OFFSHORE LNG – REVISITING THE CONCEPT

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Abstract

A new FLNG execution model is presented that brings large reductions in schedule and capital cost per ton of liquefaction capacity while de-risking project execution.

The first FLNG’s made use of multiple, crane-lifted modules borrowed from oil FPSO practice. The complexity and dimensions of FLNG topsides benefits greatly from functionally complete MegaModules™. A MegaModule™ replaces several conventional modules reducing pipework and structural steel.

The paper will describe:

- Process features such as air/water hybrid cooling that make each module self-standing,
- Optimization of layout and module steelwork, reducing bulk quantities,
- Instrumentation & electrical architectures with an eRoom in each module,
- Finalization of pre-commissioning and commissioning on the quay-side before installation on the hull to avoid the challenges of topsides integration at deck level so reducing the cost and schedule,
- Details of the MegaModule™ installation technique using commercially proven jacking and skidding,
- Fast and predictable project execution scheme,
- Overall schedule reduction and CapEx savings.

This new model of FLNG can be adapted to any capacity and can be optimized for any field in terms of feed gas and well fluid interfaces as well as location (open-sea, near-shore, at-shore). A single module can be used for small scale monetization of associated gas of 1 Mtpa or less. Four modules enable the NewWave™ concept of between 5 and 8 Mtpa from non-associated gas.

Finally, the MegaModule™ concept can also be applied for other offshore facilities such as fixed platforms or even to Onshore LNG plant.
Introduction

Floating LNG (FLNG) is now a 10-year-old industry from which TechnipFMC has emerged with several leading references, namely Petronas Satu FLNG, Shell Prelude FLNG and Coral South FLNG, and a proven ability to coordinate under a single engineering management structure all the disciplines that need to vigorously interact throughout a project from conceptual design phase to EPCIC completion.

These FLNG projects have called on skills, amongst others, in LNG process, HSE in design, naval architecture, offshore structural, piping & layout and subsea, backed by recent turnkey execution of projects in these three areas. The result has been a wide range of FLNG designs, effectively now referenced, in capacities ranging from 1.2 Mtpa to 5.3 Mtpa liquid equivalent.

In view of the expected increase in LNG demand in the coming decades and the potential for improving from these early open-sea FLNG projects, TechnipFMC has addressed our client's needs for a sharp improvement in FLNG project capital expenditure and time to market.

Within a multiyear FLNG development program, TechnipFMC has worked on improvements that are intended to be useable across the spectrum of medium, large and very large (above 5 Mtpa) scale new build FLNG facilities. The resultant solutions have benefited from the input of key licensors, vendors and yards. In the framework of this program, the first generation of FLNG concepts has been analyzed to identify improvements to the design, cost and schedule of next generation projects not only in absolute terms but also in terms of risk.

Figure 1 - First generation FLNG
The principle improvements can be listed as:

- Technical and design improvements with the introduction of new concepts, including new methods of construction,
- Simplification and design to cost engineering, resulting in several generic “lean” concepts
- Liquefaction process intensification,
- Execution strategies which optimize the fabrication of the hull and topsides.

For any given project TechnipFMC will in future engineer a customized solution to its clients’ needs, leveraging past project experience and introducing the new ideas described below to improve affordability.

This paper describes some of the major developments that TechnipFMC has conducted in the field of FLNG during these last years.
Process features

The three TechnipFMC open-sea FLNG references receive gas of very different qualities demonstrating that the pretreatment, separation and liquefaction of natural gas plus the storage and export of LNG, LPG and hydrocarbon condensate pose no particular problem using essentially proven technologies. However, with this experience behind us, opportunities were identified for FLNG specific processes that bring advantages in terms of cost and schedule, space, weight, efficiency, reliability or ease of maintenance.

As part of its development TechnipFMC therefore analyzed the full scope of FLNG facilities as previously designed, scrutinizing all process and utility units. Any improvement identified must meet Health, Safety and Environmental requirements and be suitable for a wide range of composions and conditions. A large envelope was defined so the solutions developed cover whatever is the feed composition and conditions.

Focusing on the process units, as an example, concentrations of inert components (CO\textsubscript{2}, N\textsubscript{2}) vary widely from one project to another but can be handled easily using conventional processes. Potential FLNG specific technologies are emerging such as compact and low weight amine-based acid gas removal processes and alternative non-amine CO\textsubscript{2} removal processes or compact dehydration.

In the area of NGL recovery, TechnipFMC initiated the trend towards the integration of turbo-expander based processes into LNG trains and specifically in FLNG. Indeed, all open-sea mid and large-scale capacity projects are based on this line-up. TechnipFMC licenses technology under the Cryomax\textsuperscript{TM} name.

In the field of liquefaction, the percentage of feed gas used as fuel (the auto-consumption rate) depends on efficiency that in LNG is primarily the product of liquefaction process thermodynamic efficiency and the thermal efficiency of the refrigerant compressor prime movers.

For reasons of efficiency, compactness, robustness, relatively low hydrocarbon inventory and as it has been addressed in joint development studies, TechnipFMC would offer DMR as the base case for FLNG. Obviously, depending on the plant capacity, the liquefaction process selection can be revisited to select the most suitable process, such as SMR for small and mid-scale LNG.

Through the extensive use of aero-derivative gas turbines, enhanced DMR liquefaction technology and access to low temperature cooling water for the condensation of the primary refrigerant, TechnipFMC considers that it can offer designs that are as efficient as any other LNG plant in the world.

One of the major improvements, following several studies, is to lean towards hybrid cooling consisting of a combination of Air Coolers and Water Coolers to cope with the liquefaction facilities heat rejection requirements.

Indeed, to reduce the integration between the topsides and the hull and allow flexibility to do commissioning by area, the primary cooling medium should ideally be air. However, as low temperature seawater is available on an FLNG, the exclusive use of air would significantly affect process efficiency compared to current practice, while FLNG revenues depend heavily on the primary refrigerant condensing temperature. As an example, the difference in production in a warm climate between air cooling and cooling with sea water taken typically at 150-200m can be in the range of 15-20% for a given power of refrigeration compressor).

Therefore with hybrid cooling, sea water is used directly for process coolers where temperature approach affects LNG production, primarily on the condensors of the warmest refrigerant cycle.

- Sea water pumps for cooling and for fire water are not located in the hull but outside the vessel.
- Each large module has dedicated sea water cooling pumps

The hybrid cooling concept eliminates all cooling water interconnections between areas and between the topsides and the hull and consequently there are no hull penetrations or pipe-runs on the main deck.

Moreover, the use of air for specifics users allows pre-commissioning and commissioning activities at the construction yard and not in site (as an example, the compressor aftercoolers are designed to allow for compressor operating on full recycling). A typical of such arrangement is shown on Figure 2, Liquefaction DMR using Hybrid Cooling configuration.)
Figure 2 - Liquefaction DMR with Hybrid Cooling (Air and Sea Water)
Optimization of layout and module steelwork, reducing bulk quantities

With the objective of reducing cost and schedule at the FLNG construction yards, TechnipFMC particularly focused on the approach to modularization. Consideration was given not only to plant design and construction improvements but also to the ease of module integration on deck, pre-commissioning and commissioning activities to improve on current FLNG design practice and feedback from projects.

With the target of reducing the cost associated with construction the main objectives are:

- To reduce the number of modules by maximizing the size and weight of each module.
  - The possibilities offered by maximizing size and weight have been thoroughly studied using the feedback from completed modularized LNG plants, both offshore and onshore and extensive exchanges with yards and specialist subcontractors able to fabricate, move and install large modules,
  - An alternative method for FLNG module installation has been developed and validated to overcome the constraints on module size imposed by the floating cranes used in projects to date.
- To decrease the interconnections between modules and between module and hull,
- To increase the self-dependence of each module to maximize the activities to be carried out in the module construction yard and not on the FLNG nor at final site location.

The four main advantages, among many others, are:

- The inherent reduction of bulk quantities, such as structural steel and piping thanks to module design and avoidance of interconnecting pipe-racks between the modules,
- To allow construction of modules in low cost yards - typically in China - while the hull can be built in any other yards, including Korean yards,
- The integration being minimal and most of commissioning being done at module level, the time necessary for the integration of the modules on the hull is significantly reduced,
- The decrease of the number of module lifts onto the hull.

The benefits of such approach in terms of layout and subsequent hull dimensions are overviewed on the Figure 3, which shows the effect of Mega-Modularization approach compared to the conventional one:

Each module is designed to be independent of the others as far as possible. This minimizes interfaces, and with technical buildings and safety related-systems in the module it eliminates cable pulling after installation on the hull.

The concept allows full pre-commissioning and partial commissioning of each MegaModule™ at grade on the quayside prior to installation. As a consequence, hook up and integration work post installation on the deck is reduced to a minimum obviously reducing cost and schedule of the project. Furthermore, any commissioning
activities that can be performed in the construction and integration yards save an incredible amount of time in project execution by comparison with offshore, once the FLNG is placed at its final location.

These are functional modules and depending on the FLNG targeted capacity, their number ranges from 2 to 4, including the utilities, pre-treatment, both being possibly combined and one or two modules for liquefaction. The following are typical examples of possible configurations:

- Medium size FLNG: one common module for pre-treatment and utilities (Warm Module) and one module for NGL recovery, Liquefaction, End-flash and Boil-off gas handling (Cold module),

- Large size FLNG: one module for pre-treatment, one module for utilities and two identical modules for cryogenic section.

Instrumentation & electrical architectures with an eRoom in each MegaModule™

As described in the previous section, one of the key benefits of the MegaModule™ concept is to be able to perform pre-commissioning and some commissioning activities at quay level in the module fabrication yard. For this purpose, each MegaModule™ is fitted with its own Local Electrical Rooms (LER’s) and Local Instrumentation Rooms (LIR’s). This means that cable pulling during integration is extremely limited.

Figure 6 illustrates a typical single line diagram for a medium size FLNG consisting of two MegaModules™. It shows at a high-level, how the integration of electrical works can be reduced with this philosophy leaving power connections only between:

- Warm Module and Hull
- Normal/Essential and Emergency power
  - Warm and Cold Modules
    - Direct supply of electrically driven compressors - Boil off gas compressor / Booster compressor
    - Normal and Emergency power

Figure 6 – MegaModule™ designed FLNG high level single line diagram

The electrical cables between the hull & LQ can be fully installed and pre-tested at the hull shipyard.

Regarding integration works for instrumentation, there will be a reduced amount of cable pulling from the local instrument rooms of each module to the control room located in the LQ.
Finalization of pre-commissioning and commissioning on the quay-side before installation on the hull to avoid the challenges of topsides integration at deck level so reducing the cost and schedule

In the offshore industry, in particular for FPSOs and FLNGs to date, the sequence followed has been module fabrication, partial pre-commissioning, installation, integration, final pre-commissioning and commissioning, the latter being started and performed system by system at the integration yard. The pre-com/com complete sequence is divided into three distinct and successive steps:

- On the quay (Onshore),
- On deck, at quayside (Nearshore at yard),
- Offshore (at final location).

The cost, duration and risks associated with a given commissioning activity increases substantially with each step, hence the interest of bringing activities forward wherever possible while allowing the integration of construction and commissioning.

Thanks to the newly developed FLNG design and execution strategy presented in this paper, precommissioning of many systems may be completed on the quay before module lift.

This early start improves the chances of completing all but the hydrocarbon feed introduction related commissioning at the integration yard with the objective of limiting offshore activities to a few exceptions.

TechnipFMC deployed a multidisciplinary team not only with Process, Engineering and Construction specialists for the modules definitions but also Commissioning and Operations experts to ensure that the functionality by system is also part of the fabrication strategy. As a consequence the modules are designed to include fully functional systems, cabling and E&I cabinets as described previously. This means that when a module's fabrication is sufficiently advanced - when the fabrication becomes systems oriented rather than geographical - the pre-commissioning and commissioning team can start efficient and complete activities. Not only cleaning and continuity checks can be performed but also loop checking and some dynamic commissioning (such as motor solo-runs, or even dynamic cleaning…) and finally construction equipment and materials for the offshore activities, including hook up works, are loaded and sea fastened onto the deck before departure from the integration yard.

As far as topsides are concerned and referring to the above-mentioned complete cycle, the general construction strategy, from 1st steel cut until facility Mechanical Completion, is strongly linked to the commissioning strategy that takes full advantage of the MegaModule™ concept

The construction strategy can be summarized as follows:

Maximize “Completion Level” before jacking up of modules onto the Hull.

The fabrication and assembly of the cold and warm MegaModules™ is completed, in principle, at ground level, allowing pre-commissioning activities to be performed to the maximum extent possible at the yard in question before module jack up. “Ready-for-lifting” criteria will define the degree of completion per discipline required to proceed with jack up. The application of such mandatory criteria can be seen as the last construction gate before integration.
Maximize Commissioning at ground level.

A significant benefit of MegaModule™ is to allow commissioning activities (energized dynamic tests) to be performed to a maximum possible extent at ground level before integration works. Maximum possible extent has to be understood as “100% minus the integrated systems”. Integrated systems refer to systems that require connections between the warm and cold MegaModules™, MegaModules™ and hull, MegaModules™ and LQ.

Minimize Integration/Pre-commissioning/Commissioning activities on the Hull.

This is a direct consequence of the previous two points. Activities on the Hull are known to be performed with a lower productivity due mainly to area congestion and logistics issues (lifting, material lifting from quay to hull, personnel transfer downtime etc.). Transferring activities from the hull to ground level is therefore a strategic point to control productivity and schedule.

Optimize SIMOPS Management (at ground and on the Hull)

Performing Commissioning activities before jacking up and integration implies SIMOPS conditions that must be closely monitored and managed in order to fully benefit the overall strategy: productivity loss due to improper SIMOPS management can overcome the benefits of early commissioning.

The previous key messages are illustrated through the following timeline, from start of fabrication until Ready For Sail Away (RFSA) and Ready For Start Up (RFSU) at offshore site.

![Figure 7 - Timeline from start of fabrication until RFSU](image-url)
Details of the MegaModule™ installation technique using commercially proven jacking and skidding

The installation of more than 20,000 tons in one piece at 25 meters height requires a new method, named the Skid Deck comprising the following main steps:

- Install the Skid Deck elements on the stools (Figure 9).
- Lift the MegaModule™ up to the hull deck level, using a proven elevating system such as climbing jacks or gantries equipped with strand jacks (Figure 9).

Figure 8 – MegaModule™ installation overview

Figure 9 - Skid Deck elements installed on board and lifting
- Move the MegaModule™ by using hydraulic skidding means and ensuring full control of the hull level by ballasting (Figure 10),
- Jack down the MegaModule™ onto the stools (Figure 10).

![Figure 10 - Move the MegaModule™ on board and jack down onto the stools](image)

- Retrieve the Skid Deck elements onshore.

For many years the topsides of offshore platforms have been loaded by skidding from the quay to a heavy transport vessel or a barge. In the present case, the challenge is in the combination of lifting and skidding such a heavy module at 25 meters height.

A major constraint is that the temporary skidding beams on board the vessel shall not reduce the space necessary for all the equipment and piping covering the hull deck. For this reason, the temporary skidding beams are supported on the top of the supporting stools and their height is minimized by adopting a U shape, allowing the skid shoe to move inside it with the module bottom as close as possible to the final level of supports.

Once the module is resting on the supports, there is no more access underneath to dismantle the installation equipment. Thanks to the compacity of the installation equipment, the removal of the skid beams and hydraulic equipment is performed in one operation by using pulling winches located onshore.
Overall schedule reduction and CapEx savings

The MegaModule™ concept brings several advantages in terms of overall project execution, not only in terms of accelerated schedule but also by de-risking some critical activities. Indeed:

- As the hull fabrication is not on the project critical path, the large but complete module fabrication and the pre-commissioning and commissioning onshore associated with the installation method, allows for a minimum time for the FLNG at quay as there are only few modules to be installed and subsequently almost no integration and very few remaining pre-commissioning and commissioning activities to be conducted at quay. In the same way, the duration of commissioning at the final location is reduced. An overall reduction of project duration of around 6 months is expected compared to a conventional execution scheme.

- By shifting many activities from the quayside (nearshore at yard) and offshore (at site) to onshore and increasing the time during which the module is sitting at the quay while conducting pre-commissioning and commissioning activities, more time is available to complete all fabrication activities which drastically reduces the risk of carry-over works.

Cost estimation studies have been conducted considering the new FLNG concepts developed by TechnipFMC and they indicate that the combination of process optimization, mega-modularization including associated hull size reduction, split construction between topsides and the hull, project execution timeframe and planning reduction bring savings in terms of specific CapEx (USD/tpa) of an order of magnitude of 30% to 40% compared to first-generation projects.

Figure 11 - Improved FLNG schedule
Conclusion

Extensive studies conducted over the past years have concluded that a new generation of FLNG can be built using the design and techniques which have been developed, providing a reduction of project CapEx and execution schedule sufficient to place FLNG firmly among the most competitive routes for the monetization of gas reserves located offshore.

Furthermore, this new model of FLNG can be adapted to any capacity and can be adapted to any kind of field in terms of gas composition, well fluid conditions as well as location (open-sea, near-shore, at-shore). A single MegaModule™ can be used for small scale monetization of associated gas of 1 Mtpa or less. Four modules enable the NewWave™ concept of between 5 and 8 Mtpa from non-associated gas.

Finally, the MegaModule™ concept can also be applied with other offshore facilities such as fixed platforms, gravity-based structures, nearshore floating facilities or even to an onshore LNG plant.

Figure 12 - NewWave™ Large scale open-sea FLNG with 4 MegaModules™