HOW TO DEVELOP AN ECONOMICAL SMALL CAPACITY FLOATING LNG 
TAKING ADVANTAGE OF A DESIGN FOR A LARGER CAPACITY UNIT

Eric Jeanneau  
TOTAL E&P FLNG Development Manager

Denis Chretien  
TOTAL E&P LNG Process Development Manager

Vincent Fuchs  
TECHNIP Lead Process Engineer

ABSTRACT

Gas from remote offshore fields may be difficult to monetize when technical difficulties or high costs prevent 
the installation of a pipeline to shore. Offshore liquefaction on a floating unit may then be a viable alternative 
even for a relatively small gas field.

In the past years, Total has developed studies up to pre-project level definition for a floating LNG using an 
inert gas liquefaction process. Those studies resulted in a safe, simple and economical generic FLNG design 
for a capacity of 2.8 Mtpa of LNG.

Using this solid basis, a second study program has led to a design for an FLNG of smaller capacity around 1 
Mtpa.

This paper will present the design drivers of the generic FLNG of 2.8 Mtpa capacity and the methodology 
used to develop a conceptual dossier for a smaller FLNG capacity of circa 1 Mtpa. This paper will also 
highlight how the FLNG has been specified.

This paper will demonstrate how well balanced options can be effectively selected to design an economical 
small FLNG and that the economic optimum can be achieved through consistency of the topsides and the 
hull size without compromising on safety, availability or operability.

For example, the hull capacity plan was defined following a screening of the available LNG Carriers and a 
decision was taken to proceed with a capacity of 75,000 m3, which allowed minimizing the hull length.

Likewise, in order to reduce the topsides length, Electrical & Instrumentation buildings associated with the 
Topsides were installed within the hull space.

INTRODUCTION

It is a general consideration in the industry that the effect of scale increases the profitability of projects: the 
larger the project, the cheaper each produced ton of LNG. However, for very small fields, this methodology 
does not apply because the reserves are not sufficient to justify large LNG plants. This concern is particularly 
relevant when considering offshore liquefaction plants which are expensive projects.

There is then a field of investigation to reduce the investment cost of these units for small size. Total, in 
collaboration with Technip, launched a study for a liquefaction capacity of circa 1 Mtpa. The capacity was left 
relatively open in the beginning of the study in order to keep the door open to later optimization, mainly 
depending on the maximum size achievable for each piece of equipment.

The aim of this study was hence to explore the means of simplification in order to reduce the investment as 
much as possible.
This study relied on the results from previous studies performed by Total for larger sizes up to 3.5 M tcpa. In particular, the following items are kept unchanged:

- The liquefaction process is based on the use of a nitrogen cycle with CO2 pre-cooling for safety and operability reasons (see Total’s approach to selecting the liquefaction process for F-LNG, D. Chretien, GPA Europe, Prague 2011). However, even if the use of inert refrigerants is not put into question, the simplification of the process which consists of discarding the CO2 pre-cooling has been considered.
- The use of membranes as a containment system is confirmed.
- Flexible hoses are used for the transfer of the LNG from the FLNG plant to the LNG carrier.

This study is a generic one and does not apply to a specific field. Total consequently considered favorable options for the design in order to evaluate the economics.

The CO2 content in the gas is 1 % mole and no sulfur component is considered in the gas. The LPG’s are not extracted but left in the LNG. These aspects are developed below.

Other design considerations were challenged in order to reduce the cost of a smaller FLNG mainly on the storage capacity plan, the topside arrangement associated with the module fabrication and the mooring configuration, without compromise on safety criteria.

Then a conclusion on the main application of such small FLNGs to be economical is proposed.

**BASIS OF DESIGN**

**Feed gas composition:**

<table>
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<tr>
<th>Component</th>
<th>Mol Fraction</th>
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<tr>
<td>N2</td>
<td>0.00305</td>
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<tr>
<td>CO2</td>
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</tr>
<tr>
<td>H2S</td>
<td>0.00002</td>
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<td>0.00095</td>
</tr>
<tr>
<td>C6+</td>
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</tbody>
</table>

**Location**

The F-LNG is located in the Gulf of Guinea and the sea water temperature is 17 °C when pumped from deep. The air design temperature is 30 °C.

**LNG**

The LPG's are not extracted and the HHV is determined by the gas composition. The C5+ content is below 0.1 mole %. The nitrogen content shall not exceed 1 mole %, which is easily achieved from the initial content.
Availability
The availability of the plant is anticipated at 90%.

OVERALL F-LNG DESCRIPTION

The FLNG project consists of an offshore floating facility able to treat and liquefy feed gas from subsea wells, and store and offload LNG onto LNG carriers.

The gas from subsea wells is sent via the turret to the inlet facilities where hydrocarbon condensate and condensed water are separated from the gas and stabilised. Stabilised condensates are stored in a dedicated condensate tank located in the hull.

The gas is further treated in the Acid Gas Removal unit to remove CO2 to an acceptable level for liquefaction (50 ppm). The Acid Gas removal unit consists of an amine type regenerated solvent.

The purpose of the dehydration unit is to lower the water content from the water-saturated feed gas to an acceptable level for cryogenic liquefaction. Mercury guard beds are also provided to ensure no mercury breakthrough to the downstream cryogenic units.

Then, heavy hydrocarbons are removed from the sweet gas in the NGL extraction unit on the use of a turbo-expander. The extracted NGL is combined with condensates from the stabilisation unit.

Finally the treated gas liquefaction is performed by two parallel single pressure nitrogen refrigeration cycles. Refrigeration cycle compressors are electrically driven. Produced LNG is routed to the LNG storage tanks in the hull. LNG is offloaded with the dedicated LNG offloading system ‘ALLS’ (designed and supplied by Technip).

In addition to the process units, utilities are provided either on the topsides or inside the hull to support the LNG production. It consists mainly of power generation, cooling medium through sea water / fresh cooling water loops, heating medium through hot water generation, nitrogen and air production, water systems and flares.

Other utilities dedicated to hull and living quarters are also provided.

PROCESS DESIGN

Plant capacity

The target capacity was circa 1 Mtpa, depending on the actual capacity of the different components of the liquefaction plant. By the end, the finally considered FOB capacity is 1.2 Mtpa (see below).

Feed gas composition: impact of contaminants

Any LNG plant is largely impacted by the contaminants contained in the gas. In particular, CO2 and H2S have an impact on the pretreatment and the LPG production on the cryogenic units and the storage and offloading facilities. In order to evaluate the economics of the small scale LNG plant the assumptions below on the gas composition have been considered for simplification of the process scheme in this case study.

The normal way to manage the native CO2 in Total’s standard is re-injection in order to prevent large CO2 venting to the atmosphere. Chart 1 shows the released amount of CO2 versus the percentage of contained CO2 in the gas.
However, for very small content of CO2 in the feed gas (less than one percent), its injection may not be considered on a case by case basis. In this current study, in order to avoid CO2 reinjection facilities onboard the FLNG, a CO2 content of 1% mol in the feed gas has been assumed in view of designing a plant to be as simple as possible.

No H2S is considered in the gas (less than 10 ppm).

For LPG’s, the main issue is related to the safety associated to the handling and storage of the propane and butane on an offshore production plant. In this study, the injection of the LPG’s in the LNG remains compatible with the most common HHV specifications of the markets. This injection allows a significant simplification of the facilities with the associated cost reduction and improved safety.

Consequently, a lean gas with a CO2 content limited to 1% and no H2S and no LPG production has been considered to confirm the viability of such small scale offshore LNG production units.

**Liquefaction process**

a) Introduction and process selection

For the 2.8 Mtpa FLNG Total has selected and developed during a generic PreFEED study a liquefaction scheme based on the N2 expansion cycle pre-cooled with CO2. This process is based on inert gases and has been considered by Total as the best option for a Floating LNG plant, mainly for safety and operational reasons. Total accepts the efficiency of this liquefaction cycle to be slightly lower than that of a mixed refrigerant.

However, the relevance of using a relatively complex cycle for such a small size is questionable. In particular, the CO2 pre-cooled nitrogen cycle requires two different compressors: the CO2 compressor and the nitrogen compressor. Consequently, since two compressors are necessary, it may be more efficient from an operational point of view to design the process in such a way that there are two identical nitrogen compressors.

The preliminary Total studies have showed that one train of liquefaction based on a N2 cycle and the use of Plate Fin Heat Exchanger (PFHE) would be able to produce up to 0.9 to 1 Mtpa of LNG, the bottleneck being the cold box size.

Consequently, 1 Mtpa of LNG would always require two main rotating machines: either one CO2 compressor and one nitrogen compressor or two 50 % nitrogen compressors. The advantage of having two identical
machines obviously lies in increased reliability. In case of shut-down of one nitrogen compressor, the plant remains on-stream saving time on restarts.

Similarly, 1 Mtpa would boost the size of the cold box to the upper feasible size.

It was finally decided to increase the capacity of the plant to 1.2 Mtpa with 2 trains in parallel, each provided with one cold box and one N2 cycle compressor. The size and weight of the different components of the refrigeration cycle permit a complete train in one module.

For the cryogenic heat exchanger, the PFHE technology has been selected for this liquefaction process. For nitrogen process PFHEs have been used in small scale liquefaction plants onshore or for Boil off re-liquefaction onboard LNG carriers for several years. In addition this technology is widely used in large scale LNG plants with hydrocarbon cycles (propane and ethylene).

For this FLNG, each train is fitted with its own cold box composed of 6 PFHE cores in parallel for the liquefaction section and 1 core for the subcooling section.

However spiral wound heat exchanger can also be considered.

**b) Liquefaction process description**

The liquefaction process scheme is shown in Figure 1 for one train. It consists of a nitrogen refrigeration loop with two expanders with the same discharge pressure but at different temperatures for energy optimization reasons. These expanders are driven by high pressure compressors fitted on the same shaft, commonly known as turbo-expanders (or companders by some manufacturers).

The liquefaction expander produces a cold stream at -94°C, while the temperature at subcooling expander outlet is -156°C. Each expander inlet stream is precooled by the part of the cold energy not used to liquefy and sub-cool the feed gas.

The nitrogen stream at low pressure, after heat transfer with the warm streams (nitrogen and feed gas), is compressed in the main refrigerant compressor, and sent to compressor suction of the turbo expanders.

This liquefaction cycle is based on the reverse Brayton cycle.

![Figure 1: simplified process flow sheet](image-url)
The refrigerant used in the cycle is high purity nitrogen (~99.9% mol), which can be relatively easily produced and stored onboard a FLNG. The main advantages of such refrigerant are:

- N2 is a gaseous refrigerant
- No hazardous liquid storage
- No impact of motion
- Referenced offshore liquefaction (Onboard LNG carrier)
- Onboard N2 production easy to handle with Pressure Swing Adsorption (PSA) or membrane or cryogenics
- The N2 production unit can be common to that required for the other services on board such as inerting, flare sweeping etc so that no additional unit is required.

**Efficiency / complexity**

The specific power of the N2 recycle process is around 360 kWh/t of LNG while with the CO2 precooling option its specific power reduces to around 320 kWh/t of LNG. This power difference of 40 kWh/t of LNG does correspond to a loss of 2 millions $/year in the OPEX (considering a fuel gas price of 5 $/MMBTU), which is considered as acceptable regarding the CAPEX savings.

No end flash gas cold recovery system has been considered for this case study as the plant capacity of 1Mtpa has been reached with the selected refrigeration cycle. This simplification in the process allows space and weight saving.

**Driver selection**

In previous FLNG studies, Total has concluded that the electrical drive configuration for the main refrigerant compressor has more advantages for FLNG application over the gas turbine direct drive option. This has consequently been applied to this case study, and based on the overall power balance, it is possible to install 4 gas turbines in the power plant to match the required N+1 configuration for such unit with referenced gas turbines.

The direct drive option would have led to 2 gas turbines for the drive of the nitrogen compressors and 2+1 GTG’s for the power plant. Hence, the electrical drive configuration allows the saving of one gas turbine compared to the direct drive.

**OTHER PROCESS SIMPLIFICATIONS**

As already indicated, the aim of this small scale FLNG case study is to be as economical as possible despite the absence of scale effect. For this purpose, not only the process but the utilities as well have been optimized.

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**Inlet facility**

For inlet facilities, multi stage separators have been selected instead of a stabilization column; this process has a very high availability for a low overall weight and is the preferred option when applicable.

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**NGL recovery**

No LPG production takes place in this study in order to simplify the plant as far as possible. The NGL recovery unit is then only dedicated to the removal of the BTX and heavies which are subject to freezing in the course of liquefaction. In addition, since the refrigerant is pure nitrogen, there is no need for hydrocarbon
make-up for the refrigeration cycle. The NGL recovery unit is simplified and there are no C2 – C3 storage tanks with associated lay-out and hazards.

The light condensates extracted in the NGL recovery unit are returned to the inlet facilities and mixed with the upstream condensates.

— Power generation

The power generation consists of 4 referenced gas turbines. As already underlined, the electrically driving option allows the saving of one gas turbine while providing additional reliability because the spared gas turbine covers both the power production and the compressor driver.

— Utilities

- Heating medium: the small CO2 content in the feed gas and the absence of complex NGL recovery and fractionation units contribute to the reduction of the heating duty. In this specific case, it becomes so small that the use of steam is no longer necessary, and pressurized hot water is sufficient to cover the needs. No boiler feed water or condensate treatment is hence necessary leading to additional simplification of the plant. Note the use of flammable hot oil is discarded for safety reasons in Total’s generic design.

- N2 production: the nitrogen production for the cycle make-up is common to that for purging and the inerting. The nitrogen is liquefied in the cold box at the same time as the LNG and stored in dedicated cryogenic tanks. No specific liquefaction unit is hence required. The initial start-up needs may be covered by temporary supply from the shore.

CONSTRUCTION / HULL DESIGN ASPECT

This section will demonstrate how well balanced options can be effectively selected to design an economical small FLNG and that the economic optimum can be achieved through consistency of the topsides and the hull size without compromising on safety, availability or operability.

- Hull capacity

The hull capacity plan was defined following a screening of the available LNG Carriers and a decision was taken to proceed with a capacity of 75,000 m³, which allowed the hull length to be minimised.

However in order to keep the same operability criteria as the 2.8Mtpa FLNG case, the storage capacity plan considers a spare storage tank for inspection / repair if needed.

The working level within the storage tanks remains between 5 to 90%

- Offloading systems

A tandem offloading configuration was selected for the ship-to-ship transfer of LNG.

One of the advantages of the tandem configuration is that it uses flexible hoses instead of loading arms. The vertical and horizontal amplitudes of motion between the FLNG and the LNG carriers, as well as the acceptable accelerations, are larger with flexible hoses than with loading arms. This improves the availability of the offloading system.

The main incentive for the selection of tandem offloading is safety. The distance between the LNG carrier and the FLNG is always about 70 to 100 m for the tandem configuration, reducing the collision risks accordingly.
Such LNG tandem offloading systems can be configured with aerial flexible or floating hoses, while for the condensate offloading system, the tandem configuration with floating hoses was selected.

The naval operations in tandem mode are simplified in the approach, berthing and residence phases as is commonly performed with oil in the North Sea up to 3.5m Hsmax.

- **Topside Modules design**

In order to reduce the fabrication cost by maintaining competition between the construction yards, the size of modules was limited to 2500 tons for single lift module and up to 3500 tons for modules in two lifts such as liquefaction modules. In addition, such limitation may offer more opportunity to build those modules locally considering the local content regulation.

- **Mooring type**

The mooring selection depends mainly on the site ocean conditions; if possible the spread moored configuration shall be preferred as it offers the most economical solution.

However in most sites the turret configuration is necessary due to weathervaning requirements. The choice will then be between an internal or external turret.

Based on previous studies, the recommendation was to keep the internal turret located at the bow, downwind of the living quarters and the lay down area. It makes hull orientation easier than a turret located closer to the centre of the vessel (and minimizes the tracking forces on the anchoring chains).

- **Topsides arrangement**

The cost reduction challenge was mainly to get the best compromise between the hull capacity plan and the topside surface requirement. In order not to have free space and in order to reduce the topsides length, Electrical & Instrumentation buildings associated to the Topsides were installed within the hull space. The power generation modules were considered with Cantilever option.

The power generation, with hot exhaust, is located between the turret and the process facilities.

The flare and vents are located at the stern, down-wind of all process facilities, near the LNG offloading system.

The AGRU is located at the stern, far from the living quarters. The liquefaction units are then located in between.

The living quarter was kept at the bow of the FLNG up-wind of all facilities to keep operators at the safer location.
CONCLUSION

Based on its experience in building and operating FPSOs, Total has decided upon some options in the design of the FLNG whatever the production capacity between 1.2Mtpa to 3.7Mtpa:

Despite lower efficiency, the liquefaction process based on the use of inert gas is preferred primarily for safety and operational reasons related to a significant reduction of the LPG liquid inventory in the liquefaction units and in storage.

The design of the lay-out aims to move away the living quarters from the process facilities and any potential source of ignition. In the same way, the power generation is separated from the process facilities to avoid potential hazards due to the hot exhausts and ignition points.

The advantage of tandem offloading systems is not only that it allows the transfer of LNG in rougher seas, but most importantly that the distance between the LNG carrier and the FLNG is much larger, reducing the risk of collision.

The Total preference for the electrical motors over directly driven gas turbines is because the electric drive system is intrinsically safer since the gas turbine, which are potential sources of ignition, are not located in the process area subject to leaks, but in a separate and dedicated area. Also the electric drive system allows the restart of compressors at settle-out pressure.

Total considers that these options in the design of an FLNG facility are in favor of an increased safety for the asset and the operators, based on its experience of floating and producing facilities.

The main applications for which such small FLNG can be considered economical are as follows:

- Offshore stranded gas field with low CO2 content and high CGR
- Associated gas from offshore oil field
- Near shore location to liquefy country excess gas or shale gas

And of course such small FLNG economical interest depends of the market gas price evolution.