How liquefaction technology is evolving as the game changes towards unconventional gas monetisation

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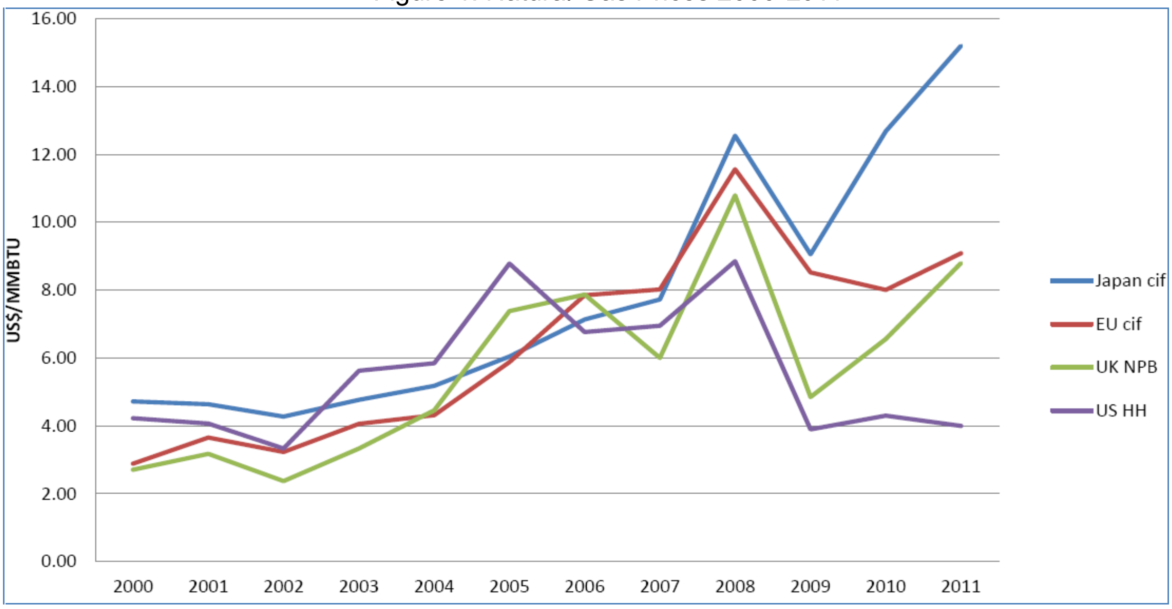
Introduction

The gas and LNG markets are changing with liquefaction of lean gas for export in Australia and North America. The cause of this evolution is the discovery of large unconventional gas reserves. The objective of this paper is to show how mixed refrigerant processes can provide high efficiency and cost effective method for liquefaction of pipeline gas with high methane content.

Unconventional gas in the market context

The combination of several factors such as technological advances in drilling and hydraulic fracturing, as well as a rapid rising of natural gas prices over the last decade as shown on Figure 1 has led to the development of exploitation of unconventional gas.

Figure 1: Natural Gas Prices 2000-2011

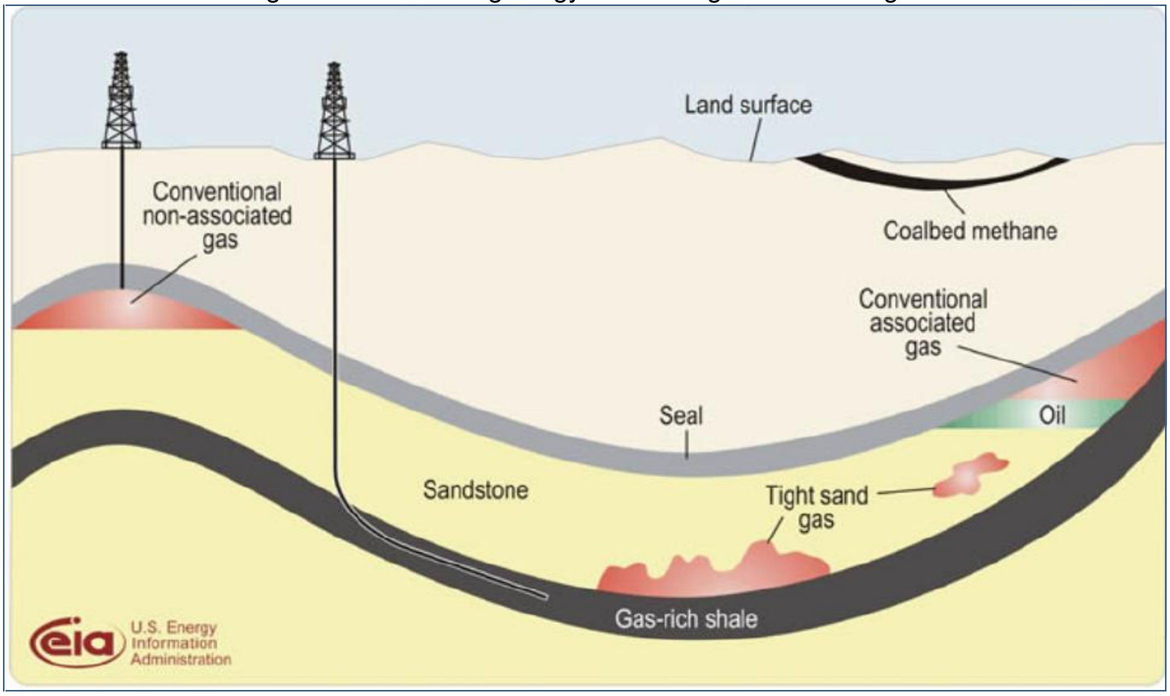


Source: BP Statistical Review

The main forms of unconventional gas illustrated below include:

- Coal-Bed Methane (CBM) or Coal Seam Methane (CSM): formed and adsorbed in coal.
- Shale Gas: formed in fine-grained shale rock and adsorbed by clay particles.
- Tight Sands Gas: formed in sandstone.
- Methane Hydrates: a crystalline combination of natural gas and water.

Figure 2: Schematic geology of natural gas resources gas



Source: US Energy Information Administration (EIA)

At end of 2011, three liquefaction projects using CBM were already sanctioned (FID, Final Investment Decision) in Australia. A few more are under study in Australia with CBM. In the US, there are numerous terminal conversion projects starting from shale gas. All these are shown in Table 1.

Even with improvement of unconventional gas extraction technologies, liquefaction cost of unconventional gas may remain high because of additional extraction costs. Furthermore, due to lean gas composition of unconventional gas, no benefit can be derived from Natural Gas Liquids (NGL) and Condensate production which are high value-added by-products and play a significant role in LNG projects' economics.

Conversion of import terminals to export is considered as a good opportunity to cut investment costs associated with the liquefaction plants.

Table 1: liquefaction projects with unconventional gas

Project Name	Gas source	Status (Dec 2011)	Capacity (MTPA) (*)
AUSTRALIA			
Arrow Energy LNG	CBM	Under study	2 x 4
Australia Pacific LNG	CBM	Under construction	1 x 4.5
Fisherman's landing	CBM	Under study	1 x 3
Gladstone LNG	CBM	Under construction	2 x 3.9
Queensland Curtis LNG	CBM	Under construction	2 x 4.25
USA			
Cove Point LNG	Shale	Under study	N.A.
Freeport LNG	Shale	Under study	2 x 4
Sabine Pass	Shale	Under construction	2 x 4.5
Lake Charles	Shale	Under study	2 x 7.5

Note (*): Million Ton per Annum

The LNG supply/demand balance is projected to become tight before the end of the next five years and unconventional gas is the game changer that will help support the world growing gas demand.

Despite the trend of increasing natural gas price over the last decade, fluctuations are inevitable and projects of unconventional natural gas liquefaction rely on high efficiency liquefaction processes that will allow liquefaction plant to be competitive against domestic consumption for power generation.

Most of the projects under development have been going ahead with the pure component cascade process as liquefaction technology. While keeping high liquefaction efficiency, the C3/MR (Mixed Refrigerant) liquefaction process is foreseen as a competitive and innovative alternative. The following sections will present Technip studies to demonstrate the attractiveness of this alternative along with various configurations and optimisations to further improve the liquefaction efficiency.

The C3/MR process, leading the LNG market

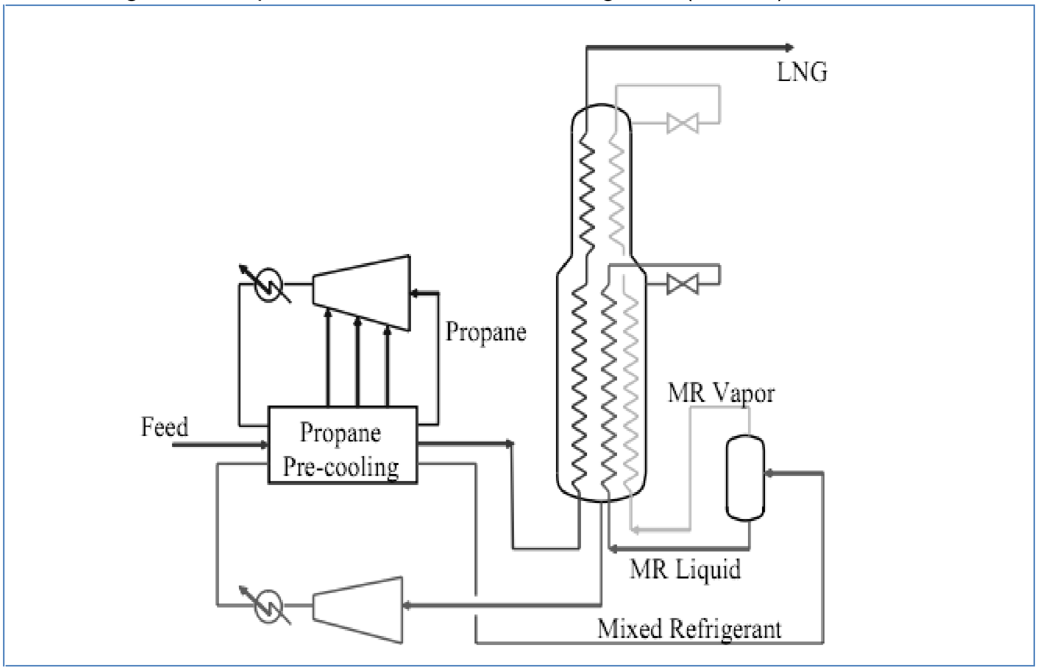
The C3/MR process is the world leading process for liquefaction of natural gas with about 80 LNG trains in operation in the world.

The C3/MR process consists in precooling the natural gas at a level of temperature around -35°C using pure propane refrigerant. This is generally achieved using kettle type propane evaporators at 3 or 4 pressure levels in series. The precooled natural gas then enters a spiral wound heat exchanger where it is liquefied and subcooled to around -150 to -160°C against Mixed Refrigerant. The heat exchanger offers a very large surface area for the refrigeration duty required to liquefy and subcool the natural gas.

The Mixed Refrigerant is also precooled and partially condensed in another set of propane evaporators using propane refrigerant. It is phase separated and both vapour and liquid MR enters the main exchanger to provide refrigeration for the liquefaction and subcooling of the natural gas.

The propane refrigerant is compressed in a multi-stage compressor at a pressure high enough to fully condense the propane using either air (air cooled plant) or water (water cooled plant).

Figure 3: Propane Pre-Cooled Mixed Refrigerant (C3/MR) Process



The C3/MR process combines the advantage of the use of precooling step using pure component for an efficient and easy operation and the use of mixed refrigerant for the liquefaction which efficiently provides refrigeration over the large temperature range required.

Opportunities around the C3/MR process to improve efficiency

The C3/MR process is by itself a very efficient process for natural gas liquefaction. However, its efficiency can be further increased to minimise plant auto-consumption while maintaining a low CAPEX per tons of LNG produced.

The sections below give examples of several convenient and robust ways to improve C3/MR process efficiency.

a – Selection of the cooling medium

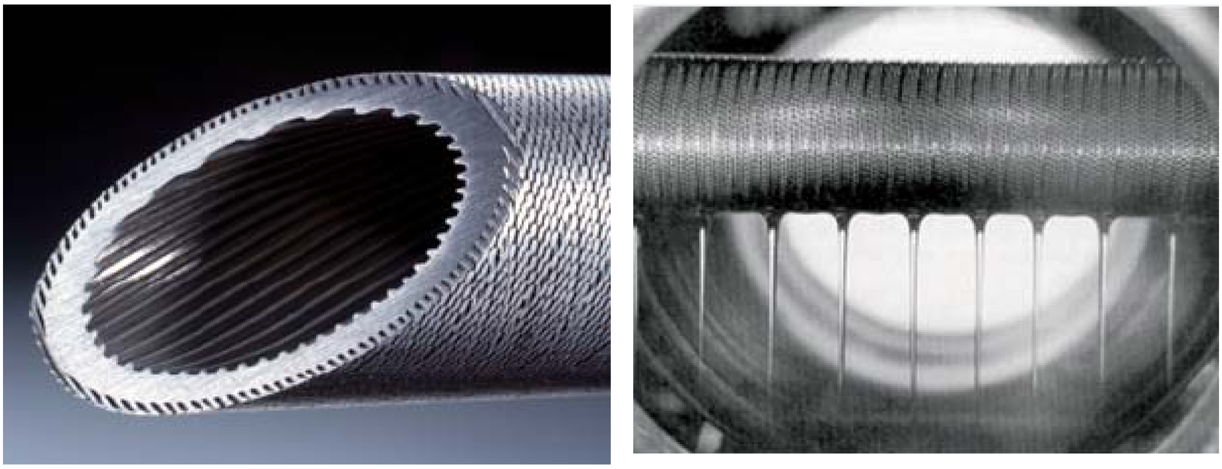
The choice of air cooled or water cooled plant remains a key option to be studied during the early stages of a project. Indeed, the selection of water cooling instead of air cooling can lead to a substantial increase of plant efficiency resulting in lower auto-consumption. This selection is however very dependent on the site conditions, including water and air average and peak temperatures, water quality, site layout, etc.

b – Enhanced heat transfer on precooling heat exchangers

Technip and Wieland have jointly developed innovative enhanced heat transfer solutions for LNG and Ethylene plants [4]. For the C3/MR process, it consists in the implementation of enhanced boiling tubes (GEWA-PB tubes), with inner and outer enhanced surface in the propane evaporators. The enhanced surface largely increases the heat transfer coefficient of both fluids thanks to the created turbulence and the increased surface area. This gives the opportunity to decrease the temperature approach in the propane evaporators hence improving the liquefaction efficiency around 1-2% while reducing the tube length of the propane evaporators.

For water cooled plant, the propane condenser can also be fitted with enhanced condensing tubes (GEWA-KS tubes) to minimise temperature approach for a higher efficiency while keeping optimum exchanger compactness.

Figure 4: Wieland Tubes: GEWA PB (left) and GEWA-KS (right) tubes.



c – Implementation of hydraulic turbines

The C3/MR process requires two important pressure letdowns of liquid fluid: one on the subcooled LNG at the outlet of the main heat exchanger and one on the MR prior it is used as shell side refrigerant in the main heat exchanger.

The efficient way to expand liquids is by using an hydraulic turbine, which recovers the lost fluid energy as electrical power. This allows further subcooling of the LNG leading to a higher efficiency. Moreover, the electrical power recovered via a generator is transferred to the electrical network and helps reducing power demand and fuel gas consumption of the plant. The use of back-pressure hydraulic turbines is nowadays a standard arrangement for the C3/MR process.

d – High pressure liquefaction

The C3/MR process and the use of Air Products spiral wound heat exchangers allow handling the liquefaction at high pressure. A higher liquefaction pressure modifies the shape of the enthalpy curves of liquefaction and allows fitting warm and cold enthalpy curves in an optimum way to have an almost constant and low temperature approach all along the heat exchanger.

Several LNG plants with liquefaction pressure around 65-70 barg are in operation around the world. Technip has developed recent projects with even higher liquefaction pressure, in the range of 80-90 barg.

e – Large range of driver selection

The driver selection is also a key parameter to maximise the liquefaction efficiency as well as for plant capital cost and layout. The C3/MR process can easily be configured either in a minimum number of drivers to minimise the plant capital cost and ease the operation and the maintenance of the machines or with several smaller gas turbines in a parallel configuration to improve plant flexibility and availability.

The use of large gas turbines could be combined to a complete heat recovery system on the flue gas of the gas turbines. The heat recovered is used in an efficient configuration to ensure heating requirement of the plant and to drive some compressors via steam turbine or to generate power.

A convenient arrangement could be to generate High Pressure (HP) Steam in Heat Recovery Steam Generator (HRSG) on Frame7 gas turbines exhaust. Then, the steam is letdown in steam turbine helper which provides additional power to the Frame7 shaft. The Low Pressure (LP) Steam is finally used as heating medium for process use rs. This arrangement is in operation on a C3/MR process in Tangguh LNG (Indonesia) [5].

The selection of drivers is done in view of having the best compromise between high efficiency, low CO_2 emissions, low capital cost, simple operation, best availability and easy maintenance.

f – LNG subcooling

Having a high efficiency of liquefaction results in low fuel gas consumption. To match the fuel gas requirement, it is necessary to produce subcooled LNG at the outlet of the liquefaction to minimise the generation of flash gas. This is easily ensured with the C3/MR process by adjusting the amount of nitrogen in the MR.

Case study: application of the C3/MR on a typical US pipeline gas

This case study applies to a liquefaction project associated with the conversion of an import terminal into an export terminal in the US. The source of gas represents excess from domestic production of the country issued from shale gas. As this excess is fluctuant due to seasonal variation, a flexible technology needs to be considered.

The case study proposes two driver configuration schemes for the C3/MR liquefaction process: the first configuration using inherently efficient aeroderivative gas turbines, the second configuration using two heavy duty gas turbines. The plant capacity is maximized for the aeroderivative driver arrangement consisting of 6 x LM2500+G4 and for comparison purpose, the production for the second driver configuration (2 x Frame7) is targeted to be similar or slightly higher depending on power available.

Table 2 shows the feed gas composition considered for the case study.

Table 2: Feed gas composition

Component	% mol
N_2	1.0
CO_2	2.0
Methane	91.2
Ethane	5.7
Propane	0.1
Butane	Traces
C_{5+}	Traces

The plant is air cooled and a design ambient temperature of 29°C is considered.

The feed gas is assumed to be delivered at 67 barg. A feed gas booster compressor is implemented to maximise the pressure of liquefaction up to 80 barg for a higher efficiency.

Pre-treatment of the feed gas consists in CO_2 removal, dehydration and demercurisation units. No Liquefied Petroleum Gas or condensate is produced but removal beds are installed to ensure the capture of possible traces of heavy hydrocarbon (C_{5+}) in the feed gas before entering the liquefaction unit.

For the case study, no extraction of C_2 and C_3 is performed given the lean composition of the feed gas and refrigerant make-up for the liquefaction needs to be imported.

a – Configuration 1: 6 x LM2500+G4

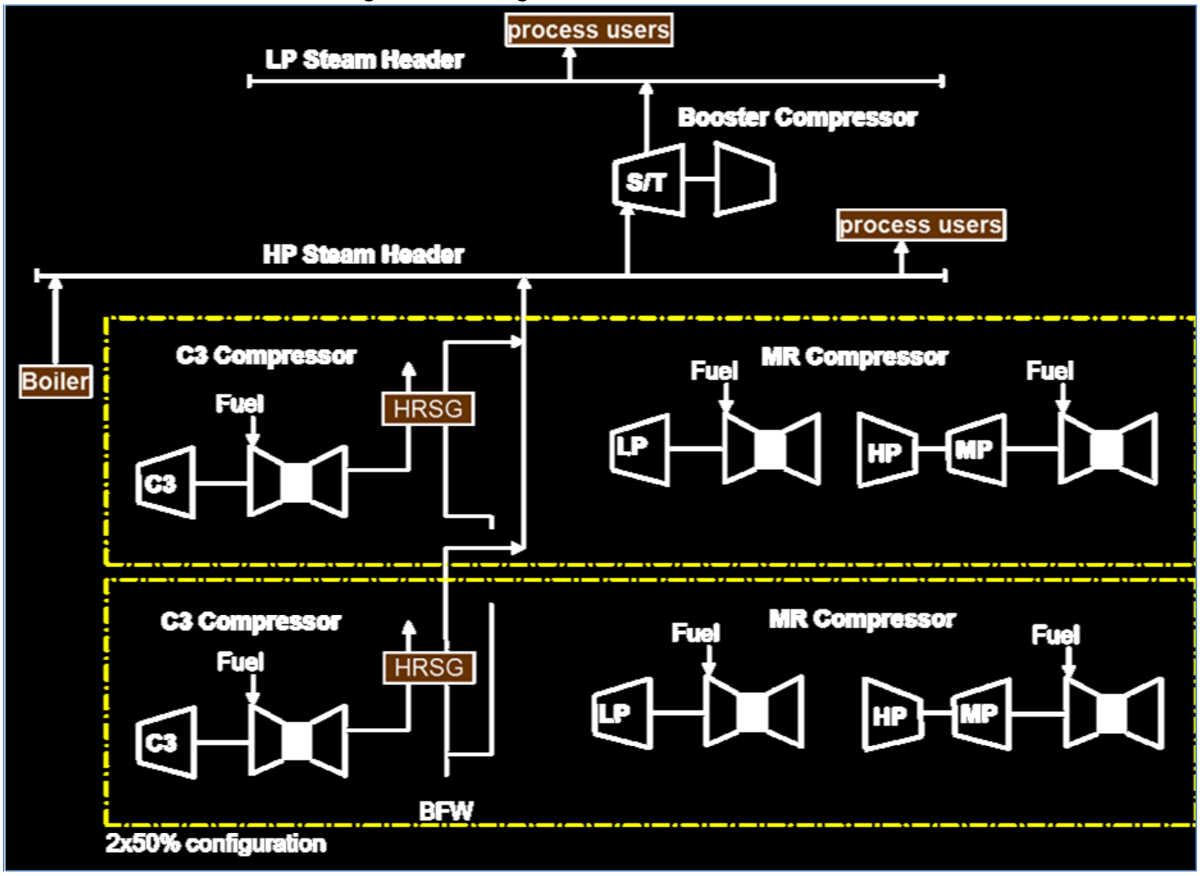
The first configuration consists of the use of high efficiency aeroderivative LM2500+G4 gas turbines as liquefaction C3/MR compressors drivers. In view of the gas turbine availability, all compressors and associated pieces of equipment are installed in a 2x50% configuration in order to maintain LNG production at a reduced rate when one gas turbine is under maintenance or when liquefaction capacity requires to be reduced.

A total of six compressors driven by six gas turbines are required as illustrated in the figure below.

Each C3 Compressor gas turbine is equipped with a HRSG to allow heat recovery from the flue gas. HP Steam produced is used in the feed gas booster compressor steam turbine driver. LP steam is used by process users, mainly Acid Gas Removal Unit (AGR) and other process heat exchangers. One steam boiler is provided to produce steam to compensate for the loss of one HRSG and for start-up.

The achieved LNG production using the total available power of the turbines is 4.1 MTPA.

Figure 5: Configuration 1 - Block flow scheme



b – Configuration 2: 2 x Frame7 + steam turbines helper

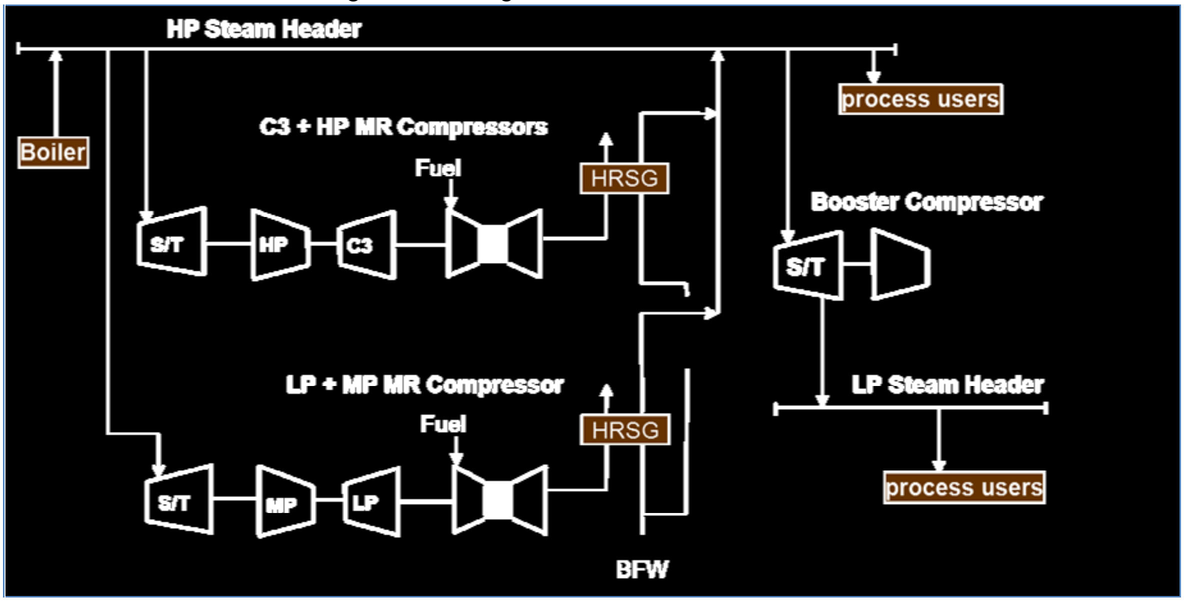
The second configuration consists of the use of two heavy duty Frame7 gas turbines as liquefaction C3/MR compressor drivers. LNG production is maximized thanks to a complete heat recovery system installed on the flue gas of the gas turbine. The plant heating requirement saved from this system allows recovering excess steam that is used in steam turbine helpers to drive part of the refrigeration compressor. All compressors and associated equipment are in 1x100% arrangement. In order to balance the available power from the two Frame7 shafts, the HP MR compressor is coupled to the propane compressor (as per Air Product's Split-MR™ configuration). The second Frame7 gas turbine is dedicated to the LP and MP MR compressors.

This configuration leads to two shafts driven each by one gas turbine and one steam turbine helpers, as illustrated in the figure below.

HP Steam produced is mainly used in feed gas booster compressor steam turbine driver and in steam turbines helpers. One steam boiler is provided to produce steam to compensate for the loss of one HRSG and for start-up.

The achieved LNG production using the total available power of the turbines plus additional power from the helpers is 4.4 MTPA.

Figure 6: Configuration 2 - Block flow scheme



c – Conclusion

The case study shows that both configurations of drivers within a C3/MR liquefaction process are well adapted for a lean feed gas liquefaction process with high LNG production rates achieved. For both driver configurations, high liquefaction efficiency is achieved resulting in very low auto consumption (less than 7%). This figure could have been further reduced by using water as cooling medium.

The 2x50% arrangement of refrigerant compressors in configuration 1 allows maintaining liquefaction production at typically 60% when one compressor trips or is in maintenance. The use of high efficiency aeroderivative gas turbines leads to low CO_2 emissions. However, frequent scheduled maintenance of the turbine is foreseen and this configuration presents a duplication of a large number of equipment due to the 2x50% arrangement.

In the second configuration, Frame7 gas turbines are well known and robust drivers. CAPEX is reduced by minimising the number of drivers, HRSG and equipment (1x100% configuration) while allowing maximum steam recovery on HRSG leading to low CO_2 emissions and increased LNG production compared to configuration 1.

The selection of the driver configuration within a C3/MR liquefaction process depends on the project constraints. The main advantages of each configuration are qualitatively summarised in the table 3 hereafter.

Table 3: Qualitative comparison of the two configurations

	Configuration 1: 6 x LM2500+G4	**Configuration 2:** 2 x Frame7 + ST helpers
Liquefaction efficiency	+++	+++
CAPEX	+	+++
Operation flexibility	+++	+
CO_2 emissions	+++	+++
Maintenance	-	+++

Conclusions and way forward

Unconventional gas is predicted to make up a growing share of the future liquefaction plants.

This paper has demonstrated that the C3/MR liquefaction process is well adapted to the economics of these projects with solutions to increase efficiency by reducing auto-consumption.

Another advantage of the C3/MR process is to enable to have the main refrigerant components extracted from the natural gas, i.e. C_1, C_2 and C_3; therefore no import is usually necessary. However, when the feed gas is very lean as for unconventional gas, the extraction of C_2 and C_3 may be difficult to achieve. In this case, different configurations can be considered depending on the feed gas composition, including standard scrub column scheme or front end NGL Recovery expander process.

The current LNG projects under development focus on a train capacity of around 4 MTPA. This capacity is driven by the liquefaction process technology but also by the capacity of the turbine driving the refrigerant compressors. New gas turbine models of larger capacity such as General Electric's LMS100 associated to a C3/MR liquefaction process open new horizons for LNG trains with higher capacity.

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