

# REDUCING LNG COSTS BY BETTER CAPITAL UTILIZATION

## LA REDUCTION DES COUTS DE GNL DANS UNE MEILLEURE UTILISATION DU CAPITAL

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### ABSTRACT

Advances in natural gas liquefaction technology have resulted in LNG plants which are highly efficient in converting natural gas into LNG for transportation to a distant market. More than 90% of the feed heating value in a modern LNG plant is shipped as product LNG. Instrumental in achieving this high efficiency has been the industry's choice of the propane pre-cooled, mixed refrigerant cycle, which is currently employed in more than 90% of the world's baseload LNG capacity. However, dual mixed refrigerant, single mixed refrigerant, nitrogen compression-expansion, and cascade cycles are again being proposed for special LNG applications (e.g. FPSO, cold climate, small plants).

The major pieces of process equipment employed in all of these cycles are evolving rapidly. The astute process designer can take advantage of these improvements to better meet the owner's needs - capacity to match the market, lower capital cost, shorter construction schedules, efficient operation, and high on-stream time. An experienced process designer can develop a design to meet product requirements, feed conditions and site-specific factors. But real world costs will be determined by how well the cycle can be "fit" to the equipment available. The better the quality of "fit", the lower the specific cost of the LNG produced.

What is quality of "fit"? It starts with compressors and drivers. Heavy frame gas turbine compressor drivers have proven to be cost effective and efficient. Aero-derivative gas turbines, which are more compact and efficient, have been proposed, but as yet are unproven in the LNG industry. Both centrifugal and axial compressors have a proven track record and add to the available options. The key to cost effective use of this machinery is a flexible process cycle that has been "fit" to the machinery effectively. Examples and benefits from operating and designed LNG plants will be presented.

The main cryogenic heat exchangers (MCHE) are also important to the "fit" of any LNG cycle. Larger, robust wound coil heat exchangers with aluminum or stainless steel shells can be manufactured in less time. Ways to reduce contractor time on the MCHE at site are being implemented. This will help bring down costs and shorten time to on-stream.

And finally, a new approach to the design process (driven by owners and designers) is eliminating costs by better utilization of the capital equipment. The result; the cost per ton of LNG produced is coming down.

## **RESUME**

Les avancements de technologie dans la liquéfaction du gaz naturel ont comme résultat les usines GNL très efficaces dans la conversion du gaz naturel en GNL pour le transporter aux marchés distants. On transporte plus que 90% du pouvoir calorifique de l'alimentation d'une usine GNL moderne comme produit GNL. Le choix de l'industrie, le cycle de réfrigérants mélangés prérefrigérés de propane, contribue à réaliser cette haute efficacité et est actuellement utilisé dans plus que 90% de la capacité mondiale de l'unité de base GNL. Pourtant, on propose de nouveau le réfrigérant dual mixte, le réfrigérant unique mixte, la compression-expansion de l'azote, et les cycles cascades pour les emplois GNL spéciaux (e.g. FPSO, le climat froid, les petites usines).

Les pièces principales d'équipement de génie chimique utilisées dans tous ces cycles se développent rapidement. Le designer astucieux de génie chimique peut profiter de ces développements pour mieux servir les besoins du client – la capacité d'offrir les conditions aussi favorables que le marché, un coût d'investissement plus bas, des calendriers de construction plus courts, une opération efficace, et une haute période de marche effective. Un designer expérimenté de génie chimique peut développer un plan pour satisfaire les demandes de produit, les conditions d'alimentation, et les éléments spécifiques au site. Mais les coûts actuels seront déterminés par la convenance du cycle avec les équipements disponibles. La meilleure la convenance, le plus bas le coût spécifique du GNL produit.

Qu'est-ce la qualité de la convenance? Elle commence avec les compresseurs et les dents d'impulsion. Les compresseurs-dents d'impulsion des turbines à gaz de chassis lourd se sont prouvés comme effectifs et efficaces. Les turbines à gaz aéro-dérivatives qui sont plus compactes et efficaces ont été proposées, mais elles ne sont pas encore prouvées dans l'industrie GNL. Les turbocompresseurs radiaux et les compresseurs à flux axial sont prouvés tous les deux et ajoutent aux options disponibles. La clef d'utilisation effective de ces équipements est un cycle d'opérations flexible qui convient effectivement aux équipements. Les exemples et les avantages des usines GNL dessinées et en opération seront présentés.

Les échangeurs thermiques cryogéniques principaux (MCHE) sont aussi importants à la convenance d'aucun cycle GNL. Les plus grands échangeurs thermiques à bobine enroulée en caisse d'aluminium ou d'acier inoxydable pourraient être produits plus rapidement. En plus, la période de temps entre la livraison et l'installation de MCHE au site diminue. Ces mesures aideront à réduire les coûts et la période avant les opérations.

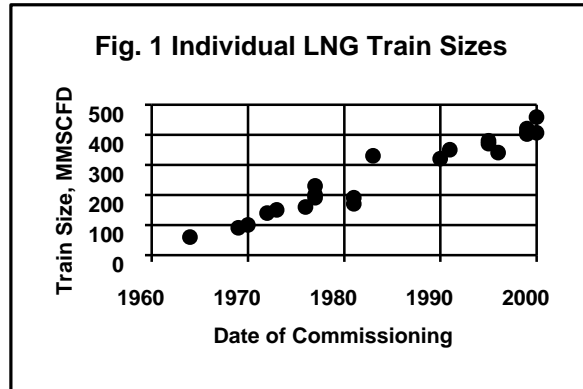
Finalement, une nouvelle façon au processus du dessin (conduite par les propriétaires et les designers) menera à une meilleure utilisation des équipements capitaux et ensuite une réduction du coût par tonne du GNL produit.

# REDUCING LNG COSTS BY BETTER CAPITAL UTILIZATION

## INTRODUCTION

The specific capital cost of producing LNG has been coming down as equipment has improved, train size has increased, and experience has allowed designers to reduce design margins. LNG train refrigeration drivers were mostly steam turbines in the early years, but all new, grass roots facilities have used gas turbine refrigeration drivers. In the 60's and early 70's, several different LNG liquefaction cycles using both aluminum coil wound and plate-fin type cryogenic heat exchangers were constructed— cascade, single mixed refrigerant (SMR), and propane pre-cooled mixed refrigerant (C3MR). The C3MR LNG liquefaction cycle with coil wound MCR<sup>®</sup> cryogenic heat exchangers, first applied in Brunei in the early 70's, has become the workhorse of the industry. Today, more than 90% of worldwide baseload LNG capacity in operation uses the C3MR process with coil wound MCR cryogenic heat exchangers. The primary cooling medium has been water, but some plants are air cooled, and some have used combinations of air and water cooling.

Figure 1 indicates how LNG train size has increased over this same time period. Starting with LNG train capacity of less than one million tonnes per annum (MTPA), train size has grown steadily to greater than 4 MTPA today. The economies of scale have driven this growth. However, many LNG trains have produced far more LNG than their design basis, indicating that full unit cost reduction has not been achieved in the design phase. The C3MR process has been flexible enough to utilize this built in capacity and get a return on this pre-investment.



This paper will address how LNG unit costs can be further reduced by better design definition and utilization of installed capital in LNG liquefiers.

## RECENT C3MR LNG LIQUEFIER PERFORMANCE

The seven most recent LNG trains put into operation (from late 1999 through September 2000) utilize the C3MR process at 4 different plant sites. Three sites utilize different combinations of gas turbine refrigeration drivers (GE Frame 6 and 7) and starter/helper motors, and one site chose to use an earlier design with duplicate steam turbine refrigeration drivers. They utilize different combinations of propane pre-cooling stages; sub-cooled or end flash systems (with nitrogen stripping column when required); and hydraulic turbine expanders (Byron Jackson and Ebara) for increased production. They all use a single, coil wound MCR<sup>®</sup> cryogenic heat exchanger (Air Products) with two or three bundles, depending on the feed gas composition and production objectives

During performance test runs, these LNG trains produced 3-3.5 MTPA of LNG with specific gas power ranging from 235 to 310 KWH per tonne of LNG produced and auto-consumption of 7.5-10%. The lowest specific power process configuration is a very efficient

C3MR liquefier design with hydraulic turbines. The higher specific power plant is a duplicate of an earlier C3MR design. The range of specific gas power and auto consumption is a result of the different process configurations as well as efficiency improvements that have been incorporated into the C3MR process by designers and operators over the last 25 years.

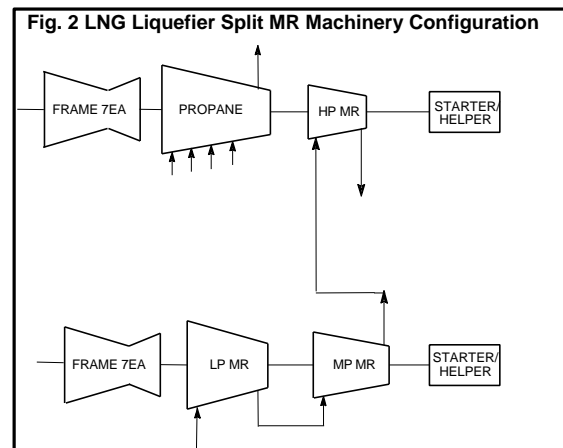
One of these plant sites has reported in presentations and literature a specific capital cost of \$190 per tonne of LNG produced. This cost includes two LNG trains of 3.3 MTPA each, two LNG tanks, a loading jetty, and all utility and infrastructure support systems. Clearly, a very efficient C3MR LNG process can be built at a very attractive cost and still meet the very exacting standards of the industry.

## FUTURE C3MR LNG LIQUEFIER CONFIGURATION

Future large LNG trains are being designed using the C3MR process, 2 GE Frame 7EA gas turbines with starter/helpers, and a single, multi-bundle, coil wound MCR cryogenic heat exchanger. The option to use hydraulic turbines for LNG and heavy MR pressure letdown is retained for incremental capacity. The capacity of such an LNG train is approaching 5 MTPA.

The ability to efficiently use all available driver power is the key to achieving the best capital utilization in LNG liquefier design. The C3MR process has the flexibility and thermal efficiency to be able to produce more LNG than other process cycles for any configuration of refrigerant drivers. This is true for all combinations of gas turbine drivers – heavy frame or aero-derivative.

The Split MR™ refrigerant compressor configuration for the C3MR process shown in Figure 2 is a good example of this flexibility. One GE Frame 7EA gas turbine drives the propane and high pressure MR compressors, and the second drives the low and medium pressure MR compressors. This configuration allows the power split between propane and MR refrigeration to be optimized while fully utilizing the power available from the two drivers. The single shaft gas turbine drivers require a starter, and it is often economically attractive to use this installed capability as a helper to provide more power for LNG production. Thorough dynamic simulation of this liquefaction plant configuration indicates there is no additional complexity to plant operation or startup. Continuous speed and guide vane adjustments are not necessary for process control. This machinery configuration has been thoroughly evaluated for several future projects and has been found to maximize LNG production using two Frame 7 refrigerant drivers.



™ Split MR is a trademark of Air Products and Chemicals, Inc.

For very large scale LNG trains, commercially available propane compressors may constrain LNG production because of the required propane volumetric flow rate. The Split MR™ machinery configuration can relieve this constraint by varying the propane and MR refrigeration power split. Ultimately, parallel propane compressors maybe required to achieve even higher capacity.

Although very large LNG trains are emphasized here, the C3MR process has been configured with all sizes and numbers of gas turbine drivers (aero-derivatives, heavy frame, or combined cycle) to achieve maximum driver utilization at any LNG production rate when compared to other LNG process cycles in use today.

Dual mixed refrigerant (DMR) cycles may also find a niche in future LNG liquefiers. In locations where ambient temperature varies widely, DMR cycles may achieve better capital utilization, and the same is true for FPSO applications. In either case, the Split MR machinery configuration can be employed to fully utilize all available power.

### **COIL WOUND MAIN CRYOGENIC HEAT EXCHANGERS**

As LNG liquefier trains have gotten larger, the size of the main cryogenic heat exchangers has also increased. Responding to this demand, Air Products has worked on several fronts to insure the performance and reliability of these larger heat exchangers. In 1995 we developed a new, proprietary bundle support system to handle these larger bundles. The seven most recent coil wound MCR cryogenic heat exchangers installed in LNG liquefier trains have used this proprietary bundle support system which is now standard in all our designs. All seven trains have met process and mechanical guarantees, and continue to operate trouble free. Additionally, several manufacturing design developments and productivity improvements are being incorporated in future coil wound MCR cryogenic heat exchangers which will reduce manufacturing time significantly and further improve performance and reliability.



Fig. 3 Coil wound MCR® cryogenic heat exchanger ready for shipment on side shifting rail car.



Fig. 4 APCI dockside manufacturing annex, Port of Bucks County, Fairless Hills, PA.

Air Products has also developed the capability to ship these larger heat exchangers from our manufacturing facility in Wilkes Barre, Pennsylvania. We have been shipping up to 4.57 m (15 ft) diameter by 56 m (185 ft) long coil wound MCR cryogenic heat exchangers from our Wilkes Barre facility by utilizing a side shifting rail car since 1998 (figure 3). We have recently completed a dockside, manufacturing annex at the Port of Bucks County at Fairless Hills, Pennsylvania (on the Delaware River north of Philadelphia) where coil wound MCR

cryogenic heat exchangers can be fitted out with nozzles and other fittings before ocean shipping. This means all aluminum welding can be completed before shipment to the plant site. Additional work can also be done at this annex as requested by EPC contractors to optimize overall construction schedule. The third Nigeria LNG coil wound MCR cryogenic heat exchanger was the first to be fitted out in this new annex in late 2000 (figure 4). With this annex, Air Products can now handle heat exchangers greater than 4.57 m (15 ft) diameter and ~60m (~200 ft) long. Heat exchangers with a diameter greater than 4.57 m will be shipped in sections from our manufacturing facility in Wilkes Barre, and then assembled at this annex.

Air Products also has the ability to provide a stainless steel shell with a 32 barg (450 psig) pressure rating for the coil wound MCR cryogenic heat exchangers. This technology was developed for floating production, storage, and offloading platforms (FPSO), but can also be used for a land based LNG train to retain mixed refrigerant on shutdown, thereby minimizing flaring where required.

The goal of these improvements is to increase performance, reduce manufacturing time, and deliver the heat exchangers to site in a more completed state to reduce overall construction schedule and costs.

## **PROCESS DESIGN FOR BETTER CAPITAL UTILIZATION**

The capacity of LNG liquefiers with gas turbine drivers is a function of ambient air temperature. Driver power is inversely proportional to ambient air temperature. If the heat sink temperature also varies widely (cooling water or air), capacity variations are further magnified. Historically, process equipment in the liquefier is sized to handle the controlling air and heat sink temperatures as well as feed composition variations, all with standard design margins applied. By definition, it is usually oversized for normal operating conditions.

To obtain better capital utilization and minimize pre-investment, the plant can be designed for the most common operating conditions and then the performance of the plant at other expected conditions can be simulated as “rating cases” shown in Figure 5. Typically, plant design will consider various feed compositions over a range of site temperatures that may vary seasonally or diurnally. Therefore, even though the LNG liquefier is designed at one point, operation is simulated at several points to assure the plant can meet all production requirements. Furthermore, bottlenecks at off design conditions can be identified and eliminated during design and engineering.

Most commercially available process simulators are not designed to do rating, i.e., simulation of performance, with fixed equipment designs. Rating cases require that expected equipment design information be used in the simulation to evaluate performance of the entire liquefier. Detailed definition of compressors, cooling water or air heat exchangers, the main cryogenic heat exchanger, propane evaporators, and process line sizes are required. This can be accomplished with multi-variable optimization with constraint algorithms in some sequential modular simulators. It is complex and time consuming when not done well. It can also be done with pressure driven equation based simulators that often include dynamic terms. Air Products has used both types of simulators to produce C3MR LNG liquefier designs in recent years.

<b>Fig. 5 Liquefaction Basis of Design</b>			
Ambient Condition	Feed Composition		
	Lean	Average	Rich
Hot	Rating	Rating	Rating
Average	Rating	<b>Design</b>	Rating
Cold	Rating	Rating	Rating

- Equipment and utility design based on Design case
- Entire PFD calculated on simulation basis for Rating cases
  - Compressor curves and MCHE rigorously simulated
  - Process exchanger UA's constrained
  - Cooling water/air rates fixed
  - Pressure drops calculated

After the design point has been determined, the rating cases will highlight bottlenecks in the off design cases. This may require adjusting the design point to ensure all production requirements are met. Both types of simulators produce partial derivatives of the variables with respect to the optimization function (e.g. a high partial derivative of cooling water rate to capacity may indicate that increasing design water flow is the most optimal way to achieve off design capacity). This “design debottle-necking” assures that the LNG liquefier has minimal over design built in.

This effort produces liquefier capacity at different conditions. Often the integrated yearly production is greater than the annual production at a single design point. This insures total available capacity is used to evaluate project economics.

To maximize annual integrated production of a design, it is then very important to control the plant operation at the optimum point during diurnal temperature changes as well as seasonal ones. Advanced process control is the final addition to insure maximum equipment utilization. The most promising advanced process control is called MPC – Model Predictive Control. Using a dynamic process simulator as the LNG liquefier plant model, Air Products has demonstrated that MPC control is very attractive for LNG plants with the Split MR machinery configuration and fixed speed drivers. Application of MPC control in the process industries does not require special computer hardware and can be applied using modern DCS systems. Model development is straightforward and plant data can be gathered with minimal

disruption to the operation. Once there is experience with MPC control in LNG plants, design margins can again be adjusted to reflect actual plant performance.

And finally, dynamic simulation can be used to evaluate non-steady state events such as startup, shutdown, and relief scenarios to reduce over design. As an example, the propane compressor blocked discharge relief scenario for the C3MR process has been re-evaluated with dynamic simulation. This relief flow often determines the height of the flare and the distance it must be from other structures due to radiation.

As can be seen in Figure 6, the propane compressor blocked discharge relief flow

<b>Fig. 6 Propane Blocked Discharge Dynamic Relief Simulation</b>			
	Traditional	Dynamic	Dynamic
Available Power, MW	84	84	96*
Relief Rate, million kg/h	1.76	0	1.01
*with 12 MW of helper power			

calculated rigorously by dynamic simulation is significantly lower than has been traditionally estimated. A single shaft gas turbine driver may not have enough available power to produce any relief flow under this scenario. It would stall and shutdown before reaching the relief valve pressure setting. In this example with a 12 MW helper motor, the relief rate is only 60% of the traditional calculation. Other relief scenarios, including equipment design pressure optimization, are being dynamically simulated to insure safe operation of the plant without over sizing the relief system.

## SUMMARY

In summary, economies of scale continue to drive to larger LNG trains to reduce the unit cost of LNG produced. As the LNG trains get larger, it is vital to maximize capital utilization. The Split MR machinery configuration mentioned in this paper and a C3MR plant design that utilizes all available refrigerant compressor driver power can produce the lowest unit cost of LNG. MPC advanced control systems can assure that maximum integrated annual production is achieved from this plant design, and dynamic analysis of non-steady state operations can avoid over sizing equipment, and thus achieving better capital utilization.