intensive energy consumption in the liquefaction of natural gas, there is a great interest in the cost of utilities required for the operation since they represent an important component of the cost of production.

The process discussed here has been conceived for opportunistic or “niche” production of LNG. The efficiency of the process may not need to be a requisite; the focus shifts to materialize the opportunity (i.e, stranded gas, associated gas, or gas currently flared).

Table 2 below shows the utility consumption for a 0.5 MMtpy LNG production.

Table 2

Fuel Gas:	5.122 MMscfd
	LHV: 1065 Btu/scf min
	HHV: 1165 Btu/scf max

(**Calculated Train Efficiency : 93.75%)**

Electric Energy: 1,075 Kw

Includes:

Cooling Water:	15,000 gpm (seawater)
Hot Oil:	1,055 gpm

Table 3 below compares the turboexpander processes with current technologies. These figures are based on a 0.5 Mmtpy LNG production.

Table 3

Process	**kW/ton day LNG**
Cascade Refrigeration	14.1
Mixed Refrigerants (Prico)	16.8
Shell Mixed Refrigerants (DMR-SMR)	12.5 - 14.5
ABB LNG Cycles	
- TEX+ C3R	**12.7 - 13.5**
- Dual TEX Cycle	**15 - 16.5**
- Pre-cooled Dual TEX Cycle	**13**
APCI	12.2

The above numbers indicate that the turboexpander processes is competitive with current technologies.

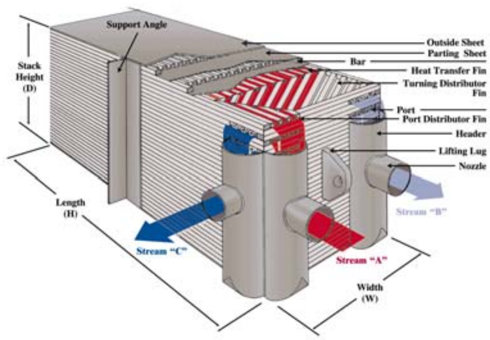
Equipment and Reliability

One important component in the analysis of LNG facilities is the equipment selection. A simple inspection of the process flowsheet shows the simplicity of this process. The main components of the dual cycle are one multi-stream plate-fin exchanger, two expanders, and one recycle compression train. These components have achieved proven operational and maintenance records.

Brazed Aluminum Plate-Fin Exchangers

Mechanical design of plate-fins (*See figure 15*) has evolved to be able to accept design pressures of 1500 psig. Different types of fins and flow arrangements allow great flexibility of design. If required, refrigeration can be incorporated in the plate-fins very effectively. Fabricators of plate-fin exchangers have standardized the design plate-fins, contributing to reduce cost. Delivery time for plate-fins is around 8-12 months.

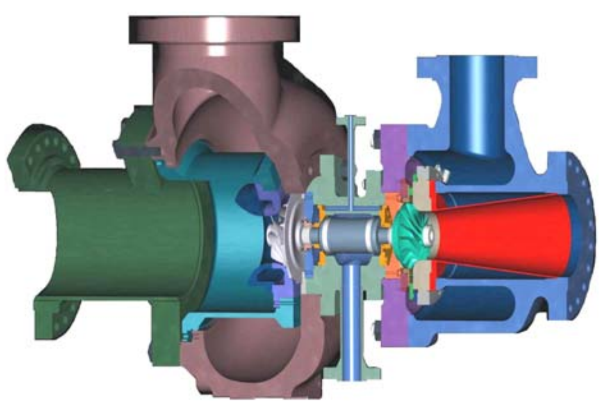
Figure 15



Turboexpanders

Turboexpanders (*See figure16)* have achieved superior mechanical integrity and thermodynamical efficiency in the last 30 years, driven mainly by the gas processing and petrochemical industry. Expansion efficiencies of 87% for the expander and 78% for the booster compressor are now achieved, compared with the initial 75% and 68% respectively, of the 1970s. There is also great expectation with the recent development of single stage liquid turboexpanders based on single wheel machines. Magnetic bearings systems have been adopted by turboexpanders manufacturers in the last 10 years, and are being used with great success introducing simplification in the supporting systems. Turboexpanders are obtained within 8-12 months of delivery.

Figure 16



Turbine Drivers-Electric Drivers
Gas turbines have been the selection of choice to drive refrigeration compression in the large base-load LNG plants. Gas turbines have also gained wide acceptance in the gas processing business, having achieved high reliability and low maintenance operating costs. In the last decade gas turbines derived from the aeronautical industry have entered in the industrial market, introducing a refined technology in this field application.

Energy recovered from exhaust gases can be used to optimize the energy usage. Further optimization could be achieved by generating electrical energy with the gas turbines and driving the compression with electrical motor drives. This concept is called *trigeneration* (generation of heat, power and refrigeration).

In base load plants compression is usually achieved with centrifugal type equipment. Process conditions of the different refrigerants used impose metallurgical requirements that increase the cost of compression.

The dual expander cycle scheme offers an advantage in compression because the process conditions do not require special metallurgy.

Gas turbines and compression equipment are the longest delivery items. Typical delivery lead times are usually around 14-16 months. *Table 4* below shows typical selection of turbines versus capacities.

Table 4
(Non Pre-Cooled Basis)

	Frame 5	**LM2500**	**LM2500+**	**LM6000**	**Frame 6**	**Frame 7**
BHP @ 85 F	33,400	28,260	34,795	48,580	47,775	95,165
Fuel Rate (Btu/HP)	9,230	7,180	6,701	6,760	8,147	8,025
MMscfd	70-75	60-65	75	100-105	100-105	200-210
MMTPA	0.45-0.5	0.4-0.43	0.5-0.55	0.67-0.7	0.67-0.7	1.35-1.4

Estimated Space Requirements and Weights

In recent FPSO conceptual studies, plant designs for 0.5 MMtpy, 1.0 MMtpy, and 1.5 MMtpy were developed. These studies considered facilities deployments in South East Asia and West African waters.

Table 5 below indicates estimated space requirements and weights for these units.

Table 5

Capacity	Length	Width	Weight
0.5 MMTPA	189 ft	85 ft	4500 tons
1.0 MMTPA	210 ft	90 ft	5000 tons
1.5 MMPTA	260 ft	100 ft	7500 tons

In Summary

We have presented a concept that has the potential to contribute a new approach to the LNG business. This concept could be instrumental to the development of stranded gas reserves or bring to markets small reserve volumes not justified to be exploited under today's current economics. The key benefits of this concept are:

- Low CAPEX and life cycle cost
- High availability
- Smaller plot area requirements through modularization
- Faster deployment
- Lower specific energy than other expander cycles
- Optimum candidate for medium size base load facilities
- Smart option for expansions on existing complexes or reduction of boil off associated with loading operations

It has been said that the 21st century is the century of gas, and that this energy resource will be brought to markets utilizing new and innovative means. (See reference 8)

Forecasts are predicting that the LNG business will grow at a rate of 8% per year in the next decade, and that a new spot trading market is emerging.

With a world economy in a process of globalization expansion and more inter-linked behavior, new LNG projects can't wait 10 years to reach definition. Innovative technologies bring the opportunity to materialize projects faster and cost effectively.

This new turboexpander technology is aimed to be a key player in this world of growing opportunities.

"*A competitive world has two possibilites. You can lose, or if you want, you can change.*"

Lester C. Thurow

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