

Floating LNG (FLNG) technical challenges and future trends

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1 Introduction

Natural gas (NG) and liquefied NG (LNG), which is one trade type of NG, have attracted great attention because their use may alleviate rising concerns about environmental pollution produced by other fossil fuels as coal and oil.

In the figure below, the typical components of NG are reported giving also the idea of their relative amount:

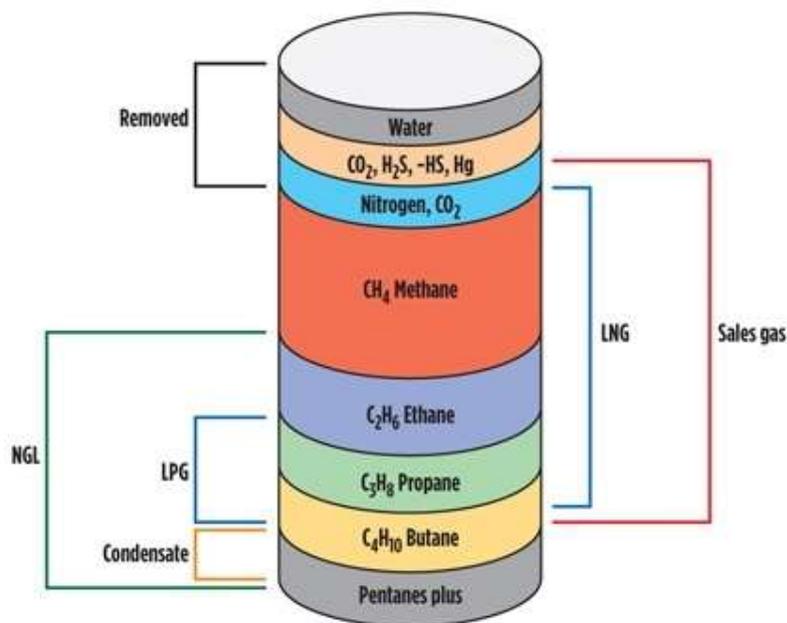


Figure 1: Natural gas composition¹

There are two main distinctions in between the final products obtained from gas processing: *Pure natural gas liquids*, meaning that at least 90% of the liquid contains ONE type of primary molecule, as:

- Ethane
- Propane
- Normal Butane
- Isobutane

¹ <https://www.saubhaya.com/chemical-makeup-of-natural-gas/>

Mixed natural gas liquids, meaning that the liquid contains at least two different types of primary molecules, are:

- Ethane/Propane (EP) Mix
- Natural Gasoline

NG reserves may locate in embedded underground areas and a significant portion of the reserve is often located off-shore. The off-shore extraction of NG and its conversion in liquified NG has reached a turning point in terms of economic feasibility; in fact, just few years ago, that extraction type was thought to be:

- Environmentally unsafe, due to the lack in LNG off-shore previous practice
- Particularly expensive, due to the installation of long subsea NG pipelines

As a result, there are many efforts to excavate and monetize these stranded and offshore reserves with floating facilities where offshore liquefaction of NG is possible. Therefore, the development of floating LNG (FLNG) technology is becoming important.

Natural gas off-shore facilities as FLNG represent a very complex condensate of chemical plant technologies, designed to be installed in limited space conditions on dynamic moving vessels.

Space limitation of floating vessels is indeed a challengeable problem to overcome. Due to this reason, the amount of feed gas that can be reserved for floating liquefaction is restricted. Units for gas pretreatment operation are supposed to occupy about 50% of the available deck space of a floating production facility, although this relies on the impurity level in the feed gas stream. This indicates that FLNG is more suited to feed gas streams including low levels of inert gases and impurities. CO₂, hydrogen sulfide, nitrogen, mercury, and acid gases are the main impurities determining the amount of feed gas.

The optimized cascade process (OCP) is a simple and reliable technology; this facility is made by a gas *pretreatment section* and a gas *liquefaction section*.

Pretreatment mainly aims to remove acid gases such as H_2S and CO_2 and usually MDEA or SULFINOL gas sweetening units are utilized for this scope.

Hg , as mercury vapor, represents another harmful component of NG and needs to be removed from the gas stream. In order to achieve Hg removal, a special unit is inserted in the gas pretreatment section; this unit can be of two different types: *regenerative* or *non-regenerative*.

A *non-regenerative* solution provided by Honeywell UOP is based on *copper-based* adsorbent material called “copper-based Mercury Removal Unit (MRU)” while the *regenerative* system is named “molecular sieve based UOP HgSIV™ adsorbents”².

In the NG cooling (*liquefaction*) section, three pure-component refrigerants (namely propane, ethane and methane) are used at different pressures during the refrigeration and liquefaction processes. The last cooling stage operates with methane to cool down the NG stream to less than $-161\text{ }^\circ\text{C}$ in order to finalize the condensation and subcooling of the NG methane. It gets methane refrigerant from the LNG vapor generated in the ships during the loading phase and after compression is partially used as fuel to power the gas turbines.

Centrifugal compressors are used for the circulation of these refrigerants, and cooled within a series of brazed aluminum vertical cold boxes. The power is supplied through gas turbines.

In the figure below, the complete cooling curve for NG and the evaporations curves of the three refrigerants in the 3 stages, is represented in a T-Q diagram:

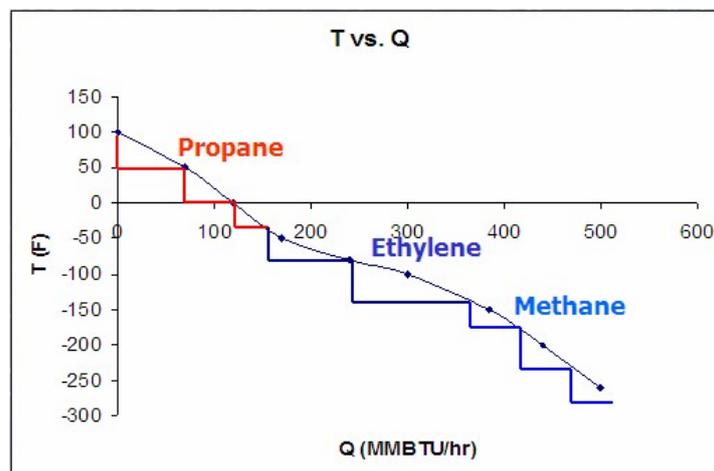


Figure 3: Example of T-Q diagram of NG cooling process

² <https://www.uop.com/mercury-removal-options-hydrocarbon-processing-facilities/>

The required work to carry out the Liquefaction process is proportional to the area between the curves. In this a multistage configuration, the segmented curve reduces its distance from the NG T-Q curve thus saving energy consumption.

The figure³ below reports the composition of a NG stream exiting a NG well and the classification of its components into the commercial mixture names (i.e. NG, NGL, LPG, LNG):

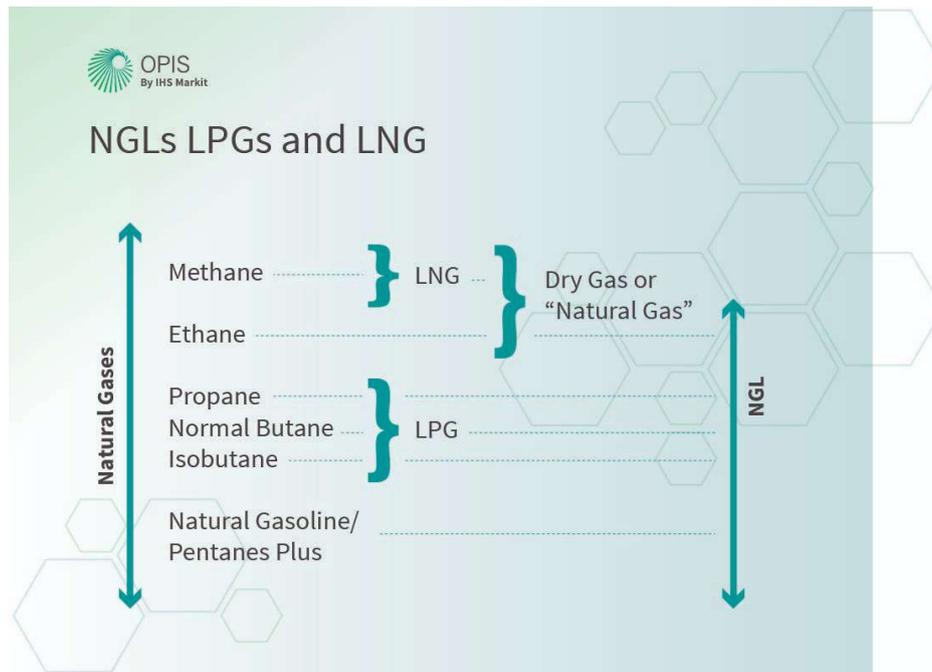


Figure 4: Acronyms' definitions of NG products

Natural Gasses (NG) is a group of hydrocarbons including *ethane, propane, normal butane, isobutane* and *pentanes plus* (AKA *natural gasoline*⁴). They are a byproduct of natural gas processing and refining.

NGLs are removed in the *second* cooling stage from NG as a combined stream, often called raw make or y-grade. This combined stream is then fractionated (separated) to produce products such as ethane, liquefied petroleum gases (propane and butanes) and natural gasoline. They are derived from a vaporous stream, while natural gas liquids are kept in a liquid state for storage, shipping and consumption.

³ <http://blog.opisnet.com/ngl-or-lpg-or-lng>

⁴ Natural gasoline is a natural gas liquid with a vapor pressure intermediate between natural gas condensate (drip gas) and liquefied petroleum gas and has a boiling point within the range of gasoline. The typical gravity of natural gasoline is around 80 API. This hydrocarbon mixture is liquid at ambient pressure and temperature. It is volatile and unstable, but can be blended with other hydrocarbons to produce commercial gasoline.

This facility represents a state of art technology in producing LNG to be sold and shipped. The facility is supposed to be coupled either with a *regasification* plant in which the methane is vaporized back to gas phase and further used or to be used directly as liquid fuel (ex. In transportation field)

2.2 FLNG technology

FLNG aims to reproduce the LNG process, described in the previous paragraph, in a floating vessel on top of the off-shore extraction well. The core of LNG FPSO is to optimize modular design for liquefaction process equipment. Modular design optimization makes installation and commissioning of the corresponding equipment more manageable.

There are two different applications of floating LNG (FLNG): floating, production, storage and offloading units (LNG FPSO); and floating, storage and regasification units (FSRU). FLNG facilities are a relatively new concept, with very few in operation today, but it is realizing its potential, with different technology solutions for different developments. FSRU concepts have been deployed regularly and successfully around the world over the last 10 years; advantages can include speed and affordability/scalability when local demand is small or new, and development of an onshore terminal is challenging⁵.

There are several notable prerequisites to install offshore an LNG terminal. The most important is to *build an appropriate platform* that is large enough to accommodate the relevant topsides. The following picture represents a large scale FLNG vessel⁶ for *nearshore* extraction:



Figure 5: Prelude FLNG facility by shell, Australia

⁵ IGU World LNG report - 2019 Edition

⁶ Prelude FLNG | Shell Australia

FLNG vessels fall into two principal categories that are almost self-explanatory:

- ***Inshore / nearshore***
- ***Offshore / open ocean***

The ***offshore / open*** ocean category requires more attention in the realization of the ***offloading*** system due to the possibility to deal with very tough marine condition. ‘*Hard arms*’ are the only currently proven system and are limited to a significant wave height of approximately 2.5 m which restricts the applications to relatively benign offshore locations. Operation in harsher environments will only be feasible through *tandem loading* system⁷.

Fuel ***gas consumption*** is typically 10-12% of the feed gas depending on the liquefaction process used. It should be noted that fuel consumption will be higher than in onshore plants due to the need to power the marine systems. This consumption figure is often referred to as ‘shrinkage’, being the difference between the feed gas and LNG produced. The main user will be the gas compressor drivers i.e. gas turbines or steam boilers for steam turbine drivers.

To install an LNG terminal, the following parts should be constructed:

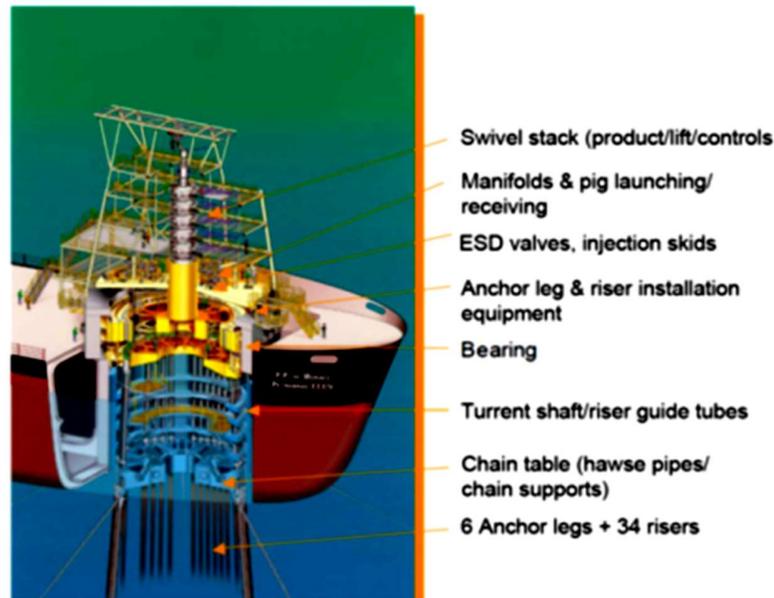
- ***floating production, storage and offloading (FPSO)*** vessel - it is the heart of the FLNG technology. FPSO is a ship-like vessel deployed to produce and store hydrocarbons from wells placed on the subsea wall or on an offshore platform. Unlike conventional oil-producing FPSOs, LNG FPSO vessels contain LNG liquefaction facilities onboard.

The vessels should also contain:

- Accommodation facilities
 - Power generations for process plant
 - Flare system
 - Cooling water systems
-
- ***Mooring system:*** The mooring system of a FLNG vessel has to be design to deal with a wide range of application in terms of water depth, sea roughness and to ensure the stability of the FLNG vessel itself. There are different configurations at the actual state of technology; a very common solution is represented by a *spread mooring* system. That system is constituted by a fixed number of mooring lines, arranged in a symmetrical pattern, that hold the vessel in a fixed position and direction. That represents also a limit for this technology, since this mooring system can only be used where the prevailing weather is directional
- For very rough sea conditions “*Turret Mooring System*” should be implemented in place of the *spread mooring configuration*. The turret system houses the vessel’s risers for production, export, gas lift and water injection, and the set of connection for the electrical

⁷ “Floating Liquefaction (FLNG): Potential for Wider Deployment” OIES paper, November 2016

and hydraulic control signal delivering. For the latter purpose, the main component of the turret mooring system is the swivel, an example of which is pictured below⁸:



3 Major FLNG projects

Shell Prelude

Royal Dutch Shell PLC completed building of PRELUDE, the hull of the world's largest floating facility that will operate offshore in western Australia. The hull of this vessel, 488 meters long, and it is designed to deal with a category 5 cyclone. The facility was commissioned in 2011, with the official investment decision by Shell. The capacity of the FLNG unit is about 3.6 Mtpa of LNG along with a production of 5.3 Mtpa of NGL. Those figures represent a fraction of the land-based plants, that can operate at 15.6 Mtpa as for Gorgon plant. At peak of construction phase around 5.000 people were working at the facility realization and more than 600 engineers were required to design it and coordinate the construction operations. Prelude cost was around 12 billion \$ and it is supposed to stay in operation for 20-25 years before needing of a turnaround for inspections.⁹

⁸ Current trends for the floating liquefied natural gas (FLNG) technologies, W. Won, S. Keun Lee, K. Choi, and Y. Kwon, Korean J. Chemical Engineering Journal, February 2014, 31(5), 732-743.

⁹ Source: <https://business.financialpost.com/commodities/energy/record-breaking-lng-ship-launched-bigger-one-planned>

Petronas's PFLNG-1

PFLNG-1 also called PFLGN SATU, was constructed at Daewoo's shipyard in Okpo, South Korea. The FLNG platform front end engineering design (FEED) was carried out by Technip, Daewoo Shipbuilding and Marine Engineering in joint venture.

PFLNG SATU design followed the Det Norske Veritas (DNV) class' directives; it is 365m-long and approximately 60m-wide, and weighs approximately 125,000t when fully-loaded.

The facility will operate 180 km offshore of Bintulu, in the second quarter of 2016. The LNG production target is fixed at 1.2 Mtpa.¹⁰

Murphy/ Petronas's PFLNG-2

Petronas has planned to exploit the deepwater Rotan Gas field, located in the South of China Sea, through the development of a second FLNG unit, called PFLGN-2.

The front end engineering design (FEED study) started in 2012 and was committed to a first consortium made by Modec CB&I and Toyo Engineering and a second consortium made by JGC and Samsung Heavy Industries. The final investment decision was made in February 2014 and Samsung Heavy Industries was selected for the Engineering, Procurement, Construction, Installation and Commissioning (EPCIC). This second Petronas unit will be 393-meter-long and is designed to produce 1.5 Mtpa of LNG. Fabrication activities in Korea were started in May 2015 and the hull was floated out from the Green Dock 3 to anchor at the quayside of the Samsung shipyard marking in May 2016 where integration work with the process facilities began.¹¹

4 Benefits and major technical challenges

Since 2006, when the FLNG sector started developing, the effort and focus on technical solutions for producing LNG on a floating platform has overcome multiple challenges . Currently, few technical issues remain and represent a significant degree of uncertainty.

It is possible to identify in five points the current key technical challenges as¹²:

- **Offloading:** although considered to be a marine rather than a topsides system, it is recognized consistently that for most projects that all of the “proven” options for offloading available currently have their weaknesses. As discussed in the previous paragraph “*side by side*” offloading is the most proven, but has severe limitations on wave height while “*tandem*” offloading can accept larger wave heights but is less proven and requires LNG carriers with dynamic positioning.

One example of innovation is represented by the robotic arms with their remote controller as reported in the figure below:

¹⁰ Source: <https://www.ship-technology.com/projects/petronas-floating-lng-facility-pflng-1/>

¹¹ Source: <https://www.offshore-technology.com/projects/pflng-2-rotan-flng-project-sabah/>

¹² <https://gastechinsights.com/article/the-top-5-technical-challenges-for-flng-projects>

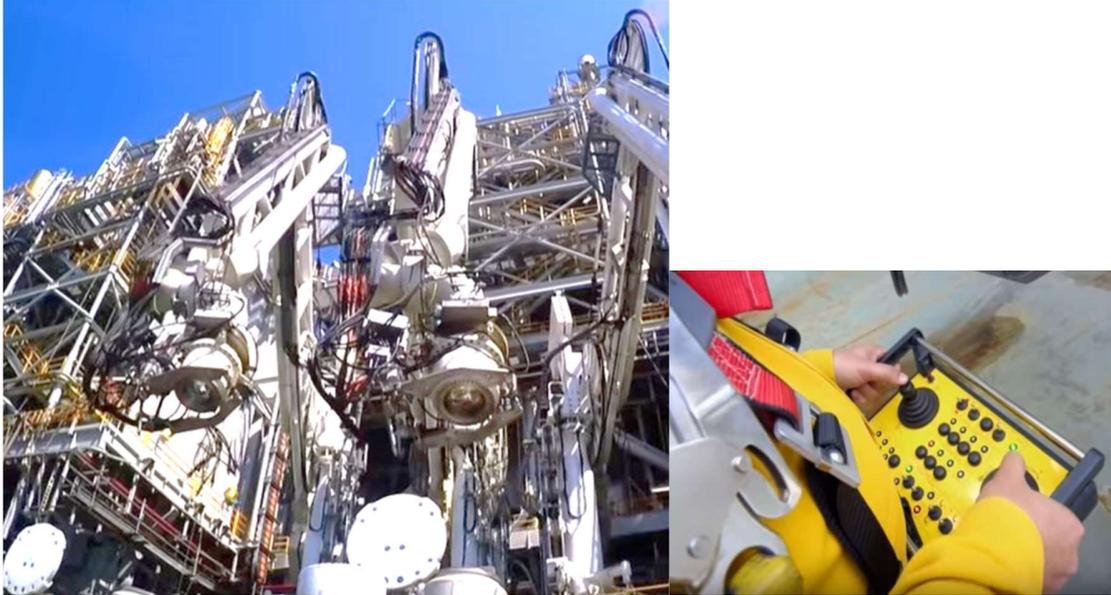


Figure 6: Robotic offloading arms in Satu FLNG facility

They belong to the Petronas FLNG Satu, located in Malaysia that has a production capacity of 1.2 Mtpa of LNG and works on Nitrogen cycle liquefaction process.

The Hull dimensions are 365 m x 60 m x 33 m with 21 modules on Topsides and one flare. 177,000 m³ of LNG and 20,000 m³ of condensate can be stored onboard.

100 MW are generated on board for the LNG operations and for 158 living quarters.

- **Technical Approach to FLNG:** the approach for designing an FLNG facility is a fundamental technical decision that is critical to any FLNG development. Many companies proposing FLNG topsides solutions are attempting to apply onshore solutions into a floating environment. This has to be accomplished carefully due to the very different dynamic conditions and diverse situations the FLNG facility is going to deal with. Among all the LNG process typologies only MR (mixed refrigerants) and N_2 (Nitrogen-based cooling cycle) can be implemented due to the space and marine limitations.
- **Capability for Modularization:** linked to the previous point regarding technical approach, the ability to modularize is a key issue. LNG plants onshore have historically been stick built so it is important to utilize partners who have experience in modularizing equipment and systems for floating production who also have LNG and FLNG experience. Modularizing equipment is not a simple task and is often underestimated by those who do not have the necessary ability or experience. Such underestimation can result in significant difficulties in project execution and compromised design.
- **Operability:** The danger is that operability is not given enough focus until lessons learned from FLNG facilities are available. Processing hydrocarbons on a floating platform requires precautions adoptions such as *fine structuring* tower packing, *more liquid*

redistributors, and *dividing column configurations*. With these methods, liquids in columns built in the FPSO can be uniformly distributed.

Also, LNG *containment* systems are important. They should prevent damage happening due to **sloshing** in filled tanks, which is attributed to irregular sea wave and current motions, while LNG transfers should withstand strong wind, waves, and currents in open seas. *IHI*'s containment system and *GTT*'s tank configurations¹³ system represent commercial options that use the process equipment units in order to reduce and withstand wave impacts expected from sloshing and to provide the flat deck required to accommodate the floating plant.

- **Safety:** Safety is a technical challenge that will always be present when producing hydrocarbons. The ability and challenges to meet the required safety and risk levels that production in a floating environment requires depends highly on a few fundamental decisions for an FLNG development. Foremost is the selection of liquefaction technology. By selecting a N_2 cooling-based technology not only the production availability and net present are value optimized, but the requirements for blast loading, blowdown volumes, steel reinforcement, hull size and operational complexity are reduced significantly while meeting required safety levels and giving lower CAPEX.

4.1 Technology Benefits

FLNG technology can result in various type of benefits and there are several arguments to support the development of such a technology; for instance, it allows to **diversify** the **supply sources and to relocate the unit** in different offshore gas fields, or blocks thanks to the absence of the pipeline connection to shore, that represents a strong limitation for traditional NG extraction facilities. The exploitation of **geographic remote areas**, as for example in Japan, South Korea and Chinese Taipei (JKT) is also a driving force factor in developing and building Floating facilities to supply natural gas in those scarce-resourced countries, that are becoming to rely on NG to substitute decreasing nuclear and coal-fired energy production.

NG is the lowest green-house-gases emitting resource among hydrocarbons, thus FLNG technology offers a realist to direct the existing energy industry towards low-carbon emission without the needs to modify the actual infrastructures and machineries (power-plants, internal combustion engines, fire-heaters, etc.).

FLNG systems are designed to be built assembling different modules on a single vessel, thus once the gas field to be operated has been identified, this technology will be able to **shorten the time** request **to build** the extraction facility. The modular design enables the parallel construction of the different modules and once the know-how of the single module design and construction is produced, that helps in scaling-up or down the facility capacity to adapt it to the specific gas field

¹³ Membrane tanks are non-self-supported cargo tanks surrounded by a complete double hull ship structure. The membrane containment tanks consist of a thin layer of metal (primary barrier), insulation, secondary membrane barrier, and further insulation in a sandwich construction.

application. Considering the Shell Prelude facility, it has needed only from 2012 to 2017 to go from FID to production phase.

5 Conclusion and Future trends

NG is likely to be the bridge between the end of the crude oil era and future energy solutions. The LNG industry, which is a dominant business model of NG trade, is paid attention due to the high price and confined reservation of the most conventional energy resource, crude oil, and the associated pollution issue of CO₂ emission.

According to KPMG Global Energy Institute¹⁴ there are up to 10 reasons why FLNG industry will develop in the next future, here below the 5 most important are reported:

- Opportunity to ***unlock smaller fields***
- Access to ***remote fields***
- Deliver projects ***cheaper*** and ***faster***: FLNG may offer reduced capital costs, particularly once shipyards have gained experience with construction and standardized solutions are employed. There could be substantial improvements in the process of integrating the hull and processing units. Modular components can be constructed at several locations. Onshore construction, marine works and the related high labor costs, in remote or hostile environments, can be minimized¹⁵.
- Avoid onshore “no-go zones¹⁶” thus mitigating ***political risk***: Onshore LNG plants represent a huge sunk investment, making the project developer vulnerable to a change of mind from the political authorities – which can include tax increases, nationalization or outright expropriation. In an extreme case, in which a host government seeks to expropriate an asset, or in which security conditions become intolerable, the FLNG plant can be sailed away, saving at least some of the project’s value, and perhaps redeployed elsewhere.

Shipbroker Clarksons estimates that by 2019, likely global FLNG capacity will be 44 million tonnes per year, about 7.5 percent of the industry’s total capacity.

FLNG technologies are making progress and, in few years, the FLNG industry will play a crucial role in the energy market, having incorporated in its scope the exploitation of a more *environmental-friendly* hydrocarbon energy source as *methane*.

¹⁴ Floating LNG: Revolution and evolution for the global industry?

¹⁵ For example, the dredging cost alone for the Wheatstone project in Western Australia – a 17 km approach channel and 26 million m³ of dredged material – is estimated at AUS \$1.5 billion.⁴ Savings on such infrastructure, and a simpler supply chain, can mean FLNG projects make it to market faster

¹⁶ Large gas fields have been found in the Eastern Mediterranean, but the surrounding coastlines are heavily built-up with tourism and real estate. Onshore plant locations may face lengthy legal and permitting delays and community objections.