ENGINEERING TOMORROW...TODAY

WHITE PAPER

# A NEW PROCESS FOR IMPROVED LIQUEFACTION EFFICIENCY

Author(s): Adam Jones and Grant Johnson, Costain Natural Resources

First published: GPAE, September 2013



**COSTAIN GROUP PLC** Costain House, Vanwall Business Park, Maidenhead, Berkshire, SL6 4UB.
Tel: +44 (0) 1628 842444

# A New Process for Improved Liquefaction Efficiency

Adam Jones and Grant Johnson, Costain Natural Resources Division

## Abstract

Liquefied Natural Gas (LNG) production plants need to operate with low specific power consumption (per unit of LNG) to maximize LNG production and plant profitability. Specific power is a key parameter; but for small scale at ~0.05 million tonnes per annum (mtpa) onshore LNG plants, and more recently for floating LNG (FLNG) plants even up to around 1 to 3 mtpa; safety, reliability and operability can outweigh liquefaction efficiency in selection of optimal technology. Even so, maximizing LNG production is important for all liquefaction plants so high liquefaction efficiency is valuable.

Liquefaction efficiency depends on several parameters, some of which are fixed and some of which can be optimized by the process designer. Increasing feed gas pressure increases LNG production, and operating pressure is one of the most important parameters that can be optimised in process design.

Heavy hydrocarbons are normally required to be removed to avoid freezing (possibly along with natural gas liquids (NGL)) and typically the feed gas pressure has to be limited to less than about 50 bar to permit NGL extraction and for liquid product to be separated from the feed gas. This extraction often limits the maximum available pressure for liquefaction and hence the efficiency and performance of the liquefaction process.

This paper describes a new process that removes the limitation imposed by extraction pressure as the feed gas can be conditioned for hydrocarbon liquids removal and subsequently increased in pressure as an integrated part of the liquefaction process. The process combines simplicity and operational performance with improved liquefaction efficiency, via a minor but novel adaption of a conventional liquefaction process. It provides valuable performance benefits for floating LNG and small onshore liquefaction plants that require removal of heavier hydrocarbons prior to liquefaction. It uses well-proven, conventional and reliable equipment to ensure high availability. Costain has patent applications for this liquefaction technology in the US, Europe and Australia.

## Introduction

Processes for the liquefaction of natural gas involve condensing the natural gas to produce a liquid for storage and transportation at atmospheric pressure. It is widely accepted that optimising feed gas pressure is important for maximising the performance of liquefaction processes. Liquefaction efficiency is improved at higher pressures, with a practical upper limit of approximately 75 bar due to limitations in the mechanical design of heat exchange equipment.

Typically the natural gas fed to the liquefaction processes comprises greater than 80% methane, together with small amounts of ethane, propane and butane. Heavier hydrocarbons (C5+) including aromatics such as benzene, toluene, ethylbenzene and xylene have the potential to freeze in the liquefaction process and as such are typically removed upstream of the liquefaction plant. Water and $CO_2$ must also be removed to prevent their freezing in the liquefaction plant. In some cases deeper hydrocarbon removal is also used to recover a saleable natural gas liquid (NGL) product in addition to a condensate product. This may be done to increase revenue, or to adjust LNG composition to avoid it being too rich and therefore having a heating value that is too high.

In some process configurations, the removal process may be combined with the liquefaction process through the use of an integrated scrubbing column. In this case, the liquefaction process operating pressure is limited by the critical pressure of the gas, which is typically 50 to 55 bar. Alternatively, heavy hydrocarbon removal may be carried out in a separate upstream treatment facility, particularly if producing NGL. In this case, the pressure of the feed gas to the liquefaction plant can be boosted through the use of a feed gas compressor.

In this paper, a new process [Ref. 1] is presented that, through a modification of an established, proven turbo-expander based liquefaction process, provides a way to compensate for this loss of feed gas pressure without using an additional compressor and driver. The process is of particular interest in FLNG due to its inherent safety (using nitrogen refrigerant) and simple operation.

By boosting the feed gas pressure, the efficiency of the liquefaction process is increased, and so greater LNG production is possible for a given refrigeration cycle compressor driver. This is of benefit to project economics as power is constrained by the output of a particular compressor driver or a particular power generation configuration.

## The Dual Nitrogen Expander Process

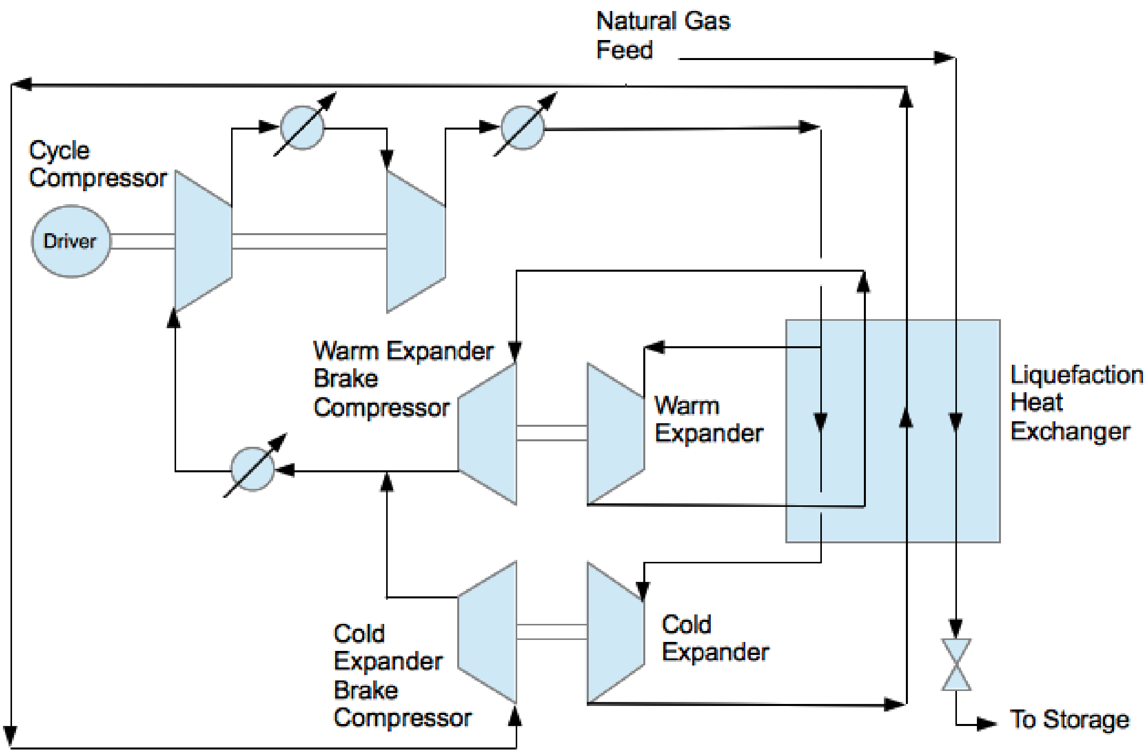
The dual nitrogen expander process serves as a basis for the improved process presented in this paper. The dual nitrogen expander process is widely used for the cryogenic liquefaction of industrial gases and for small scale LNG production up to around 0.05 mtpa, and has been recognised as strong choice for FLNG even at 1 to 3 mtpa, representing an excellent balance between safety, operability and project economics [Ref. 2, 3, 4]. It has a number of advantages well suited to offshore and floating applications. These include:

- Use of proven and well understood technology
- High inherent safety level (as there is no flammable refrigerant inventory)
- Relatively low complexity
- Small footprint and low weight
- Not affected by vessel motion due to the use of a single phase gaseous refrigerant
- Capability to handle changes in feed gas composition and pressure
- High availability

Although well suited to small applications, nitrogen expander cycles are not suitable for large-scale onshore applications. An exception is the efficient use of nitrogen expander cycles in the sub-cooling of LNG in very large trains.

Figure 1 shows an example of a typical dual nitrogen expander process. This process is described below.

**Figure 1: Typical Process Flowsheet for the Dual Nitrogen Expander Process**




## Liquefaction Feed

The liquefaction feed gas is fed to a multi-stream heat exchanger. Heat transfer against cold nitrogen refrigerant produces a condensed and sub-cooled liquid product. This sub-cooled liquid stream is let down to storage pressure, across a valve or liquid expander, and flash gas is separated from the produced LNG.

## Nitrogen Cycle

The refrigeration to produce the LNG product stream is provided by a dual nitrogen turbo-expander refrigeration cycle. Returning nitrogen is compressed in the cold and warm expander brake compressors, which are driven by the warm and cold expanders respectively. The compressed nitrogen is cooled before being fed to cycle compressor, incorporating inter- and after-coolers (typically against air or water) to produce a high-pressure nitrogen stream, which is fed to the liquefaction heat exchanger, in which heat is exchanged with the returning cold nitrogen.

A portion of the nitrogen is expanded at a higher temperature in the warm expander, and returned to the liquefaction heat exchanger. The remainder of the nitrogen is expanded at a lower temperature in the cold expander, and the resulting expanded, low-pressure streams are rewarmed, providing refrigeration.

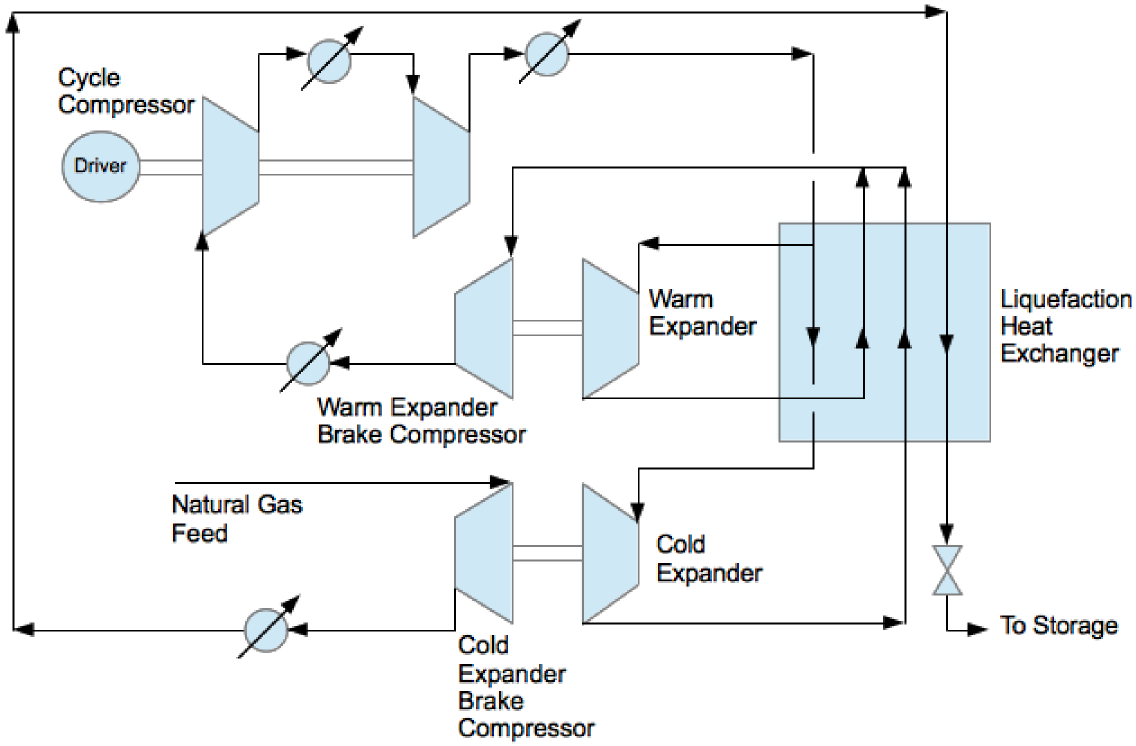
## Improving Efficiency

As previously stated, boosting the feed gas pressure is beneficial to the efficiency of the liquefaction process.

This process adapts the dual nitrogen process described above, through the use of part of the power from work-expansion of the refrigerant to drive a feed gas compressor. This is in contrast to the conventional dual nitrogen expander process, in which this power is used to boost the refrigerant pressure. Figure 2 shows a dual nitrogen expander flowsheet, which has been modified in this way.

Although this modification reduces the power available to boost the refrigerant pressure, the increased feed gas pressure results in a net improvement in specific power and hence LNG production for a given driver. While the use of a separate feed gas compressor would also result in an increase in liquefaction efficiency, this would require an additional machine, and additional cost. The increase in footprint and weight is also a significant disadvantage for offshore and floating processes.

**Figure 2: Flowsheet for the Improved Process with Integrated Feed Gas Compression**




In explaining the reasons for the increase in liquefaction performance, it is helpful to consider the temperature-enthalpy curve for the process.

Figure 3 shows a typical composite temperature-enthalpy curve for the dual-nitrogen expander process, with a feed gas pressure of 35 bar. The gradient of the curves is equal to the product of the mass flow and the heat capacity. In cryogenic processes, it is very important to minimise the temperature difference between the hot & cold streams, as low temperature driving forces reduce thermodynamic losses and increase process efficiency, albeit at the expense of additional heat transfer area. It is therefore advantageous to match the curve of the hot and the cold curves as closely as possible.

The curved region on the temperature-enthalpy curve for the hot composite corresponds to the region of natural gas condensation in the process. Once the gas is fully condensed and starts to sub-cool, the temperature-enthalpy relationship again becomes linear.

Increasing the feed gas to the liquefaction process to 75 bar results in the composite temperature-enthalpy curves given in Figure 4, with a noticeably straighter curve, allowing a closer match between the hot and cold composites.

At higher pressure, the warm expander inlet temperature is also higher, which increases the specific power recovery from the expander.

**Figure 3: Temperature-Enthalpy Curve for the Dual-Nitrogen Expansion Process at 35 bar**

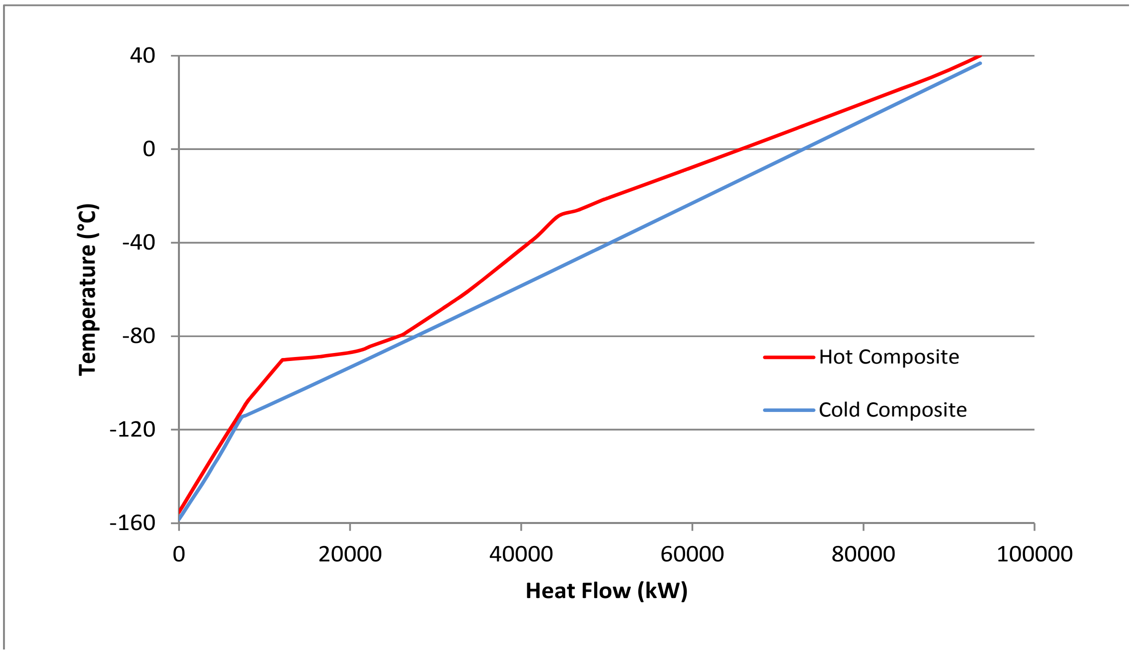
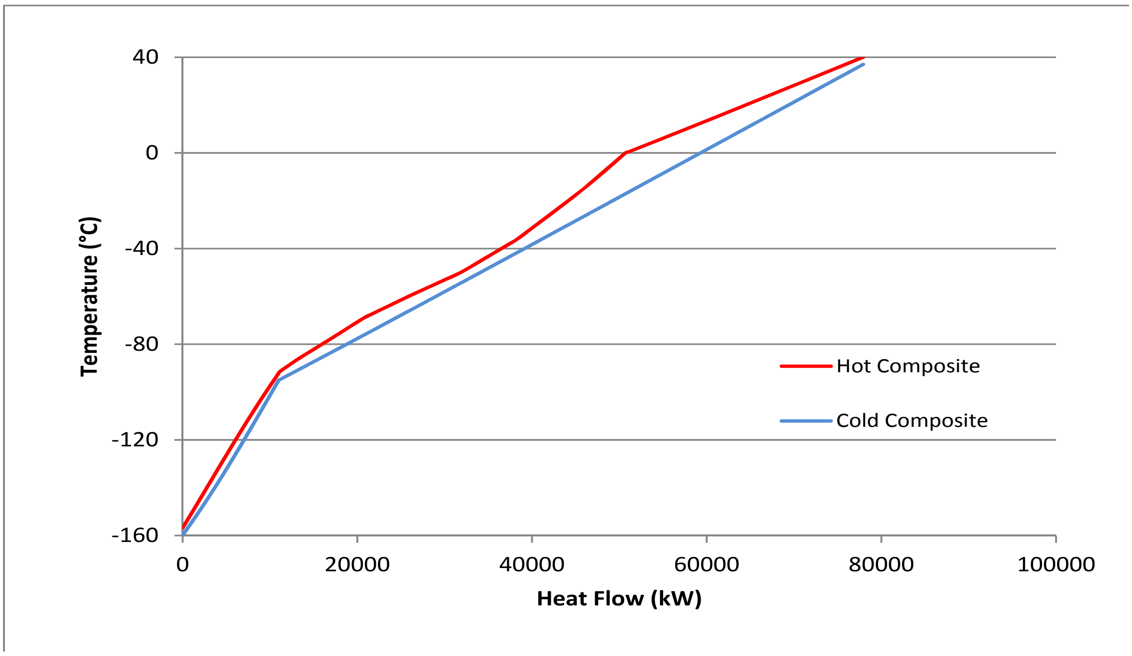



**Figure 4: Temperature-Enthalpy Curve for the Dual-Nitrogen Expansion Process at 75 bar**



# Case Study

## Basis

The performance of the improved process has been evaluated by process simulation. This case study considers a dual nitrogen expander liquefaction process with an upstream treatment process incorporating water, $CO_2$ and heavy hydrocarbon removal. The upstream treatment process will typically need to remove benzene to < 1 ppm.

Three configurations for the liquefaction process have been considered:

A. No feed gas compression; the liquefaction process operates at the outlet pressure from the upstream hydrocarbon removal process (flowsheet as per Figure 1);
B. Flowsheet as per Figure 1, modified to include additional feed gas compression provided by a stand-alone feed gas compressor (and additional driver) on the feed gas inlet stream;
C. Integrated feed compression as per the improved process flowsheet in Figure 2.

In configurations A and B, the power recovered from the turbo-expanders is used for nitrogen cycle compression. In cases B and C, the feed gas is compressed to 75 bar prior to entry to the liquefaction heat exchanger.

Two upstream pressures are considered, 35 bar and 50 bar, and the performance figures for each of the three configurations with each of the two pressures are given below.

Other assumptions used in the comparison are as follows:

- The LNG product is sub-cooled such that 5 mol% is flashed on let down to storage pressure (1.05 bar) across a valve (the use of a liquid expander would allow for further power recovery and reduced subcooling requirement and/or less flash gas production).
- There is a 1% loss in turbo-expander power transmitted to expander brake compressor
- Refrigeration cycle compressor polytropic efficiency taken as 85%
- Warm and cold expander-brake compressor polytropic efficiencies taken as 82%
- Warm and cold liquefaction cycle expander isentropic efficiencies taken as 82%
- Compressor interstage/after-cooler outlet streams cooled to 40°C
- The nitrogen refrigerant is compressed to 60 bar
- A minimum temperature approach of 3 °C is used in the liquefaction heat exchangers
- Specific power calculated by dividing the sum of the cycle and feed gas compressor duties by the LNG production rate.
- Annual facility uptime assumed to be 95%

For all cases, the gas composition at the inlet to the liquefaction process is given in Table A.

**Table A: Gas Composition at Liquefaction Process Inlet**

| Component | Mol % |
|---|---|
| Nitrogen | 0.25 |
| Methane | 94.78 |
| Ethane | 2.42 |
| Propane | 1.51 |
| Butane | 0.98 |
| Pentane | 0.06 |
| Benzene | 0.00 |
| C6+ | 0.00 |

## Results and Discussion

Tables B and C, show the relative efficiency of each configuration for each of the two simulation pressures, for a nominal 1 mtpa liquefaction train.

**Table B: Simulation Results with Liquefaction Inlet Pressure of 35 bar, nominal 1 mtpa**

| | Units | Config. A | Config. B | Config. C |
|---|---|---|---|---|
| Cycle Compressor Duty | MW | 58.1 | 49.8 | 55.1 |
| Feed Gas Compressor Duty | MW | N/A | 5.2 | N/A |
| Total Power Input | MW | 58.1 | 55.0 | 55.1 |
| LNG Production | mtpa | 1.0 | 1.0 | 1.0 |
| Specific Power | kWh/kg | 0.484 | 0.457 | 0.459 |
| % of Config A Specific Power | | 100 | 94.8 | 94.6 |
| Warm Expander Power | MW | 30.8 | 29.9 | 29.9 |
| Cold Expander Power | MW | 7.1 (boosting $N_2$) | 7.1 (boosting $N_2$) | 7.1 (boosting feed) |

**Table C: Simulation Results with Liquefaction Inlet Pressure of 50 bar, nominal 1 mtpa**

| | Units | Config. A | Config. B | Config. C |
|---|---|---|---|---|
| Cycle Compressor Duty | MW | 54.5 | 49.7 | 52.3 |
| Feed Gas Compressor Duty | MW | N/A | 2.6 | N/A |
| Total Power Input | MW | 54.5 | 52.3 | 52.3 |
| LNG Production | mtpa | 1.0 | 1.0 | 1.0 |
| Specific Power | kWh/kg | 0.454 | 0.435 | 0.435 |
| % of Config A Specific Power | | 100 | 95.8 | 95.8 |
| Warm Expander Power | MW | 31.1 | 29.9 | 29.9 |
| Cold Expander Power | MW | 7.1 (boosting $N_2$) | 7.1 (boosting $N_2$) | 7.1 (boosting feed) |

These figures demonstrate a decrease in specific power of 4 to 5% when the feed gas pressure is boosted. The lower the upstream feed gas pressure, the greater the benefit that can be derived. Configuration C, the improved process flowsheet, gives the equivalent performance to Configuration B, but without the increase in equipment count, complexity, weight and footprint that would result from the installation of an additional compressor/driver.

Applying the specific power figures calculated from the 50 bar case and applying these to a typical train size with a compressor driver of 45 MW gives the results shown in Table D.

**Table D: LNG Production for a 45 MW Cycle**

| Cycle Compressor Power: 45 MW | | | | |
|---|---|---|---|---|
| | Units | Config 1 | Config 2 | Config 3 |
| Specific Power | kWh/kg | 0.454 | 0.435 | 0.435 |
| Specific Power | MW/mtpa | 54.5 | 52.3 | 52.3 |
| LNG Production | mtpa | 0.825 | 0.861 | 0.861 |
| Increase in production | mtpa | - | 0.036 | 0.036 |

The results in Table D show that an extra 36,000 tonnes of LNG could be produced annually for a 45 MW refrigeration train if the feed pressure was boosted from 50 bar to 75 bar. For a two-train facility this equates to approximately an extra LNG cargo per year, with a value of approximately US$17 million, based on US$10 per mmbtu. For the 35 bar case, the additional LNG production would be higher still.

## Conclusions

It is shown that feed gas pressure to a dual nitrogen expander liquefaction process can be boosted using power from a nitrogen expander, with all power input via the main cycle compressor, improving efficiency and increasing LNG production. This is of particular interest where liquefaction plant feed pressure is limited by the requirement to extract heavier hydrocarbons. The performance increase is achieved without compromising the advantages of the nitrogen expander liquefaction process. In particular, the use of a nitrogen expander to drive a feed gas compressor allows the inherent simplicity, low equipment count, weight and footprint to be maintained.


## Acknowledgments

The authors would like to thank Adrian Finn and Terry Tomlinson for their assistance in preparing this paper.


## References


[1] G. Johnson and T. Eastwood, UK Patent 2479940; Process and Apparatus for the Liquefaction of Natural Gas, 2 November 2011.

[2] D. Chretien, *Total's Approach to Selecting the Liquefaction Process for F-LNG*, GPA Europe Annual Conference, Prague, 21 - 23 September 2011.

[3] T. Haylock, *Shipshape*, The Chemical Engineer Issue 861, March 2013.

[4] A. J. Finn, *Floating LNG Plants - Scale-up of Familiar Technology*, GPA 88th Annual Convention, San Antonio, March 9-11 2009.