A BREAKTHROUGH FOR FLOATING LNG?

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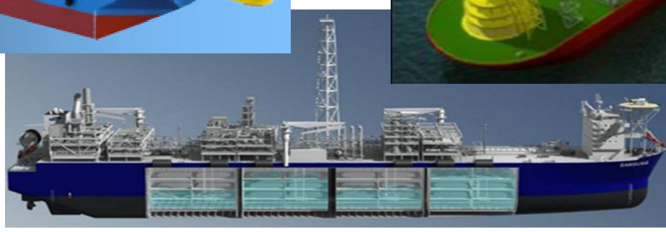
Keywords: 1. Floating LNG; 2. LNG FPSO; 3. FLNG; 4. Liquefaction

1 Introduction/Background

Floating LNG production, storage and offloading concepts (LNG FPSOs) have a number of advantages over conventional liquefaction plants for offshore resources, not least the ability to station the vessel directly over distant fields thus avoiding expensive offshore pipelines and the ability to move the production facility to a new location once the existing field is depleted. The technology has been discussed and evaluated in various forms for several decades, but has yet to reach commercial reality. However, recent buoyant LNG prices and, in particular, diminishing opportunities for conventional LNG projects have provided a major spur to development.

LNG FPSOs are now on the cusp of commercialisation following an upturn in interest over the last several years from a number of developers. However significant technical and commercial challenges still remain.

Many Floating LNG Concepts Being Developed

Sources: Höegh LNG
SBM Offshore
Shell
Flex LNG

2 Objectives of the paper

The objective of this paper is to review the current status of LNG FPSO projects, to highlight the technical and commercial obstacles that still confront them, and offer insight into how these obstacles might be overcome.

3 Discussion

a. The Floating LNG Renaissance

Floating LNG production, storage and offloading concepts (LNG FPSOs) have been discussed and evaluated in various forms for many years. The large oil companies led early LNG FPSO development in the late 1990s, with Shell, Mobil and Statoil developing large barge-based Floating LNG concepts for locations such as Nigeria, Australia and Namibia.

But recent times have seen an unprecedented flurry of development activity. Floating liquefaction technology has emerged as a means of bringing on additional LNG supply by accessing stranded gas reserves once deemed too remote, too small, or otherwise too difficult for conventional land-based LNG development. LNG FPSOs have shown a number of other inherent advantages over conventional onshore liquefaction plants that have boosted their profile. First of all, Floating LNG units can be stationed directly over an offshore field, eliminating the need for a long and costly subsea pipeline to shore. The investment for marine and loading facilities is also sharply reduced. Many of the issues around land-based site selection and an LNG facility's environmental footprint can be avoided and, in addition, once the field is depleted, the unit can potentially be floated to another gas resource for employment there. Floating assets also reduce security and political risks in some of the less stable regions where stranded gas is increasingly being found. Finally, cost savings may be available during the construction phase. This has become increasingly important as Engineering, Procurement and Construction (EPC) costs have skyrocketed in recent years, particularly for isolated locations where labour must be flown in and accommodated in construction camps. By contrast, a floating production unit can be built in a controlled shipyard environment where a skilled workforce is readily available. This potentially allows for a shorter development and construction time schedule. Moreover shipyards, seeing a shrinking newbuilding order book, are anxious to undertake this work.

The attractiveness of the opportunity has kicked-off a slew of new development concepts. These initiatives are proceeding down two distinct development paths; smaller scale LNG, exemplified by the units being developed by Flex LNG, and larger scale units being promoted by the likes of Shell.

Table 1: Small vs. Large Scale Floating LNG – Key Characteristics

Characteristic	Small-scale Floating LNG	Large-scale Floating LNG
Liquefaction capacity:	less than 3.0 mtpa	3.5 to 6.0 mtpa
Required reserves:	0.5 to 3.0 Tcf	more than 3.0 Tcf
Hull:	Ship-like	Barge-like
Storage capacity:	up to 220,000 m^3	more than 250,000 m^3
Liquefaction processes:	Simpler processes (e.g., Single Mixed Refrigerant processes, dual expander processes)	Baseload-type processes (e.g., Dual MR, Mixed Fluid Cascade)

Both the small and large scale LNG FPSO development models are relevant to LNG's future growth. Smaller-scale developments expand the reserves base deemed suitable for LNG development by targeting smaller 1-3 trillion cubic foot (Tcf) stranded gas reserves that would otherwise be inadequate to support a traditional baseload LNG project. These projects also require less sponsor resources than traditional baseload projects, broadening the range of developers, development concepts, technology vendors and construction resources capable of participating in LNG developments. The goals for larger-scale floating concepts are somewhat different. Large-scale Floating LNG is foremost a means to avoid long distance submerged pipelines to shore, enhancing the prospects for fields where traditional LNG development would involve a lengthy or difficult feed gas pipeline. In general, these more-expensive developments remain the domain of the industry's established oil company participants.

The last few years have seen a sharp upsurge in development activity followed by some drop-off as the economic environment and financing conditions became more difficult. Yet despite these difficult times, there remains a solid core of development efforts that continue to make headway, with some efforts seemingly on the brink of putting it all together for an actual development opportunity. However the first firm project commitment remains elusive – should the lack of Final Investment Decisions cause concern amongst floating LNG's backers? We would argue probably not. Floating LNG is progressing along a development path that is typical and appropriate for this type of capital-intensive emerging technology. However, some of the market excitement generated over the last few years may have been a little overzealous and premature, and should be tempered. It has become increasingly clear that early Floating LNG projects will need to offer the "complete package" – a combination of a clear, strong commercial prospect, sound technical offerings and a core of project participants from throughout the value chain that understand how to manage and mitigate early stage development risks. The quest for this ideal combination continues unabated.

b. Marine Settings Present Technical Challenges

A unique and demanding set of technical challenges must be overcome to move LNG production to an offshore setting. Yet it is perhaps the technical arena that has made the greatest strides to date, and where the risks are now viewed as most manageable. This is in large part because much of the technology development needed to take LNG production afloat has been evolutionary rather than revolutionary. Most proposed solutions are adaptations of technologies currently applied in either offshore oil production or onshore liquefaction. In addition early stage developments tend to place an overemphasis on conquering technical obstacles, so it is perhaps expected that this aspect of the project would be the first to gain clarity.

However the proposed solutions must still be proven reliable and safe in practice. Floating LNG facilities – small or large scale – will be amongst the largest and most-complex investments in offshore oil and gas processing capability to date, and will need to operate reliably in changing – and sometimes harsh – marine environments to meet their backer's goals. This requires that a vast number of process and operational elements simultaneously perform "just right", and that many risks associated with liquefaction plant performance and offshore operations must be well understood, and successfully mitigated.

Many of the challenges are due to moving processes offshore. Wave motion cannot be allowed to affect the performance of process equipment, most notably the distillation and separation columns required for condensate stabilisation, LPG extraction and acid gas removal in feed gas pretreatment ahead of the liquefaction unit. LNG containment systems must be capable of withstanding the damage that can occur when the sea's wave and current motions cause sloshing in partly filled tanks, while LNG transfers must also deal with the effects of winds, waves and currents in open seas.

Potential solutions lie in wait for all these concerns. Structured tower packings, liquid redistributors and split column configurations are all currently being used to ensure uniform liquids distribution in columns aboard oil and condensate FPSOs, though typically under less-stringent performance specifications than those demanded by LNG pretreatment. Both IHI's SPB-type containment design and a two-row membrane tank configuration from GTT appear capable of reducing and withstanding the wave impacts expected from sloshing, while providing the flat deck needed to accommodate the process plant. Traditional LNG loading arms have also been adapted to enable LNG transfers in open water, while hose-based solutions for both side-by-side transfers in calmer seas and tandem transfers in rougher conditions are nearing maturity. Understandably, it seems likely that early floating liquefaction ventures will confine their attentions to reserves in relatively benign marine environments, such as in West Africa and Asia until system performance and availability become proven.

A floating vessel's space constraints also limit the range of gas reserves that might be suitable for floating liquefaction. Gas pretreatment operations can be expected to take up as much as 50% of the available deck space on a floating production facility depending on impurity levels in the feed gas stream. This makes Floating LNG better suited to feed gas streams with low levels of inert gases and impurities. All carbon dioxide in the feed must be removed within a single-step operation, while the difficulty of removing and treating hydrogen sulphide offshore drives tolerance for this impurity to near-zero. Feed streams with high nitrogen levels are also to be avoided, both to avoid installing nitrogen rejection equipment and to maximise available liquefaction capacity. Floating LNG is also restricted in the levels of condensates and LPGs that can be directly handled aboard the vessels. While these liquids classically represent a valuable supplemental revenue stream for onshore LNG developments, their revenue benefits are offset in offshore settings by the increased processing and storage obligations they impose on the floating facility. They also increase the operating complexity for what is already the most-complex offshore production operation yet attempted and potentially increase safety concerns.

c. Liquefaction Choices Remain Immature

While Floating LNG's liquefaction technology choices are adaptations of mature onshore baseload and peak-shaving technologies, much work remains to migrate these solutions to offshore LNG production. Amongst smaller-scale LNG FPSO developers, the drive for simplicity, robustness and compactness has taken choices down one of two liquefaction process paths:

- **Single Mixed Refrigerant (SMR) cycles**, from technology vendors such as Black & Veatch and Linde are being applied to Excelerate and SBM Offshore's Floating LNG concepts respectively. These processes have a long track record in both baseload and peak-shaving applications, and require only a single liquefaction exchanger, refrigerant compressor and compressor driver. However, SMR systems are less efficient than the precooled mixed refrigerant processes more-commonly applied in baseload liquefaction, although this is less of an issue for small stranded gas reserves than larger developments. They also require the storage of LPG refrigerants, giving rise to particular safety issues in confined offshore settings.

- **Gas expander-based refrigeration cycles**, using either nitrogen gas or a combination of methane and nitrogen cycles are adaptations of processes used in small-scale peak-shaving and air separation. These processes use gas phase refrigerants, avoiding safety issues around the storage and emergency release of hydrocarbon liquids. They also require less equipment and take up less space than baseload processes, promising high reliability and good turn-down performance. However, these processes also remain less efficient than those used in baseload liquefaction facilities and will require significant scale-up from current applications – around an order of magnitude – to meet Floating LNG's production duties.

All the small-scale liquefaction processes need to be proven effective and reliable in the 0.8 to 1.2 million tonnes per annum (mtpa) range required for LNG production – a large step change from current applications – and they need to be proven robust under marine conditions. Neither of these requirements is expected to be particularly onerous, but neither should these requirements be overlooked – it is going to take some time for these processes to reach proven status.

Larger scale projects closely resemble onshore baseload facilities with some adaptations for offshore settings. These projects use liquefaction processes that are typically close variants on available onshore options – two- or three-stage liquid mixed refrigerant processes from technology providers such as Shell, APCI and Linde. While these processes are more efficient than the smaller-scale options, they are also more complex, require the storage of LPG refrigerants and must maintain uniform liquid distributions within and between their main cryogenic exchangers under wave motion.

d. Economics Mired in Uncertainty

As floating liquefaction development has advanced out of its earliest stages, attention has shifted from the technical arena to the concept's economic and commercial obstacles. Many economic, commercial, financial and even legal considerations will need to be better understood and their risks mitigated before offshore LNG production can become a widespread gas monetisation solution.

At the most fundamental level, Floating LNG's economics remain somewhat opaque. While it remains early days, the development costs being pitched by LNG FPSO promoters appear highly competitive with many baseload development opportunities. Early capital cost estimates amongst the smaller scale LNG developers have been between $600 and $1,200 per tonne of annual production capacity (tpa) – not cheap, but also not the LNG industry's most expensive upcoming projects. Large-scale LNG's cost numbers are less well-developed at this stage, but are anticipated to be over $800 per tpa, as might be expected for marine adaptation of established baseload processes. The current economic slowdown has seen potential development and construction costs fall by as much as 20% to 30%, but this remains well below the decline in gas and oil prices. In addition final cost levels remain far from certain at all scales. Margins of error on early developer's estimates are very high, and better accuracy will not be available until full designs are completed on actual resource prospects.

Availability and reliability also remain highly uncertain. The combined effects of Floating LNG's marine environment, LNG's stringent feedgas pretreatment requirements and the application of new or adapted technologies mean it may take some time before process uptime and operational cost expectations become normalised, and hence project cash flows predictable, without significant allowances for uncertainty.

Reserves depletion curves bear closer scrutiny for Floating LNG developments than for long-life onshore LNG projects. Additional late-life investment in drilling and compression capacity may be required to sustain the field's production plateau, as Floating LNG's high investment requirements mean the economics may not tolerate long, slow depletion profiles. Similarly liquefaction processes require high feed gas pressures, providing an additional rationale for higher feed gas compression costs.

Relocating a floating liquefaction between different fields could also be commercially contentious. No two gas fields are alike, so a facility's condensate processing and gas pretreatment sections may need costly and time-consuming retrofits to make it suitable for a second location. The extent of this work, or conversely the tolerance for sub-optimal performance on the second field, is likely to depend on the factors such as the timing of the move within the facility's economic life and whether gas monetisation is fundamental to the overall economics of the field development. Relocation could also create misalignment between an upstream gas supplier and the liquefaction plant operator, as the LNG operator may wish to abandon a field and move onto a new prospect earlier in the depletion curve than the field owner would like. Optimal abandonment strategy may also be an issue with the host government, who are interested only in maximising returns from the resources within its borders.

Given Floating LNG's high capital requirements and fledgling development status, it seems likely that early floating projects will not be sanctioned on the basis of stranded gas monetisation alone. Other project drivers such as access to oil and condensate reserves or flaring restrictions are likely to be needed. While this may justify and spread the LNG risk, it sharply reduces the available opportunities for early LNG development and substantially increases the overall investment, reducing the number of potential players capable of undertaking such an endeavour.

e. Commercial Structures Tied to Project Participants

Business models are likely to vary considerably depending on the strength, capabilities and number of project participants. Several established business models from the LNG industry could be adopted for Floating LNG projects, with the likely outcome being some hybrid of two or more of these models:

- **An integrated project** where the gas resource owners own the LNG FPSO facility and market the LNG themselves. This model requires either a strong gas resource owner with a willingness to accept downstream risk or one of the existing Integrated Oil Company players (IOCs).

- **A merchant project** where the gas suppliers sell gas to the LNG FPSO project, which then sells LNG for its own account. This type of arrangement is likely to be favoured when there are multiple gas owners or owners with limited financial resources, or the project is being developed by a strong downstream LNG buyer or marketer.

- **A tolling facility** where the gas suppliers pay for the processing, liquefaction and storage of LNG via a capacity fee. In this model the production vessel may be owned /operated by the LNG FPSO developer and remuneration received through time charter and capacity charges.

While a tolling arrangement bounds an LNG FPSO developer's investment requirements, the dilemma may be that the returns available from the liquefaction segment alone are too low to compensate them for early-stage technical risk. LNG FPSO developers will try to overcome this by seeking a hybrid structure that offers greater exposure to the rewards (and risks) of the whole project by becoming involved either upstream or downstream through such measures as taking a direct interest in the gas field or becoming involved in marketing the LNG. The developer's ability to participate in this manner will depend upon the positions of the other partners in the project, its breadth of expertise across the various required capabilities, and in particular its ability to secure financing for the project.

An LNG FPSO project will, in many cases, be a dedicated export project. The upstream fiscal terms, whether within a Production Sharing Contract (PSC) or a concession agreement will need to address LNG sales, and government approvals will likely be required for export of the gas in the form of LNG.

f. Construction Risk-Sharing must be Addressed

Construction risks also differ between Floating LNG technologies and conventional onshore facilities. Typically LNG FPSO developments will bring together several different players – shipbuilder, process vendor and EPC contractor. The issues of cost and risk sharing between the parties will need to be addressed as will the ownership of the jointly developed technology, and how this may be licensed on future projects.

Decisions will need to be made as to the starting point for the EPC contracting structure. Will this be the shipbuilding contract or the topside facilities contract? How will the risks for problems or delays due to the integration of topsides and hull be allocated? Which party will take the overall performance risk for the facility? While these types of completion and performance risks are typically borne by the EPC contractor when the project is well understood, this will not happen for an emerging technology as EPC contractors simply do not have sufficient balance sheet resources. Rather the project owners and/or the LNG buyers can expect to bear more of this risk for new technologies, making strong project sponsors essential to getting early projects to market.

In regard to the LNG FPSO engineering and construction structures the FPSO industry may provide a broad contractual framework, but there will likely be new contract formats required, and the early versions of these will certainly be subject to close scrutiny.

g. Offshore Location Affects Fiscals; SPAs

The offshore setting is also likely to affect the emphasis and terms in critical contracts. An LNG FPSO project will need a solid Sales and Purchase Agreement (SPA) with a creditworthy buyer as would any other LNG project. But a number of issues covered by the SPA become more important for an LNG FPSO project. Tighter loading and storage conditions make a number of scheduling issues more important in a floating project SPA – issues such as late arrival and departure, demurrage, take or pay volumes, and maintenance outages. LNG tankers may have to co-ordinate berthing with natural gas liquids offtake vessels and may experience more weather delays than when loading at a sheltered shore facility. If LNG is to be supplied on a Delivered Ex-Ship (DES) basis, diversion opportunities will be more difficult to execute as having the tanker return on time will be more critical.

h. A Challenging Financing Environment

The financing of LNG FPSO projects will undoubtedly provide several challenges in the current environment. While debt financing has become an established part of the oil FPSO business, LNG FPSOs bring a number of additional considerations. Emerging technologies are seldom debt financed, at least in the first instance, as lenders are inherently averse to uncertainty, preferring to lend only once technical, execution and operational precedents have been established. While all of the technology elements to be utilised have been tried and proven in various other applications, the concept as a whole can be considered technically feasible and Health, Safety and Environment concerns should be met, the fact that no fully operating marine system yet exists will give lenders concerns, particularly in relation to project execution and operational risks. In addition LNG FPSO projects are expected to be more capital intensive than oil FPSOs, increasing the size and complexity of potential deals beyond current lender experience.

Financing for Floating LNG is also going to depend heavily on the quality of the project sponsors. LNG FPSO projects are far more likely to expose lenders to reserves risk, either directly through lending to a strong project sponsor, or indirectly through the financing of an FPSO charterer. Another issue will be the gas field's producing life relative to the tenor of the project finance. As the tenor of conventional LNG project finance may be on the order of 7.5 to 10 years based on a reserve life of more than 20 years, what loan life can be expected for smaller floating plants supplied by smaller reserves?

Early LNG FPSO projects are likely to wholly or substantially equity financed until lenders can establish suitable precedents and risk parameters. The first LNG FPSO projects will be unique and can expect to be subject to rigorous review. Project structures will need to apportion risk optimally in order to attract funding at "efficient" rates. The allocation of risks across the parties will depend upon the project structure but particular interest will be taken in the design, construction and integration of the hull, process facilities and containment systems, the acceptance tests, how the responsibilities are allocated through the warranties and which party takes performance risk.

As the industry matures, redeployment risk and residual value of the FPSO facility may become more significant considerations as lenders become more comfortable with incorporating redeployment opportunities into their project valuations. However it is unlikely that any lender will consider lending based on vessel redeployment prospects for the early projects, particularly in today's restrained lending environment.

In principle a floating LNG facility has some merits over the traditional land-based plant for financiers. Unlike a fixed location onshore project, the asset (i.e., the vessel) could be repossessed by the financier and utilised elsewhere in order to fulfil the financial commitments should a project developer default on paying back the loan. In practice this may not be so straightforward.

The high level of investment in an LNG FPSO due to production, storage and offloading facilities being concentrated on a single hull also raises insurance issues, as the loss of the hull results in the total loss of the project.

i. Legal/Regulatory Landscape can Affect Design

The legal and regulatory frame work for LNG FPSOs will, in general, more closely resemble that for oil FPSOs rather than land-based LNG development. The marine location brings into play a broader range of rules and regulations and it will be important to distinguish the applicability of national legislation, flag state regulations, class rules and international conventions. In some jurisdictions there may also be some issues arising from ambiguity as to whether the facilities are permanent or temporary. The vessel will require a classification society approval, Protection & Indemnity (P&I) Club insurance approval, approvals from the host government's maritime authorities for the vessel and International Ship and Port Facility (ISPS) compliance.

There are some regulatory issues that may affect facility design, such as establishing whether the facility will be classified as a ship or a static facility and whether the vessel will be deemed to be transporting gas (as there will be a difference in approval authorities and the processing times). It is important that the legal and regulatory landscape be fully understood at the initiation of the project as starting the design without a clarified regulatory basis may result in changes, with detrimental cost and schedule implications.

There are other considerations that may be more complicated for LNG FPSOs, such as where a country has local content requirements for oil and gas developments. LNG FPSOs will likely be developed and constructed remotely, leaving little scope for local input.

j. Floating Liquefaction Projects – Current Status

While it is evident floating LNG is no panacea for the LNG industry's growth constraints, the types of issues and obstacles outlined above are not all that unusual for an emerging technology. Indeed many concepts are approaching key milestones in the development path that will better define the risks and prospects for the whole industry. SBM Offshore and Höegh LNG are perhaps the most-advanced, both having completed generic FEED-level designs that narrow down many of the technical and cost risks associated with their concepts and continuing to work with prospective clients on specific opportunities. Flex LNG continues to hold four construction slots at Samsung's Korean shipyards, though immediate prospects for a Final Investment Decision on any of these hulls remain cloudy. Other concepts are currently in earlier stages of development from the likes of Golar/PTTEP, Excelerate/Exmar, Petronas/MISC/Mustang, Teekay/Merrill Lynch and Sevan Marine.

The upcoming issues facing the smaller-scale developers remain very similar – they must all fill out their offerings to be credible across all project elements. Firstly they must secure appropriate stranded gas resources for a prototype development. Secondly, their technology and execution capabilities must bear close scrutiny and finally (and potentially most critically), they need project sponsors – either upstream Exploration and Production companies or downstream LNG buyers – with the balance sheets and risk tolerance to bring these projects to fruition.

Larger floating LNG projects have remained the domain of the large IOCs with the engineering, project development and financial resources to drive these large projects. There are fewer current initiatives for this type of facility, but the strength and experience of their sponsors potentially makes these projects more likely to advance. Shell's 3.5 mtpa "generic" development process currently remains in its competitive FEED/EPC tendering process with three shipyard/EPC contractor consortia, with bids and possibly an award scheduled for later in 2009. Japan's Inpex is also considering a 4.5 mtpa floating facility for the Abadi field in Indonesia, with first LNG planned for 2016. Finally, floating production remains an option for the Greater Sunrise project in the Timor Sea, with final concept selection scheduled on this project the first half of 2009.

k. Economic Downturn Shifting Development Emphasis

While floating LNG will be a growing component of the LNG industry over the long run, its pace of development has not been entirely immune to the effects of the current economic downturn. Lower oil prices and falling LNG demand projections have affected economic evaluations as well as the preferred timing for market entry. Financing sources for technology development have diminished, potentially making it more difficult for developer-led initiatives to finance later development stages. However oil company-backed projects have been less affected due to their inherently-conservative economic assumptions and their sponsor's strong balance sheets. Falling materials costs, weak shipping order books and increasing cancellations amongst the energy industry's marginal construction projects could all induce a pause in development as projects wait for materials prices to settle and negotiate lower engineering and construction prices.

On the brighter side, it has become increasingly evident that other industry pressures have ensured that the industry development will not collapse entirely. The increasing relevance of stranded gas reserves to the growth of the international gas trade combined with LNG's ability to monetise reserves at internationally-tradable prices continue to raise floating LNG's profile as a monetisation option. In addition, greenhouse gas concerns and regulations have increased floating LNG's attractiveness both as a source of lower-emissions fuel and as a means to reduce flaring of associated gas.

4 Summary

While we might all wish LNG FPSO development to be a straightforward exercise in applying proven technology elements in a new setting, this is unlikely to be the case. Like any capital-intensive emerging technology within the energy industries, Floating LNG's development path is likely to be long, difficult and fraught with technical and commercial obstacles.

Nonetheless, the types of issues discussed in this paper are not all that unusual for an emerging technology, with most of these being readily solvable given the right mix of resources and opportunity. Indeed, a solid core of development efforts continue to make headway despite difficult energy and financial markets, seemingly poised to strike the right balance of resource opportunity, technology and development capabilities to find a way to market. However, at this point in time, exactly when this will happen and at what cost remains difficult to predict.