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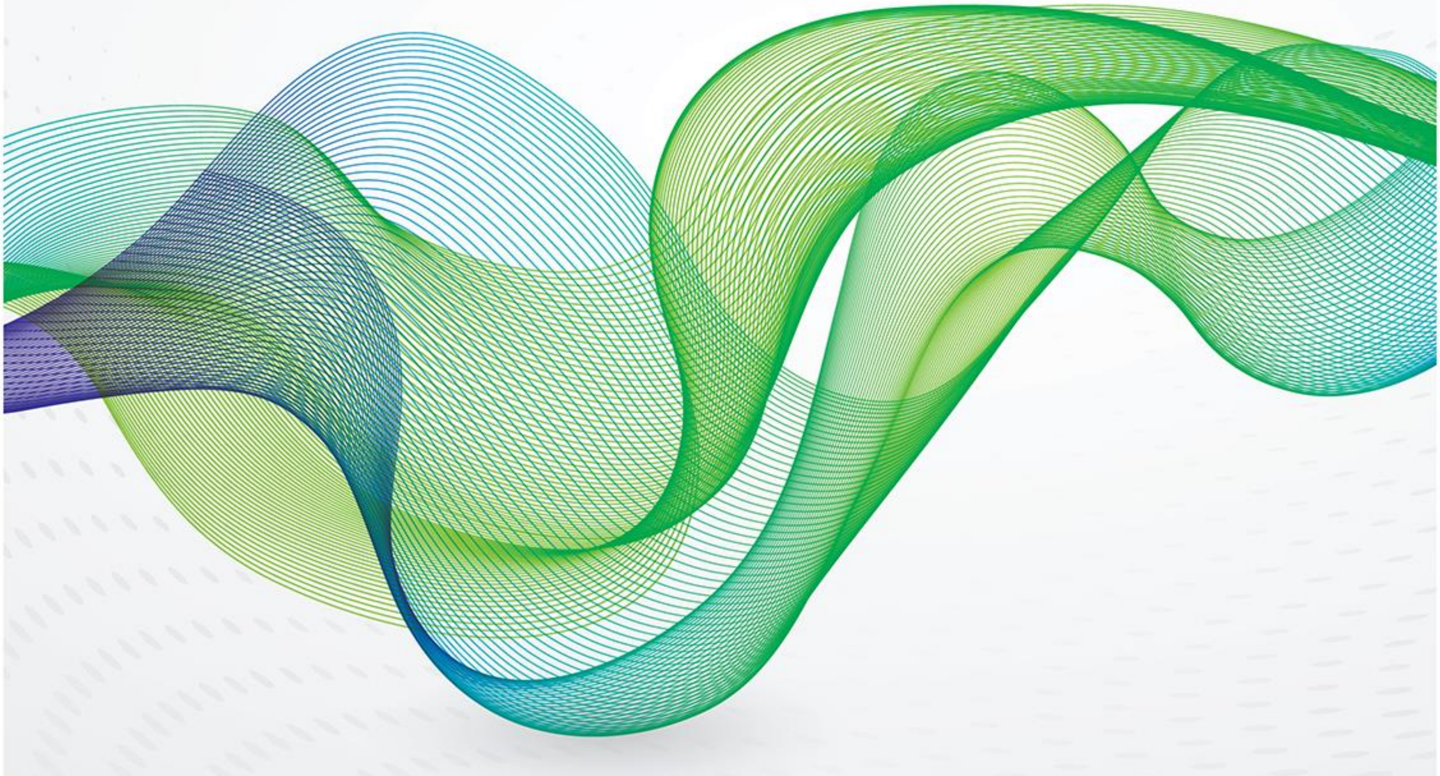
Floating Liquefaction (FLNG):
Potential for Wider Deployment



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Brian Songhurst
OIES Research Associate

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Acknowledgements

My thanks to colleagues in the LNG industry for their input and final review.

Preface

The softening of European hub prices and Asian LNG spot prices in early 2014, followed by the plunge in oil prices later that year has created an extremely challenging business environment for the LNG industry. Current prices – whether spot or oil-indexed LNG contract prices - are well below levels recently regarded as necessary for projects to achieve FID. To make matters worse, new capacity from projects under construction will continue to add supply to a market in which demand growth is slower than had been anticipated. The market will clear as Asian demand absorbs new volumes and as Europe continues to require new import volumes to offset domestic gas production decline with perhaps some demand growth in the power sector. It may be however that the current 'glut' persists until the early 2020s.

Against this background, it is a testament to the resilience and adaptability of the LNG industry that it is embarking on an 'experiment' to test the hypothesis that FLNG provides a means by which stranded gas discoveries can be monetised and, perhaps more fundamentally, that with its shorter lead times, lower fabrication execution risk and the entrepreneurial vibrancy which comes from competing providers and approaches, FLNG could prove more generally to be more viable than conventional onshore liquefaction plant.

Following from his 2014 paper on LNG plant cost escalation, Brian Songhurst provides a comprehensive review of the state of play of FLNG, the competing approaches and the advantages and disadvantages compared with conventional onshore liquefaction. Brian also hints of further potential technology step-out in FLNG once the first wave of projects is successfully commissioned. The lessons of the post-2009 period have, it can be argued, demonstrated the need for the LNG industry to address both cost base and contractual price formation mechanisms if it is to remain a viable channel for the delivery of gas in the world's fast growing markets.

The Oxford Institute for Energy Studies Natural Gas Programme is pleased to add this paper to its list of publications which aim to address the key issues impacting the market fundamentals, geo-politics and pricing. Whether FLNG provides a more viable supply-side renaissance for LNG is still to be proven; this paper provides a valuable description of the challenges and motivations of the players involved.

Howard Rogers

Oxford October 2016

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Glossary

Bcfd – Billion Cubic feet per day. A flowrate or production output of typically natural gas commonly used in North America.

Bcma – Billion cubic metres per annum. A flowrate or production output of natural gas commonly used internationally.

Capex or CAPEX – Industry term for Capital Expenditure.

DMR – Dual Mixed Refrigerant

EPC – Engineering, Procurement and Construction

FEED – Front End Engineering Design

FID – Final Investment Decision – Typically made by the investors in an LNG project when all necessary sales contracts and other government and regulatory approvals are in place.

FLNG – Floating LNG liquefaction vessel

FPSO – Floating Production Storage & Offloading

FSRU – Floating storage and regasification vessel

LNG – Liquefied Natural Gas

Liquefaction – The process by which pre-treated natural gas is cooled to minus 160^0 Celsius when it becomes a liquid at atmospheric pressure.

m^3/h – Cubic metres per hour

mtpa – Millions of tonnes per annum

mtpa/ha – LNG production in million tonnes/annum per hectare of vessel deck space

Natural Gas Liquids – Typically the ethane, propane, butane and higher alkanes occurring within a natural gas reservoir extracted from the methane in the course of processing it to grid or liquefaction specification.

OLAF - Offshore Loading Arm Footless

OPEX – Industry term for Operating Expenditure

SMR – Single Mixed Refrigerant

SPB - Single Prismatic Type B tanks

Sponson - A feature on a vessel that extends from the hull to aid stability while floating and provide space for additional other equipment.

tpa - Tonnes per annum

$ - US Dollar

$/tpa – metric of capital cost/tonne/annum calculated by dividing the capital cost by the production rate in tonnes/ annum

Chapter 1

1.1 Context & Reason for Paper

The concept of floating liquefaction plant (FLNG) has been studied since the mid-1970s but made very slow progress until May 2011, when Shell announced their decision to proceed with the development of Prelude FLNG, to be located in the Timor Sea. Since then six further projects have been approved as shown in table 1 and most are in construction. Caribbean FLNG is complete and waiting for a new field assignment as gas is no longer available at the original location. None of the vessels is yet in operation but Satu is now on location at the Kanowit gas field is expected to be the first to start up in late 2016 or early 2017.

Table 1: FLNG Projects Currently under Construction

Project	mtpa	Start up	Location	Operator	Contractor
Caribbean FLNG	0.5	2016	TBA	Exmar	Exmar/Wison/B&V
PFLNG Satu	1.2	2016	Kanowit Field, Sarawak, Malaysia	Petronas	Technip/DSME
Prelude	3.6	2017	Timor Sea, Australia	Shell	Technip/Samsung
Kribi	1.2	2017	Cameroon	SNH/Perenco	Golar/Keppel/B&V
Speculative	0.6	2017	TBA	TBA	Exmar/Wison
Fortuna[1]	2.2	2018	Equatorial Guinea	Ophir Energy	Golar/Keppel/B&V
PFLNG2[2]	1.5	2020	Rotan Field, Sabah, Malaysia	Petronas	JGC/Samsung

Source: Collated by author from various industry sources

It is worthy of mention that an inshore small capacity FLNG barge was installed and successfully operated in 1959 in Louisiana and supplied the first LNG to the Canvey Island terminal in the UK. More information is included in Appendix 1.

The concept of floating liquefaction development follows closely behind the successful deployment of floating storage and regasification units (FRSUs) which have been accepted by the industry at an impressive pace. The first FSRU vessel was installed in the Gulf of Mexico in 2005 and by mid-2016, 19 vessels were in operation with many more on order (refer to Appendix 3). Such a rapid take up of new enabling technology in the LNG industry is quite unprecedented. It will be interesting to see if FLNG progresses at the same rate.

Currently 24 FLNG developments are in progress – 7 in construction and 17 in the planning/pre-engineering stage as listed in Appendix 2.

[1] Final Invest Decision expected mid 2016 but construction (conversion) is underway. See Quinn (2016) pp 29 - 32

[2] Delay to 2020 announced in April 2016, probably due to low current energy prices
http://fairplay.ihs.com/commerce/article/4263426/petronas-delays-rotan-flng-project

FLNG offers many advantages over conventional onshore liquefaction plants:

- Can be located at the offshore field avoiding the high cost of a subsea pipeline to shore.
- Can be built in a shipyard with higher productivity and often lower labour rates than the construction of a conventional onshore liquefaction plant.
- Shipyard construction provides a higher confidence in delivery date than many onshore construction locations.
- Avoids onshore permitting issues which can be expensive and often result in delays.
- Can be leased avoiding the initial capital outlay.
- Can be redirected to another field when gas production declines enabling the asset to be reused and avoiding the full sunk cost experienced with an onshore plant which cannot be relocated.
- 90% of the commissioning can be completed in controlled shipyard conditions prior to installation.

FLNG has every potential to be a game changer for the liquefaction industry from both technical and commercial stand points in the same way as FPSOs[3] have enabled the economic development of remote offshore oil fields.

The opportunity provided by the FSRU and FPSO contractors to lease the FLNG vessel enables the smaller independent energy companies to avoid arranging project finance for the liquefaction facility and carrying the asset on their balance sheet and a good example of this is the Fortuna project[4]. However it could also assist the major energy companies where current low oil prices are restricting capital investment. Many major energy companies already lease FPSOs[5] and the same could equally apply to FLNGs.

Golar LNG has secured financing for its first FLNG vessel and has three FLNG vessels under construction in Singapore and a possible fourth[6] is to be announced – a measure of how it feels this approach will be taken up by the industry. Three of these vessels have already been assigned to offshore gas field developments. Golar LNG has also just announced a joint venture with Schlumberger 'OneLNG'[7] that will offer to supply, operate and finance the complete offshore scope – reservoir, subsea and FLNG facility. This will be of particular interest to the smaller independent energy companies who have limited technical and financial resources.

[3] Floating Production, Storage and Offloading unit.
[4] Quinn (2016) pp 29-32
[5] See list compiled by FPSO company at: http://fpso.com/fpso/?page=2 [Looks as if the company is called Intership Pte Ltd?]
[6] Fourth FLNG conversion announced by Golar LNV at: http://www.lngworldnews.com/golar-starts-fourth-flng-conversion-talks-with-keppel/
[7] http://www.slb.com/news/press_releases/2016/2016_0725_slb_golar_onelng.aspx

Chapter 2

2.1 FLNG Configurations

FLNG vessels fall into two principal categories in terms of deployment mode – inshore/nearshore and offshore/open ocean.

2.2 Inshore/Nearshore

Inshore or Nearshore FLNGs are located in relatively benign water conditions with the protection of a harbour or breakwater and are not exposed to harsh open ocean sea states. An example of inshore configuration is shown in figure 1 with the vessel moored to a jetty. With these configurations the feed gas is normally supplied by pipeline from the producing field, which may be on- or offshore.

Figure 1: Typical Inshore/Nearshore Configuration

Source: Courtesy Höegh LNG

2.3 Offshore

Offshore FLNGs are located in open water and exposed to the prevailing sea state conditions for that location. An example offshore configuration is shown in figure 2. For relatively benign waters e.g. Prelude[8] (Browse Basin, Australia), LNG will be exported using an OLAF[9] system based on a proven hard arms design with the vessels located on a side-by-side basis. However, harsher conditions e.g. Scarborough, (remote Carnarvon Basin, Australia) will require a tandem offloading arrangement[10] with the vessels located one behind the other as used for oil offloading from FPSOs in harsh conditions. It should be noted that whilst Prelude is in normally benign conditions, the facility must be structurally designed to withstand the harsh category 5 cyclone conditions experienced in that area albeit the facility will cease operations for the duration of those conditions.

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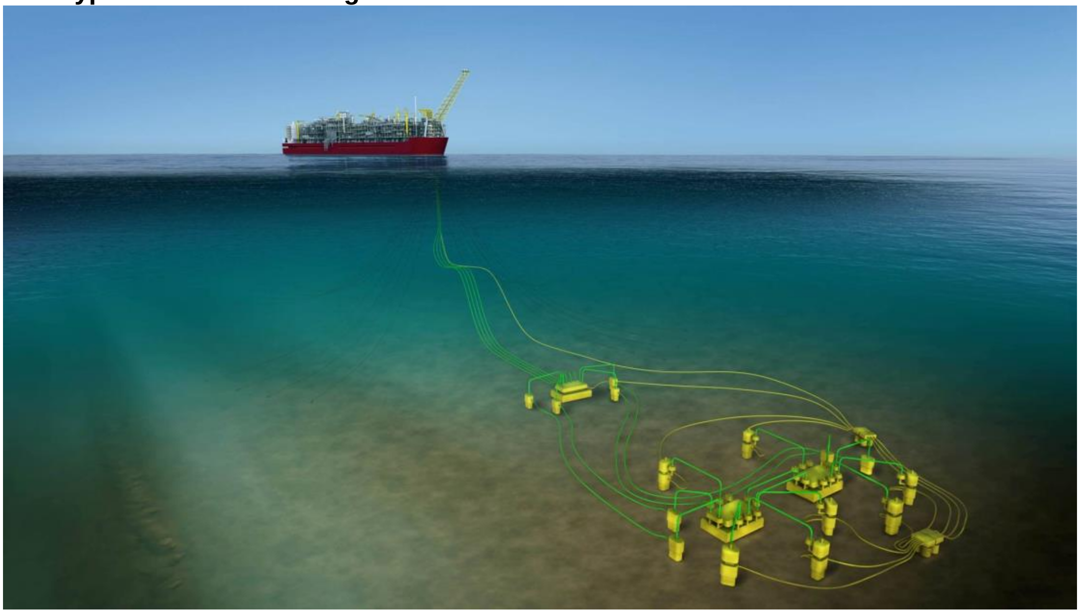
[8] Shell Prelude Project Description pp 4 , http://s00.static-shell.com/content/dam/shell-new/local/country/aus/downloads/about-shell/prelude/chap4highres.pdf

[9] OLAF – Offshore Loading Arm Footless http://www.lngworldnews.com/olaf-by-fmc-video/

[10] 'Scarborough Project, Preliminary Environmental Documentation Report, September 2013, http://www.exxonmobil.co.uk/Australia-English/PA/Files/scarborough_enviro_final.pdf

Figure 2: Typical Offshore Configuration



Source: Courtesy Shell International Ptd

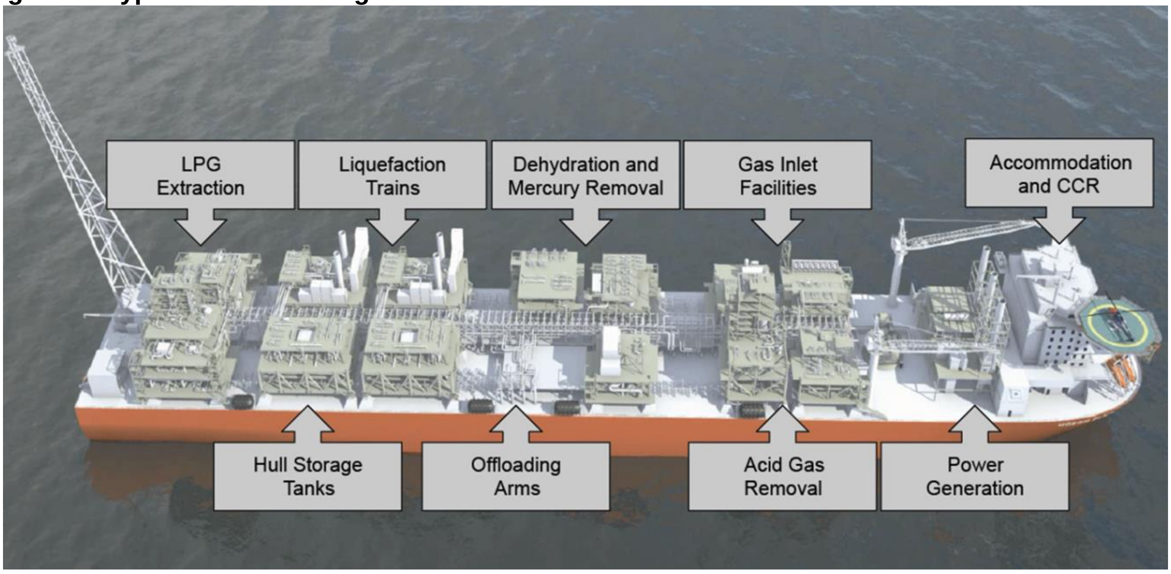
It should be noted that the main limitation of the offshore location is the LNG offloading system. 'Hard arms' are the only currently proven system and are limited to a significant wave height of approximately 2.5 m which restricts the applications to relatively benign offshore locations e.g. Timor Sea, West Africa, East Africa and Malaysia. Operation in harsher environments e.g. offshore Brazil (South Atlantic) will only be feasible when tandem loading has been proven for LNG transfer to the satisfaction of the operators. Tandem loading systems have been developed and qualified and this is discussed further in section 3.4.

Chapter 3

3.1 FLNG Technology

Offshore FLNG production vessels can best be described as placing the traditional onshore liquefaction plant on an LNG tanker which also provides the storage capacity and the offloading jetty, as shown in figure 3. In addition to the traditional gas processing facilities, the vessel will include the necessary processing and management of the fluids produced from the subsea wells. For inshore FLNG applications the gas is usually delivered by pipeline and the LNG tanker ship shape hull is replaced with a flat fronted barge.

Figure 3: Typical FLNG Arrangement



Source: Courtesy Höegh LNG

The FLNG industry has deliberately retained as much proven onshore process technology as possible to minimise the technical risks. More innovative process concepts may be developed at a later date when the first group of vessels have demonstrated reliable operation for some time and more experience is gained.

3.2 Gas Processing & Liquefaction

The FLNG vessel comprises the same processing steps as used in onshore plants:

- Gas inlet treatment and condensate removal;
- Acid gas (CO_2 and H_2S) removal;
- Dehydration (water removal);
- Mercury removal;
- LPG extraction;
- Gas liquefaction to produce LNG.

The well fluids are transported from the subsea wells via risers to the inlet treatment facilities in the same manner as for oil FPSOs. The risers in all current offshore developments are routed via a turret to allow to allow the vessel to turn into the wind for better stability, but other configurations e.g. spread moorings as used in West Africa, (on oil FPSOs), are possible. The well fluids are separated into gas and condensate. The condensate is stabilised prior to storage in the hull and normally exported via hoses to appropriate tankers.

The gas stream is treated with an amine solution to remove the acid gas (CO2 and possibly H2S) which would otherwise freeze in the liquefaction process. Amine is regenerated by heating and the acid gas vented.

Water is then removed using molecular sieve beds and finally any mercury removed in a guard bed.

The gas stream is then cooled to extract LPG (propane & butane) which is sent to storage in the hull and exported via hard arms or hoses.

The treated gas comprising mainly methane and ethane is cooled to -162^{0}C in the cryogenic heat exchanger and liquefied. The resulting LNG is flashed to remove the excess nitrogen and stored in the hull prior to export via offloading arms.

The main differences between FLNG and onshore liquefaction are:

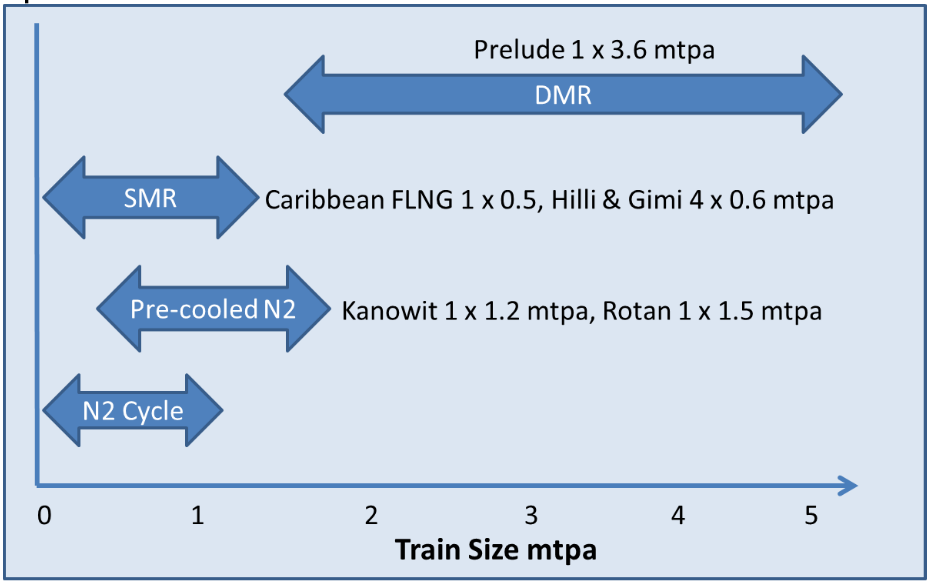
- A much smaller plot space is available – typically just 60% of an onshore plant;
- The need to accommodate vessel motions of heave, surge, pitch, roll & yaw;
- The manoeuvring of two moving vessels alongside each other for LNG offloading;
- The use of modularised plant rather than stick built[11], but modular onshore plants are now being used in areas where construction labour is limited or expensive;
- Higher operations and maintenance costs due to offshore logistics;
- The need for the plant to be compact and low weight;
- Continuous offshore operation with no dry-docking for major overhauls requiring higher design margins and high quality equipment to minimise the need for in-service repair and replacement.

3.3 FLNG Liquefaction Processes

Only proven onshore liquefaction processes have been selected to date on the basis of minimising technical risk. There are many new features on a FLNG vessel but these do not involve introducing the fundamental risk of using an unproven process. Due to the space and marine limitations the mixed refrigerant (MR) and nitrogen cycle (N_2) processes have been selected. Figure 4 shows the typical production range of the proven processes and those selected for the current projects with their train size.

[11] Traditional plant construction method where equipment and materials are delivered to site as individual components and erected at site

Figure 4: Liquefaction Process Selection



Source: By author
Note: DMR = Dual Mixed Refrigerant; SMR = Single Mixed Refrigerant .

Advantages & Disadvantages

Table 2 compares the advantages and disadvantages of the MR and Nitrogen Cycle processes.

Table 2: Comparison of MR & N_2 Processes

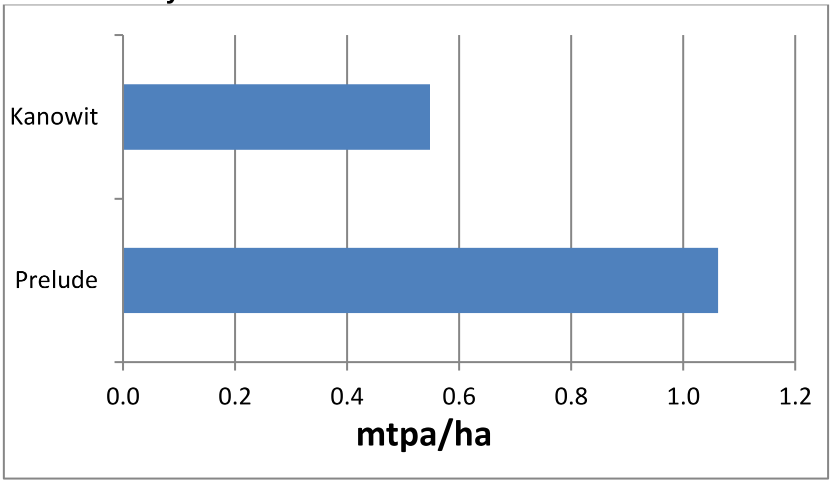
Feature	DMR	SMR	N_2 Cycle	Pre-cooled N_2 Cycle
Proven Process	Yes	Yes	Yes	Yes
Liquefaction Efficiency	Higher	Higher	Lower	Similar MR
Flammable Refrigerant	Yes	Yes	No	No
Refrigerant Storage	Yes	Yes	No	No
Import Refrigerant	No	Yes	No	No
Space Required	Lower	Lower	Higher	Higher
Sensitive to motion	Yes	Yes	No	No
Complexity	Complex	Simple	Simple	Complex
Flare Size	Larger	Larger	Smaller	Smaller
Capital Cost/ton LNG	Specific studies required for each case			

Source: By author

The MR process offers the advantage of using liquid refrigerants rather than those of a gaseous nature which significantly reduces the refrigerant volume, but has the major disadvantage of these being flammable and a potential source of vapour clouds with attendant safety risks. The nitrogen cycle process has the opposite characteristics – it is a gaseous refrigerant requiring a high volume plant (large piping and heat exchangers) but is not flammable.

This impact is demonstrated by comparing the Kanowit[3] and Prelude[4] projects. Kanowit uses nitrogen and produces 1.2 mtpa on a vessel 365 m x 60 m (2.2 ha) i.e. 0.5 mtpa/ha but Shell Prelude uses mixed refrigerant and produces 3.6 mtpa on a vessel 488 m x 74 m (3.6 ha) i.e. 1.1 mtpa/ha. Prelude produces twice as much LNG for the same plot area, as shown in figure 5.

Figure 5: Production Density



Source: By author

Mixed Refrigerant Process (MR)

Shell has selected its Dual Mixed Refrigerant (DMR)[12] process for Prelude and Exmar and Golar have selected the PRICO[13] single mixed refrigerant process (SMR) for their projects. DMR is in operation on the Sakhalin LNG plant and more than 50 PRICO SMR processes are operating world-wide, mainly on small scale LNG plants.

Nitrogen Refrigerant Process (N_2)

Petronas is using the nitrogen cycle process for its Kanowit and Rotan vessels and has selected the AP-TN[14] process offered by Air Products using a triple cycle for high efficiency. Single and double cycles are also available. Single cycles have been used extensively for onshore peak shaving plants but offer a lower efficiency than dual or triple.

3.4 LNG Storage & Offloading

The FLNG vessel comprises

- LNG storage in the hull;
- LNG offloading via hard arms;
- Condensate and LPG if produced are also stored in the hull and exported.

The LNG produced is stored in the hull in the same way as for LNG tankers and FSRU vessels. All the major large new build FLNG units use reinforced membrane tanks[15] arranged in a double row with a central bulkhead to reduce sloshing and provide strength to support the topside modules. The conversion projects under construction use Moss tanks[16]. The smaller barge units e.g. Caribbean

[12] Article 'Double Mixed Refrigerant LNG Process provides viable alternative for tropical conditions', Oil & Gas Journal (subscription service) at: http://www.ogj.com/articles/print/volume-100/issue-27/processing/double-mixed-refrigerant-lng-process-provides-viable-alternative-for-tropical-conditions.html
[13] See Black & Veatch brochure 'World-Class LNG Capabilities' at http://bv.com/docs/energy-brochures/lng
[14] See short Air Products paper 'Simulating Operational transitions in a Nitrogen Recycle LNG Plant' at: http://www.airproducts.com/~/media/Files/PDF/industries/lng/en-simulating-operational-transitions-nitrogen-recycle-lng-plant.pdf
[15] See description of membrane containment system on NWS website at: http://www.nwsssc.com/fleet/ship-technical-information/membrane-containment-system
[16] See description of Moss spherical tanks on Mossmaritime website at:http://www.mossww.com/technologies/lng_carriers.php

FLNG use type C tanks[17] (pressure vessels) but this is not economic for larger vessels. SPB[18] tanks are also an option and were considered by Flex LNG, but while they are extremely robust they are considerably more expensive than the membrane type.

The offloading method being used on the projects currently under construction is the proven approach of loading arms with side-by-side transfer[19]. There is a desire by the industry for tandem loading using either articulated arms[20] or hoses[21]. Hoses are currently used for side-by- side transfer but not for tandem or floating in the water. Four 16" aerial cryogenic hoses are currently being offered by Technip, Nexans, Trelleborg and Dunlop. The Technip, Nexans and Trelleborg hoses are fully qualified and Dunlop expects their hose to be qualified by late 2016. A 20" floating hose is currently being offered by Trelleborg and has been fully qualified. The 16" aerial hoses can each transfer 5,000 m^3/h and would be supported by a deployment frame with the hoses connecting the stern of the FLNG with the bow of the offloading tanker as a catenary. The 20" floating hose is also capable of transferring 5,000 m^3/h but would be longer running from the stern of the FLNG to the mid-ships manifold on the tanker. In addition to tandem arrangements Sevan Marine has developed the 'HiLoad LNG'[22] concept which uses a self-propelled L-shaped unit to latch on to the tanker. A recent article[23] in Upstream Technology provides an update of these flexible hose developments.

Condensate and LPG are also stored in the hull and exported. LPG is normally exported using hard arms and condensate using hoses.

3.5 Accommodation & Utilities

The FLNG vessel comprises

- Accommodation facilities
- Power generation for process plant
- Fuel gas system
- Flare system
- Cooling Water systems
- MEG for hydrate management
- Miscellaneous systems

Accommodation facilities for the larger vessels are typically for 100-150 persons and provided in the same manner as for FPSOs.

Power generation for the running of the vessel's utilities and accommodation facilities is typically via dual-fuelled diesel engines located in the engine room.

Other process utilities include nitrogen and refrigerant storage.

Vessel utilities are also provided to maintain the FLNG vessel.

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[17] See article on C Cargo tanks at: http://worldmaritimenews.com/archives/98464/tge-marine-delivers-c-cargo-tanks-for-exmars-lng-flsru-china/

[18] Single Prismatic Type B tanks - See article on SPB LNG carriers at: http://www.ihi.co.jp/offshore/spbmenu_e.htm

[19] OLAF system used on Prelude has been fully tested prior to delivery, see description at: http://fuelfix.com/blog/2014/05/08/otc-spotlight-award-fmc-technologies-offshore-footless-loading-arm/#23039101=0

[20] See description at: http://www.fmctechnologies.com/en/LoadingSystems/MarineSolutions.aspx

[21] See description at: http://www.trelleborg.com/en/fluidhandling/products--and--solutions/offshore--oil--and--gas--hoses/gas/cryoline--lng

[22] http://www.sevanmarine.com/solutions/hiload-lng

[23] http://www.upstreamonline.com/hardcopy/technology/article1443757.ece

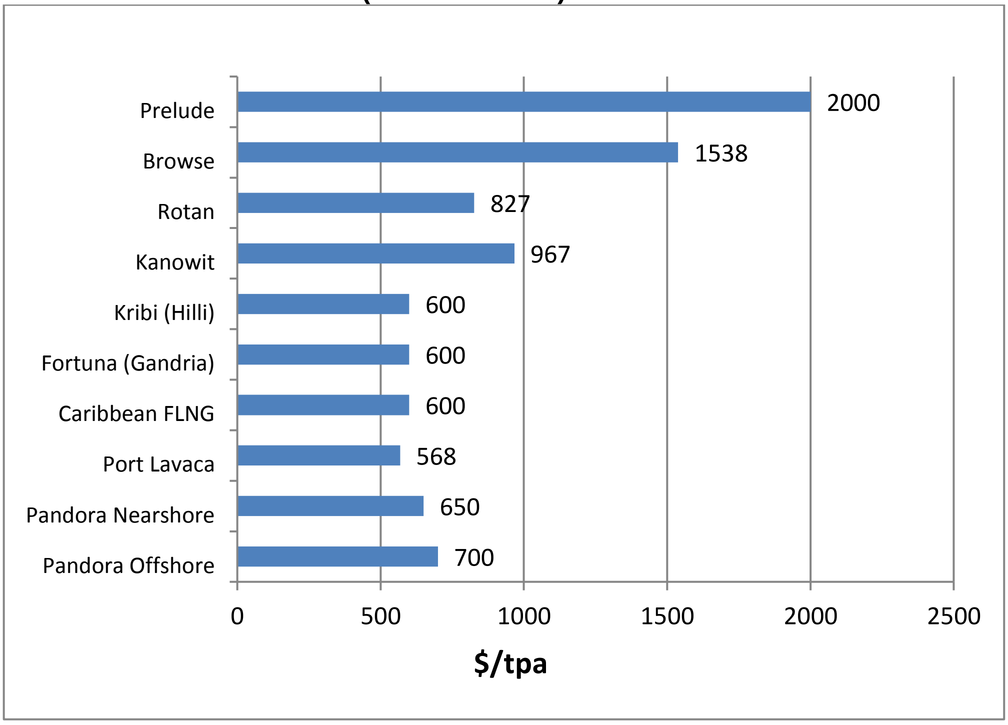
Chapter 4

4.1 Capital Costs (CAPEX)

Accurate cost information for the FLNG vessels currently under construction is difficult to obtain due to confidentiality, scope differences and that the projects are still in construction. This currently makes comparison on a like for like basis very difficult.

Figure 6 summarises the indicative CAPEX of the current developments expressed as $/mtpa[24]. These costs have been estimated from various press releases and statements made at recent conferences as discussed later in this chapter. These costs are for the vessel only and exclude the subsea systems, well activities, moorings, onshore base and owner's costs. The cost of these other components can be significant and close to that of the vessel, depending on the scope of the project e.g. number and complexity of the subsea wells and water depth. Using the vessel only cost allows direct comparison with onshore plants as the functional scopes are similar i.e. gas processing, liquefaction, storage and export. In addition to the costs for the vessels under construction, the reported costs of the Browse, Port Lavaca and Pandora proposals have been added for comparison.

Figure 6: INDICATIVE FLNG CAPEX (VESSEL ONLY)



Source: Industry sources collated by author

Prelude

Industry sources indicate the cost of the 3.6 mtpa Prelude project to be around $12 billion[25] giving a project metric cost of $3,300/tpa ($11.7/MMBtu[26]). Assuming the FLNG facility (vessel) represents

[24] A metric used for comparison calculated by dividing the capital cost in US$ by the LNG production rate in tonnes per annum.
[25] Article 'Shell's Prelude FLNG Project: An Offshore Revolution?', Peter Staas, Investing Daily, June 3rd 2011, http://www.investingdaily.com/13544/shells-prelude-flng-project-an-offshore-revolution/
[26] Using a conversion factor of $/tpa to $/MMBtu of 0.35%. This factor of 0.35% CAPEX is a typical industry figure and is calculated by spreading the project capital cost including interest over an agreed production period.

60% of the total project cost gives a metric of $2,000/tpa ($7.0/MMBtu). If the total fluids production of 5.4 mtpa is used (LNG + LPG + Condensate) this reduces to $1,385/tpa ($4.8/MMBtu).

Browse

A budget cost of $30 billion[27] has recently been reported for 3 x 3.9 mtpa FLNG facilities, which represents a project metric of $2,564/tpa ($8.97/MMbtu). Assuming the same 60% for the FLNG facility only (vessel) gives a metric of $1,538/tpa ($5.4/MMbtu). This cost is lower than Prelude and aligns with Shell's statement of significantly reducing the costs during the conceptual design.

Satu (Kanowit Field) & PFLNG2 (Rotan Field)

The value of the contract with DSME for the construction of the 1.2 mtpa Satu vessel is stated as $771 million[28]. Allowing an additional 50% for client supplied items and cost growth, would give a vessel cost of $1.16 billion i.e. $967/tpa ($2.9/MMBtu). PFLNG2[29] is slightly larger at 1.5 mtpa so assuming an economy of scale gained from this 25% increase in capacity still on a single vessel would indicate a metric of $827/tpa ($2.9/MMBtu).

Hilli[30,31], Gimi[32] and Gandria[33]

Golar LNG is far more forthcoming with costs as it is actively selling its solutions to the LNG industry and the costs are likely to be the first major consideration when comparing FLNG to an onshore plant option. Golar has stated at various conferences that its costs for the Hilli and Gimi FLNG vessels are in the order of $600/tpa ($2.1/MMBtu) and is confident of this cost as contracts have been placed for the conversions. However care needs to be taken with these quoted costs as this is a new technology and the vessels have not yet been completed. It has also announced the conversion of a third vessel 'Gandria' and a likely fourth as the second FLNG for Fortuna.

Caribbean FLNG

Exmar has quoted similar costs to Golar LNG for its Caribbean FLNG vessel[34]. Black and Veatch in their OTC paper[35] quotes a barge cost of $220/tpa but this on a 2012 basis. Adding escalation to 2016 plus the inshore jetty and the FSU for storage would indicate an overall cost of ca. $500-600/tpa.

Port Lavaca

Excelerate Energy originally developed its concept as an inshore FLNG for Port Lavaca in Texas at a cost of $2.5 billion[36] to produce 4 mtpa ($568/tpa). Its offshore concept was quoted at $700/tpa. The

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[27] Article 'Woodside scraps Browse LNG in Australia amid global oversupply', Sonali Paul, Gas Processing, March 23rd, 2016, http://gasprocessingnews.com/news/woodside-scraps-australia%E2%80%99s-browse-lng-amid-global-oversupply.aspx
[28] Article in Petronas in-house magazine at: http://www.petronas.com.my/our-business/Upstream/Documents/PETRONAS%20flow,%20Volume%2002.pdf
[29] Project description on offshore technology website at: http://www.offshore-technology.com/projects/pflng-2-rotan-flng-project-sabah/
[30] Article on Golar Cameroon project on Golar LNG website at: http://www.golarlng.com/index.php?name=seksjon/Stock_Exchange_Releases/Press_Releases.html&pressrelease=1955666.html
[31] Article on Golar's FLNG conversion on Poten website at: http://www.poten.com/wp-content/uploads/2015/01/Golar-Pushes-Forward-With-First-Ever-FLNG-Conversion.pdf
[32] Article on Gimi FLNG project on Rigzone website at: http://www.rigzone.com/news/oil_gas/a/136592/Keppel_Shipyard_Bags_705M_FLNGV_Conversion_Contract_from_Golar_LNG
[33] Article on Gandria FLNG project at: http://www.offshoreenergytoday.com/keppel-bags-flng-deal-from-golar-worth-684m/
[34] Article on Caribbean FLNG project on LNG Industry website at: http://www.lngindustry.com/floating-lng/12032014/Wison_to_deliver_FLNG_concept_study_for_Cott_275/
[35] Talib & Price (2013)
[36] See article on project being halted, Argus, 2nd September 2015 at: http://www.argusmedia.com/pages/NewsBody.aspx?id=1097475&menu=yes

higher cost for the offshore vessels is due to the inclusion of additional inlet gas treating and a slightly lower production rate.

Pandora

Wison has undertaken studies for Pandora FLNG[37] proposed for the Gulf of Papua and estimates the vessel costs to be $600/mtpa for the nearshore option and $700 for the offshore option.

Cost Comparison of the FLNG Offerings

With the exception of Prelude the costs are reasonably aligned at between $600-$1,000/tpa. The Kanowit and Rotan costs are slightly higher and this may be due to Petronas following a more traditional EPC capital project approach and applying its corporate standards. Golar LNG and Exmar are following a more industry standard design approach based on functional specifications and vendor standard equipment rather than client standards and design methods as used by the energy companies. The reason for the standard design approach is that the facilities are intended to be leased and reused so are not specific to a particular energy company.

The cost of the Prelude facility has been reported as being over the original budget. It is a very complex vessel when compared to the others currently in construction and could be regarded as a technology development project. It is using steam turbines to drive the refrigeration compressors requiring boilers and boiler feed water systems. Petronas is taking a simpler approach of using gas turbines to generate power to drive the electrically driven compressors on Kanowit. Golar LNG and Exmar appear to be taking the even simpler method of direct gas turbine-driven compressors. It is interesting to note that Shell appears to be proposing this simple direct gas turbine drive approach for its FLNG Lean vessel[38].

Cost Comparison with Onshore Plants

Cost comparisons between FLNG and onshore options will be very much project specific and must be studied on a case by case basis to determine whether FLNG offers a lower cost. However the recent decision by Woodside to move to a FLNG solution for Browse[39] was reported to be based on lower cost and a shorter schedule which makes sense when considering the high cost of Australian construction and that a 425 km pipeline to shore is required. Browse has just been shelved due to low energy prices.

The situation for USA Gulf Coast liquefaction projects is completely different in that the gas is sourced from the onshore transmission grid and construction costs are relatively low due to the extensive oil and gas facility fabrication infrastructure in the area. Excelerate Energy proposed an inshore barge solution for Port Lavaca at a cost of ca. $600/tpa but this was not progressed probably because the cost was very similar to the $660/tpa quoted by Cheniere for their Sabine Pass project[40]. New technology always has an inherent risk and an FLNG solution would need to show a significant cost advantage to justify that risk.

However looking at the possible East Africa developments and the likely high cost of onshore construction due the remote location (ca. $1600/tpa[41, 42]) and also the difficult decision making processes it is likely that FLNG would offer both a cheaper and quicker solution than onshore – for

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[37] See project presentation at: http://www.cottoilandgas.com.au/files/8714/0236/3949/Cott_Feasibility_Study_Presentation_Final_Issued.pdf

[38] See short Shell paper ‘A High Capacity Floating LNG Design’ at: http://www.gastechnology.org/Training/Documents/LNG17-proceedings/12-1-Barend_Pek.pdf

[39] See Woodside announcement of April 2015 at: http://www.woodside.com.au/Our-Business/Developing/Documents/FLNG%20browse%20fact%20sheet.pdf

[40] See Analyst presentation at: http://media.corporate-ir.net/media_files/IROL/10/101667/Analyst_Day_Presentation_WEBrev.pdf

[41] See Songhurst (2014) Page 29

[42] See Gaffney Cline Presentation at: http://www.gaffney-cline.com/downloads/east_africa_workshop/Major%20Gas%20Projects%20Development%20Plans%20and%20Costs.pdf

either inshore or offshore applications. This is demonstrated by ENI's decision to look at a FLNG solution for Coral South[43] where it is considering two FLNG vessels to operate as an early production system ahead of the onshore plants.

4.2 Operating Costs (OPEX)

Operating costs will include:

- Personnel on board
- Fuel gas
- Maintenance
- Consumables
- Waste disposal
- Supply base costs
- Support vessel costs e.g. tugs
- Insurance

Personnel on board

The number of people on board depends on the size and complexity of the vessel. On a large and highly complex facility like Prelude, which includes LPG and condensate production, this would be around 170 on a regular basis and increasing to 340 during start-up and maintenance. A middle range 2 mtpa vessel is likely to have 100-140 people on board. For a simple nearshore facility such as Exmar's Caribbean FLNG this will be less.

Fuel gas

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. In addition, gas will be used for power generation as well as other small fuel gas users. The cost of the gas is accounted for very differently by different energy companies. Some regard it as a zero cost item as it is owned by the energy company and if not used now would be produced in 20 years at a very low discounted value. Others regard it as a lost opportunity cost and will charge it at LNG cost. This paper assumes a cost of $5/MMBtu but this could be higher for deep water developments.

Consumables

This covers the make-up of refrigerants losses, lubricating oil, diesel oil, chemicals and similar items. For some processes the refrigerants may be extracted from the feed gas but this will depend on the composition i.e. extraction of propane and butane.

Maintenance

This includes the ongoing maintenance of the vessel and the subsea systems handled by the crew plus the major overhauls expected every 3-4 years, which will require additional personnel. It is not economic to return the FLNG to a shipyard due to the high cost of disconnection, decommissioning and downtime to sail to and from a shipyard.

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[43] Article 'Eni's Coral FLNG development plan approved by Mozambique', 26th February, 2016, World Oil, http://www.worldoil.com/news/2016/2/26/enis-coral-flng-development-plan-approved-by-mozambique

Tug and Support Vessels

A minimum of two and possibly three tugs will be required to manoeuvre the shuttle tanker alongside the FLNG vessel for offloading. These tugs would probably be dedicated to the project as it may not be practical to return to port between offloading, depending on the offloading frequency. A 2.5 mtpa vessel offloading to a 140,000 m^3 tanker will require approximately 39 ships/year (three/month). Security and standby vessels will also be required.

Supply base costs including supply vessels and helicopters

This will cover the onshore supply base supporting the offshore operation.

Insurance

Insurance rates for new technology are subject to negotiation. The rate for FLNGs is likely to be higher than onshore plant, which typically costs 0.03-0.07% of the site value.

OPEX Estimate

Recent proposals by the solution providers for a 2.5 mtpa vessel indicated an OPEX of $250,000/day i.e. approximately $90 million/year excluding fuel cost. Feed gas will be used as fuel at a typical rate of 12% of the feed rate and assuming $5/MMBtu adds a further $69 million/year. This total OPEX of $159 million/year represents $1.3/MMBtu as shown in table 3.

Table 3: OPEX Cost Estimate for 2.5 mtpa

Component	**$ m/year**		
Manning (100 people)	10	100,000	$/year per person
Maintenance	45	3%	CAPEX
Consumables refrigerant make-up, lubricants & chemicals	5		
Tugs, Support, Security Vessels	10	3	Tugs
Base Support, Helicopters	10		
Miscellaneous	10		
Sub total excl fuel	**90**		
Fuel Gas (12% Gas Feed)	69	5.0	$/mmbtu
Total	**159**		
OPEX	**1.3**	**$/mmbtu**	

Source: By author based on proposals

Production Cost & Value Chain

Using the typical solution providers' CAPEX estimates of $600-800/tpa ($2.1-2.8/MMBtu) plus an OPEX of $1.3/MMBtu gives an estimated production cost of $3.4-4.1/MMBtu. Adding a contingency of 20% for new technology growth increases this to $3.7-4.5/MMBtu. These costs are for the vessel only and exclude the drilling and subsea costs.

The Pandora FLNG[44] proposed for the Gulf of Papua states a tolling charge of $4/MMBtu plus OPEX of $2/MMBtu giving a production charge of $6/MMBtu, but this is for the complete production facility and not just the vessel and includes profit, so the $3.7-4.5/MMbtu for the vessel only is in the same range.

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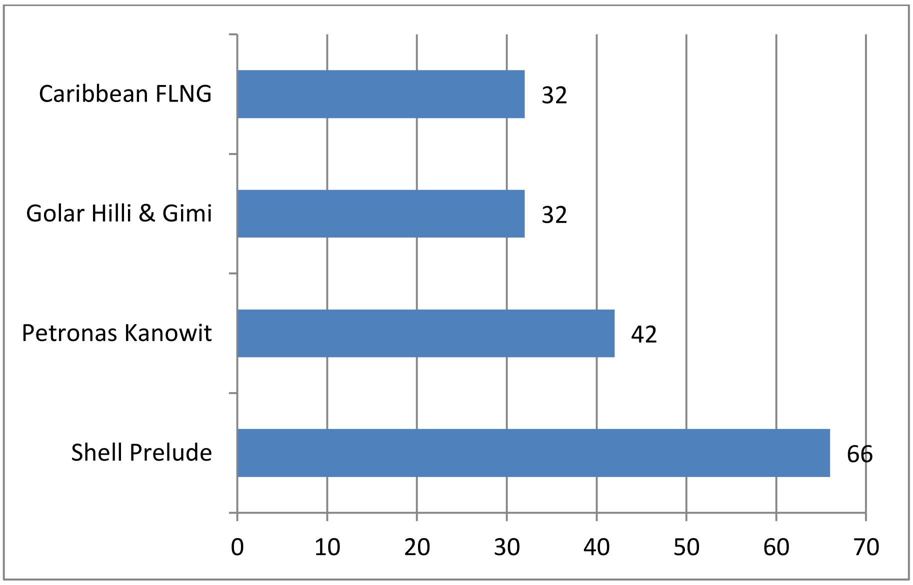
[44] See 'Wison offers Pandora FLNG concepts', Offshore Engineer, 2nd June, 2014, http://www.oedigital.com/vessels/flng/item/5795-wison-presents-pandora-lng-concepts

4.3 Development Schedule

Figure 7 shows the overall EPC schedules for the FLNG projects currently being built. They range from just 32 months for the simple Caribbean FLNG inshore barge to 66 months for the complex Prelude facility. The Kanowit vessel is also complex and 42 months is probably representative of mid-sized vessels (ca. 2 mtpa). Caribbean FLNG, Kanowit and Prelude are new builds whereas the Golar Hilli and Gimi vessels are LNG tanker conversions

These schedules cover the EPC phase only i.e. duration from the final investment decision to completion of construction and do not include pre-FID activities e.g. planning, permits, conceptual engineering, arranging project financing, nor the post construction activities of towing to site, installation and commissioning. Onshore plants typically take 48-60 months to construct.

Figure 7: Current FLNG Schedules in Months



Source: By author from published data

The extent to which FLNG can offer a schedule saving over an onshore development is project and location specific. However, reduced schedule risk will likely be a more significant factor in choosing a shipyard fabricated FLNG than an onshore constructed plant which frequently experience delays. The Korean shipyards have a good track record of delivering major projects on time (and on budget) but the same cannot be said of many onshore projects which can suffer from extreme weather conditions, limited infrastructure, limited resources (particularly when in competition with other projects) and poor industrial relations[45].

FLNG may also offer significant schedule savings in obtaining the necessary consents, which can be a lengthy process for greenfield onshore developments. An offshore moored FLNG vessel has relatively little social and environmental impact when compared with an onshore plant.

[45] See Ledesma, Palmer and Henderson (2014)

Chapter 5

5.1 Commercial Considerations

As stated earlier, the cost of producing LNG from offshore gas reserves using FLNG should be lower than from onshore plants due to the lower CAPEX, albeit this will be somewhat offset by higher OPEX.

Further, the project cash flow exposure, payback period and rate of return will be improved due to the expected shorter schedule and earlier production and therefore earlier revenue. The schedule could also be reduced further if speculative units are built on a standard design functional basis and become available as proposed by Golar LNG and Exmar. This is the same model being used by them for the FSRU market.

The option to lease from the FLNG solution providers further improves the cash flow and offers an advantage to the smaller independent oil and gas companies who do not have the capital available to purchase the FLNG vessel and carry it on their balance sheet. This benefit could also apply to the major energy companies who currently have limited investment capital due to the low energy process.

This standard design approach by the leasing companies also enables possible re-use, reducing the sunk cost risk on a specific project. Whilst this approach is common on FPSOs it is a ‘first’ for the LNG liquefaction market.

5.2 Project Financing

The major lending banks are still reluctant to finance FLNG developments due to the ‘first of a kind’ factor, but this stance is softening as confidence is increasing, with 7 projects now under construction. Confidence should increase further when the first vessel comes on stream in 2016 – assuming it performs as specified.

Exmar was able to arrange project financing for the Caribbean FLNG[46] through the Industrial and Commercial Bank of China (ICBC) that was underwritten by the Chinese EXIM bank[47]. It is expected that this will also be the case on further Exmar projects.

Golar LNG has been able to raise $960 million[48] of financing from China’s shipbuilding conglomerate China State Shipbuilding Corp for the Golar Hilli. Financing arrangements for the second vessel (Golar Gimi) and the proposed 3rd vessel (Gandria) have also been arranged[49] enabling all three vessels to be converted without needing further equity.

Golar LNG has also just announced a joint venture with Schlumberger ‘OneLNG’[50] that will offer to supply, operate and finance the complete offshore scope – reservoir, subsea and FLNG vessel. This

[46] Refer to Exmar Finds Funding for Caribbean FLNG, World Maritime News, 7th April 2016: http://worldmaritimenews.com/archives/164622/exmar-finds-funding-for-caribbean-flng/

[47] See EXIM bank is among the early financiers of FLNG, HIS Fairplay: http://fairplay.ihs.com/article/13485/flng-projects-face-financing-challenges

[48] Golar LNG gets $960M financing for Golar Hilli conversion, Refer to Seeking Alpha: http://seekingalpha.com/news/2642485-golar-lng-gets-960m-financing-for-flng-conversion

[49] For more information on Golar enters Into agreements for 3rd Floating Liquefaction Facility, refer to Golar website: http://www.golarlng.com/index.php?name=seksjon/Stock_Exchange_Releases/Press_Releases.html&pressrelease=1940318.html

[50] http://www.slb.com/news/press_releases/2016/2016_0725_slb_golar_onelng.aspx

will be of particular interest to the smaller independent energy companies who have limited technical and financial resources. This is discussed further in section 7.1.

Excelerate Energy[51] has stated that FLNG projects also offer new financial challenges. According to Excelerate chief executive Rob Bryngelson, “Projects are likely to be only 50-60% debt financed, rather than the 70-80% debt financing we see with onshore liquefaction projects”. This means that early projects will have to be funded by more equity financing than their onshore counterparts.

[51] FLNG projects to accelerate addition of new supply – New Importers, Argus article 29th April, 2013: http://www.argusmedia.com/pages/NewsBody.aspx?id=844756&menu=yes

Chapter 6

6.1 SWOT Analysis

A summary of the strengths, weaknesses, opportunities and threats for FLNG projects is shown in table 4 and these are discussed further in the following sections.

Table 4: SWOT Analysis

Strengths	**Weaknesses**
Wide range of production - 0.5 to 6.0 mtpa	Uptime of berthing & transfer due to sea state
Option to lease	Unproven offshore experience
Lower CAPEX for high cost locations	Tanker Conversions have a limited design life
Avoids costly gas pipeline from field to shore	High OPEX, high maintenance cost
Likely quicker schedule - fast track	Perception that it is 'too difficult'
Higher confidence in schedule and cost	Congested layout
Less 'NIMBY' issues	Minimal local content
Technology backed by IOCs	Safety design and risk analysis not mature
Onshore site (land) is not required	Offloading system sea state limitations
No jetty or breakwater required	Marine classification process not mature
Opportunities	**Threats**
Relocation so not a 'sunk cost' as onshore	Low LNG prices due to lower oil prices
Monetise stranded offshore gas fields	Low cost onshore shale gas LNG from USA
No land for onshore	Lack of finance from commercial banks
Little infrastructure onshore	Ship yard capacity or willingness to bid
Limited onshore permitting required	Unproven contractors enter the market
Early monetisation (EPF)	Geopolitics demand high local content
Opening for smaller energy companies	
Convert retired LNG tankers adding value	
Meeting increasing demand for gas	
Financing by banks when technology proven	

6.2 Strengths

World scale onshore plants tend to be designed as multiple 4-5 mtpa trains whereas FLNG offers a wider range of train size e.g. from Caribbean FLNG at 0.5 mtpa up to Prelude at 3.6 mtpa.

Further FLNG units can be leased or contracted on a tolling basis improving cash flow for the energy company e.g. Ophir Fortuna and not carrying the asset on the balance sheet.

The other major cost advantage is avoiding the need for a subsea pipeline to shore. An example of this is the Ichthys project where the 890 km x 42" pipeline to Darwin required 700,000 tons of steel. Such pipelines cost in excess of $1 billion and can be avoided by using FLNG.

Small to mid-scale FLNG can typically be delivered quicker due to shipyard manufacturing techniques and typically with a higher schedule confidence than onshore constructed plants. Traditional onshore plants can often be delayed due to local labour problems or take longer due to the need to build the required infrastructure.

FLNG with possible lower capital costs, the opportunity to lease or toll and faster schedule should enable earlier monetisation of the gas assets and improve cash flow.

FLNG also provides a solution where land onshore is not available or difficult to develop due to permitting issues. An example of this is the possible development of the gas fields just 80 km offshore Israel where space is not readily available along the highly developed coastline.

6.3 Weaknesses

FLNGs are currently not suitable for harsh environments where tandem offloading, as used for oil FPSOs, is required. Current proven technology limits offloading to the use of hard arms in a side-by-side configuration. This limits offloading operations to a significant wave height of approximately 2.5 metres and may negatively impact availability. Several cryogenic tandem transfer systems have now been developed and qualified as discussed in section 3.4. Tandem offloading employing stern-bow loading systems will require dedicated LNG carriers with bow loading manifolds and dynamic positioning capability. The use of a floating hose may require the mid-ship manifold to be strengthened to take the additional load.

FLNGs are not suitable for very large developments due to shipyard limitations on the size of hull that can be built. FLNG developments up to 7.5 mtpa against 4 mtpa currently are being considered e.g. Abadi, 7.5 mtpa and Scarborough 6-7 mtpa. In addition, whereas onshore plants may add additional liquefaction trains, incremental expansion of FLNG units is not possible without taking the entire facility out of service for a considerable period of time. However, it is possible to add multiple repeat FLNG units but this will not offer any economy of scale as for onshore plants.

Low local content is another potential drawback as construction is almost exclusively out of country. Many developing countries view LNG projects as a major opportunity for local employment, with thousands of people employed during construction of an onshore plant. FLNG limits local employment opportunities to the operational phase which will not meet the required expectations of many developing or developed countries which promote the use of their in-country labour resources e.g. Brazil, Indonesia and Nigeria.

Offshore OPEX will be higher than onshore due to increased logistics costs and the requirement for various support vessels to service the facility. Potential CAPEX savings will be offset by the higher OPEX over the life cycle of the project. However, CAPEX is very often ‘king’ when FIDs are made.

The banks are still reluctant to finance FLNG due to the perceived risks of ‘first of a kind’ developments but this appears to be changing. The Caribbean FLNG was in part financed with US Exim and Sinosure support and Golar LNG have recently announced financing arrangements for the Hilli and Gimi conversions. This is a positive step and financing is likely to become easier when operating experience of the first units becomes available from 2016 onwards.

Concerns have been expressed over the field life expectancy of FLNGs developed as LNG tanker conversions. However it has been pointed out that the tanks are in excellent condition and the hull will be reinforced. Furthermore, the processing plant will be new and located on new deck space created by adding floating side structures (sponsons).

Finally, many have regarded the liquefaction process as being too complicated for offshore application. FLNG vessels are certainly more complicated than major FPSOs but, following many years of major studies including physical equipment modelling and pilot unit testing, the companies now constructing these vessels feel these issues have been solved. However the industry is waiting to see how they perform in practice.

6.4 Opportunities

The major opportunity for FLNG is the monetisation of offshore gas fields that cannot be otherwise developed due to high cost of a pipeline to shore or the lack of a suitable onshore location due to land issues, permitting issues or lack of infrastructure. Also FLNG can offer the possibility of lower production costs and earlier production improving the project economics. The option to lease will enable smaller independent energy companies with limited capital to enter the market and meet the increasing world-wide demand for gas. FLNG also provides the opportunity to convert retired Moss LNG carriers into small to mid-scale floating liquefaction units. Moss tanks are ideal for offshore application due to the lack of sloshing issues and process plant can be added by way of sponsons as proposed by Golar LNG for the 'GoFLNG' concept. Finally FLNG provides financing opportunities for the banks albeit they have been somewhat reluctant to date due to FLNG being new technology but this appears to be easing.

6.5 Threats

Low oil indexed and 'spot' gas prices are a major threat for both FLNG and onshore plants. Assuming future higher prices, there is an opportunity to place an order now with a competitive shipyard, although a mid-scale 2.5 mtpa FLNG will likely take 48 months to construct.

Shipyard capacity is a possible threat for larger FLNGs due to the limited number of large dry docks available but China is keen to enter the market and the existing shipyards are likely to add larger dry docks if there is market opportunity. There is also the threat of other shipbuilding and module construction work becoming more profitable and less risky.

FLNG is a combination of cryogenic process plant engineering and marine engineering and only a limited number of contractors have those combined skill sets in-house. There are many very capable onshore cryogenic contractors but they will need to ensure their designs reflect the knowledge of offshore plant operation and maintenance, which has been learnt by the major FPSO contractors over many years. This knowledge must be incorporated into the design to ensure the vessels work efficiently and, more importantly, safely – a poorly executed project would likely set back the FLNG business and would not be helpful in increasing the confidence of the banks to provide finance.

Chapter 7

7.1 Small to Mid-Scale Solution Providers

In addition to the FLNG projects being developed by Shell and Petronas on a traditional capital project EPC basis, the FSRU solution providers and the oil FPSO contractors are now aggressively pursuing the FLNG market on a leasing or tolling basis, where they would build and own the vessel and ideally operate it too. The major FSRU companies are Exmar, Golar LNG, Höegh LNG and Excelerate Energy and the major FPSO contractors are SBM Offshore, BW Offshore, Bumi Armada and MODEC.

However, Höegh LNG and Excelerate Energy who are major FSRU providers have recently stated they will no longer pursue the FLNG market and will focus their resources on the FSRU market. Flex LNG which was the pioneer of leased FLNG has also withdrawn. These companies have been included in this chapter for completeness.

Exmar

Exmar[52], a specialised maritime logistics company based in Belgium, offers energy solutions to the oil and gas industry. It owns 5 LNG tankers, 10 FSRUs and the 0.5 mtpa Caribbean FLNG. A second prospective 0.6 mtpa FLNG vessel is under construction. Exmar's FLNG strategy is the same as for the FSRU market – build, own and operate and focus on new build FLNG vessel of smaller capacities (0.5-0.6 mtpa).

Golar LNG

Golar LNG[53,54] is based in Norway and operates 20 LNG tankers of which nine have been added to the fleet in the last two years, and four FSRU vessels with three more in construction. It is currently converting three of its LNG tankers into FLNG vessels – Hilli, Gimi and Gandria - and is in discussions regarding the conversion of a fourth vessel. Its strategy is conversion of its existing vessels by installing sponsons on the side of the tanker for the installation of the liquefaction plant. To date three vessels have been based on adding four liquefaction trains of a nominal 0.6 mtpa each, providing a production capacity of 2.4 mtpa. Its approach is a standard design that can be reused rather than being project specific.

Golar LNG has recently announced a joint venture with Schlumberger referred to OneLNG^{SM} [55]to rapidly develop low cost gas reserves. This will combine Schulmberger's reservoir knowledge, wellbore technologies and production management skills with Golar LNG's FLNG skills to provide a 'one stop shop'. This will be ideal for the smaller independent energy companies with limited in-house resources. OneLNG^{SM} is also looking to provide project financing. They have stated that they expect to conclude 5 projects in the next 5 years.

SBM Offshore

SBM Offshore[56] is based in the Netherlands and provides FPSO solutions to the offshore energy industry, over the full product life-cycle and has multiple units in operation. The Company's main activities are the design, supply, installation, operation and the life extension of FPSO vessels. These

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[52] Refer to Exmar Floating LNG - FLNG home page: http://www.exmar.be/en/activities/lng/floating-liquefaction-flng
[53] Refer to Golar LNG Floating Liquefaction (FLNG) home page: http://www.golarlng.com/index.php?name=Our_Business%2FFloating_Liquefaction.html
[54] See Golar press release 'Cameroon FLNG Project Reaches Major Milestone' 30th September 2015: http://www.golarlng.com/index.php?name=seksjon/Stock_Exchange_Releases/Press_Releases.html&pressrelease=1955666.html
[55] http://www.slb.com/news/press_releases/2016/2016_0725_slb_golar_onelng.aspx
[56] Refer to SBM home page http://www.sbmoffshore.com/who-we-are/company-profile/

are either owned and operated by SBM Offshore and leased to its clients or supplied on a turnkey sale basis. For the FLNG market it is offering a mid-sized (1.5-2.0 mtpa) twin hull FLNG[57] using converted Moss tankers.

BW Offshore

BW Offshore, based in Norway, is one of the major FPSO providers and has 25 years' experience. It has delivered 13 FPSO projects and 50 turrets and offshore terminals. It is currently working with Pangea LNG and pursuing the Noble King project in Israel[58]. It also operates 17 LNG tankers with 4 more under construction. Sister company BW Gas has just supplied the second FSRU (BW Singapore) for Ain Sokhna and a further FSRU will be supplied for the second Port Qasim terminal in Pakistan further establishing itself in the LNG supply chain.

Bumi Armada

Bumi Armada Berhad ("Bumi Armada") is a Malaysian based international offshore oil and gas services provider and has a fleet of 6 oil FPSOs. It has recently entered the LNG market with the award of the Malta LNG FSU project and has been working with Keppel and IHI on possible FLNG concepts[59].

MODEC

MODEC[60] is a major Japanese based company and currently operates 17 FPSOs with 4 more in construction. It has teamed up with Toyo Engineering and IHI to design a 2 mtpa FLNG vessel called LiBro[61]. The refrigeration cycle will use lithium bromide as a pre-cooling refrigerant followed by a nitrogen cycle using the AP-N process. IHI will provide the SPB tank design.

Höegh LNG

Höegh LNG[62] based in Norway operates five LNG tankers and five FSRUs. Three further vessels are under construction. It was one of the earliest to pursue the FLNG market and has been in discussion with energy companies about developing a generic design. Its concept is based on a new build vessel and originally using the novel and unproven Niche liquefaction process, which is a dual gaseous refrigerant scheme using nitrogen and methane. This has now changed to proven SMR and DMR options in line with other FLNG developers. Höegh LNG has recently decided to not to pursue floating liquefaction but to focus its resources on the FSRU business.

Excelerate Energy

Excelerate Energy[63] based in the USA was a pioneer of the FSRU concept with the Gulf Gateway project offshore Gulf of Mexico. It currently has ten vessels operating either as LNG tankers or FSRUs. A further eight vessels are under construction by DSME with a capacity of 173,000 m^3 and a regas capacity in the range of 3-4 mtpa. Excelerate developed its FLSO liquefaction concept for both inshore (Port Lavaca) and offshore use. The inshore concept located the gas treatment onshore, freeing up deck space for 4 mtpa liquefaction, whereas offshore was 3 mtpa. Excelerate Energy like Höegh has decided to not to pursue floating liquefaction and focus on the FSRU business.

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[57] For description of SBM Mid Scale Floating LNG concept refer to: http://www.sbmoffshore.com/mid/

[58] See article Pangea and BW Offshore to partner for Tamar FLNG, 7th March 2013: http://www.2b1stconsulting.com/pangea-lng-and-bw-offshore-to-partner-in-israel-noble-king-flng/

[59] Refer to Borneo Post, 1st April 2014 'Bumi Armada eyes the FLNG market': http://www.theborneopost.com/2014/04/01/bumi-armada-eyes-flng-fsru-market-segments/

[60] Refer to MODEC home page: http://www.modec.com/about/index.html

[61] See HIS Fairplay communication 'MODEC Eyes the FLNG market' 12th September 2014: http://fairplay.ihs.com/ship-construction/article/4048021/modec-eyes-floating-lng-market

[62] Refer to Höegh LNG home page: http://www.hoeghlng.com/

[63] Refer to Excelerate Energy Floating LNG home page: http://excelerateenergy.com/flng/

Flex LNG

FlexLNG[64] was the pioneer of the commercial pursuit of FLNG projects on a leasing basis. It decided to withdraw from the FLNG business and is now pursuing the LNG tanker business[65].

[64] Refer presentation 'FLEX LNG Changing the LNG Industry' 7th January 2010: http://www.flexlng.com/publish_files/FLEX_LNG_Presentation_at_SEB_Enskilda_Nordic_Seminar_Copenhagen_7_January_2010.pdf

[65] Refer to FlexLNG home page for new strategy: http://www.flexlng.com/

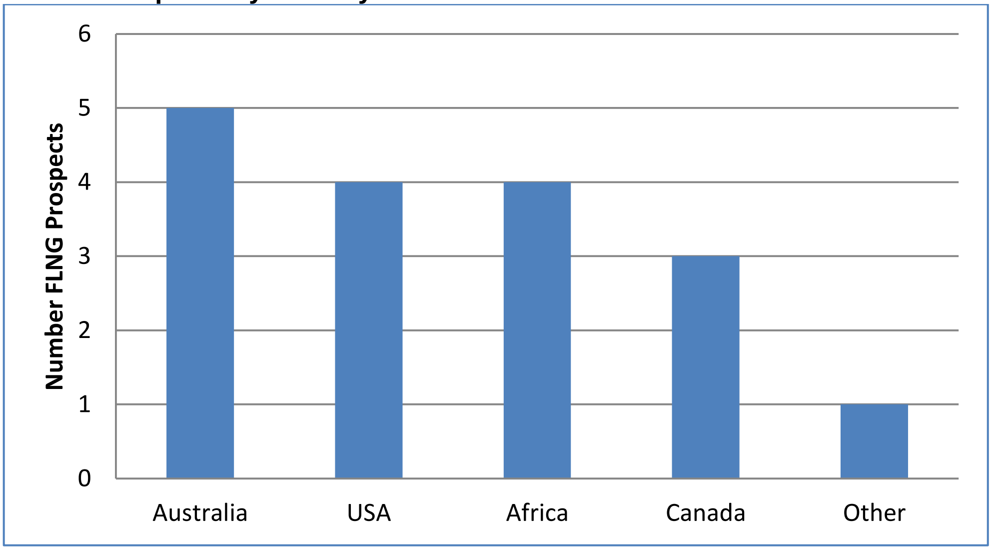
Chapter 8

8.1 Market Impact

FLNG will enable the development of currently stranded offshore gas reserves delivering more LNG into the gas market. The current 7 projects under construction will produce a total of 17 mtpa and a further 17 probable projects have been identified with the potential of delivering a further 55 mtpa i.e. a total FLNG production of around 72 mtpa into the market. If only 50% of the probable projects proceed this would still represent **18% of the 2014 global trade**[66] of 241 mtpa – a significant amount.

The locations of these prospects are shown in figure 8 and the list is shown in Appendix 3.

Figure 8: FLNG Prospects by Country



Source: Author

The potential market impact has been well summarised by the following statements:

Golar LNG – '*In an era of intense competition in the LNG industry and the high cost and long lead time of land based LNG facilities, Golar LNG Limited believes highly cost efficient approaches based on floating LNG liquefaction, …. facilities of the types now being developed …… will be key to substantial additional growth opportunities'*[67]*.*

Douglas Westwood – '*Operators are attracted to FLNG, as, compared to its onshore alternative, FLNG facilities are more secure, can have shorter lead-times, remove the need for long pipeline to shore and offer a potentially lower-cost alternative to monetizing stranded gas fields.*
There is a huge interest in the pioneering projects that will drive market spend over the coming years. Future commitments by operators to the FLNG market hinges on the success of these pioneering projects. Following

[66] Refer to IGU (2015), page 7 'LNG Trade'
[67] See Golar LNG FLNG home page: http://www.golarlng.com/index.php?name=Our_Business%2FFloating_Liquefaction.html

these projects is a second wave of new projects that are yet to be sanctioned but are expected to drive a growth in expenditure from 2019 onwards. This includes major projects in frontier regions such as East Africa'.[68]

The Maritime Executive – '*Despite a current pause in commitments to new projects, the capital expenditure for FLNG vessels is expected to amount to $35.5 billion over 2015-2021'*[69].

The Maritime Executive - '*Operators are attracted to FLNG, as, compared to its onshore alternative, FLNG facilities are more secure, can have shorter lead-times, remove the need for long pipeline to shore and offer a potentially lower-cost alternative to monetizing stranded gas fields'.*[70]

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[68] See description of Douglas Westwood World FLNG Market Forecast 2015-2021 Report Description: *http://www.douglas-westwood.com/report/energy/world-flng-market-forecast-2015-2021/*

[69] See first paragraph in article ''Waiting for the second FLNG wave' by Wendy Laursen 8th February 2015' : *http://maritime-executive.com/features/waiting-for-the-second-flng-wave*

[70] See article ''Waiting for the second FLNG wave' by Wendy Laursen 8th February 2015, 'The attraction of FLNG': *http://maritime-executive.com/features/waiting-for-the-second-flng-wave*

Chapter 9

9.1 Conclusions

Current Projects & Prospects

After 40 years of engineering studies the first FLNG project was approved in 2011 by Shell for its Prelude field located in the Timor Sea. Following that decision 6 further projects are now in construction albeit Rotan has just been delayed by 2 years due to current low energy prices. The first vessel to start operations is likely to be the Petronas PFLNG Satu located on the Kanowit gas field, offshore Malaysia. The vessel sailed to the field location in May 2016 and start-up is expected in late 2016 or early 2017. The Caribbean FLNG inshore barge is complete and ready for operation but was not installed due to the lack of available gas feed and the owners Exmar are looking for another location.

A further 17 FLNG prospects have been identified representing 55 mtpa of LNG production. If half of these proceed it will result in FLNG production representing 18% of the 241 mtpa global production in 2014 – nearly a fifth of the market.

Advantages & Disadvantages

FLNG offers many advantages for the development of remote offshore gas reserves which are often referred to as ‘stranded’ gas. FLNG production costs should be lower than the equivalent onshore development by eliminating the cost of the pipeline to shore and the need for a jetty and, where required, a breakwater. Further cost reductions will apply where onshore construction costs are high e.g. Australia. A recent demonstration of this is the decision by Woodside to develop the Browse field in Australia as an FLNG and not an onshore plant, albeit this has now been shelved due to current low energy prices. Similarly ENI is considering FLNG for offshore Mozambique as an early production system due to expected high construction cost of an onshore LNG plant.

In addition to lower cost, FLNG offers a much higher confidence in meeting the delivery schedule and production date by using a shipyard rather than onshore construction in remote and challenging areas which frequently experience major delays. First production date is critical to project profitability and very important to lenders on financed projects.

FLNG also lends itself well to inshore developments for the same reasons of lower cost and on time delivery for projects located in areas where onshore construction is difficult or expensive, or land is not readily available, or permitting is very difficult. Simple FLNG facilities (liquefaction only) are typically in the cost range of $700-800/tpa which is similar to the onshore plants currently under construction in the USA reflecting the cost effectiveness of shipyard fabrication.

However there are disadvantages. The main one currently is that offloading is currently restricted to relatively benign ocean conditions due to the need to use proven offloading arms which have a limit of 2.5 m significant wave height. Cryogenic hoses and other concepts that can employ tandem loading have been developed and qualified by 4 suppliers and this will widen the operating window for offloading. As with any new technology the operators have selected the least demanding projects for the first deployment of this approach and will leave the more challenging developments to a later date when more experience has been gained. The other disadvantage is the very limited local employment content with FLNG which is often a major political consideration.

Commercial Considerations

From a commercial standpoint FLNG has opened the opportunity for energy companies to obtain liquefaction facilities on a leased or tolling basis from the FSU and FPSO contractors. Further the approach of these companies is quite different from the major energy companies in that they are looking to supply relatively standard designed vessels using functional specifications that can be reused on other fields. This is very different from the energy company approach to design on a project bespoke basis and follow the exacting design methods and specifications developed over many years. Most vendors would say that this approach adds considerable cost. However, both Shell[71] and ENI have stated that they are seeking a ‘design one and build many’ philosophy for future developments.

This functional approach would appear to reduce the development cost considerably based on the costs currently being quoted by the leasing companies. This will be tested over the next few years as the first developments become a reality and the actual costs are established. It must be stated that these same companies introduced leased FSRUs into the terminal market and their success has been unprecedented in what is a conservative LNG business. The industry is waiting to see if the same will happen with FLNG.

Golar LNG and Exmar are also looking to build vessels on a speculative basis. This has proved very successful in the FSRU market by reducing project lead times and enabling earlier production and revenue and the same would apply here for the liquefaction market. It is likely that these speculative vessels would need some project specific modifications before delivery but would likely be delivered far more quickly than a project specific new build vessel or onshore plant.

The recently announced a joint venture between Golar LNG and Schlumberger ‘OneLNG’[72] is going one step beyond by offering a ‘one stop shop’ for the supply and operation the full offshore development scope - reservoir, subsea and FLNG vessel including project financing. This could be a ‘game changer’ for the smaller independent energy companies who wish to monetise gas reserves but have limited technical and financial resources

Looking Forward

Many in the LNG industry view FLNG as a ‘game changer’ for the development of offshore gas fields in the same way that FPSOs enabled oil production for remote & deep water fields . However their success will depend on the performance of the projects currently in construction – performance not only in terms of reliable LNG production but whether the expected cost and schedule savings can be realised. The industry is waiting with interest, particularly in the current low cost energy market where lower production costs and earlier revenue would offer a major advantage over onshore plants.

[71] Refer to ‘The Engineer’ article on Shell Prelude ‘Design, 4th July 2011: https://www.theengineer.co.uk/shell-set-to-build-worlds-biggest-floating-structure/

[72] http://www.slb.com/news/press_releases/2016/2016_0725_slb_golar_onelng.aspx

Appendix 1 – First Inshore Barge 1959

Figure 9: The First Inshore LNG Barge

The FLNG barge was installed in 1959 on Lake Calcasieu close to Lake Charles and was designed as a pilot unit producing 50,000 tpa of LNG.

The plant comprised all the necessary processes including amine wash, drying, pre-cooling to remove heavy hydrocarbons followed by liquefaction using the turbo-expander process. Gas that was not liquefied was compressed and cooled and recycled back into the turbo-expander.

LNG was sent to a land based double containment 5,700 m^3 LNG tank constructed from aluminium with perlite insulation.

This LNG was originally destined for shipment to Chicago by barge but supplied the first cargoes to Canvey Island terminal in the UK until the Algerian plants came on stream.

Appendix 2 – List of FLNG Developments

Country	Developer	Project	mtpa	Start-Up
Construction				
Malaysia	Petronas	PFLNG Satu, Kanowit Field	1.2	2016
Australia	Shell	Prelude	3.6	2017
Cameroon	SNH/Perenco/Golar LNG	Kribi (Golar Hilli)	1.2	2017
Malaysia[73]	Petronas	PFLNG2, Rotan Field	1.5	2020
Equatorial Guinea[74]	Ophir	Fortuna (Golar Gandria)	2.2	2019
TBA[75]	Exmar	Caribbean FLNG	0.5	TBA
TBA	Exmar	Speculative	0.6	TBA
		Total	**10.8**	
Planning/Pre-engineering Phase				
Australia	ExxonMobil	Scarborough/Thebe	6.5	TBA
Australia	Woodside	Browse FLNG1	3.6	TBA
Australia	Woodside	Browse FLNG2	3.6	TBA
Australia	Woodside	Sunrise	4.0	TBA
Cameroon	NewAge/Euroil/Lukoil	Etinde	1.0	TBA
Canada	Altagas/EDFT/Idemitsu	Exmar Kitimat	0.6	2018
Canada	Orca LNG	Orca LNG	4.0	2020
Canada	Altagas	Triton	2.0	2020
Congo	NewAge/SNPC	BLNG	1.0	2019
Indonesia[76]	Inpex/Shell	Abadi	7.5	On hold
Israel	Noble Energy	Tamar	3.4	TBA
Mozambique	ENI	Coral South	2.5	2020
Tanzania	Ophir/BG/Statoil	Mzia/Chaza/Jodari	2.5	TBA
USA[77]	Excelerate Energy	Lavaca Bay	4.4	On hold
USA	Delfin	Defin LNG	5.0	TBA
USA	McMoran Exploration	Main Pass Energy	4.0	TBA
USA	Cambridge Energy	CE FLNG	2.5	TBA
		Total	**58.1**	

[73] Was delayed to 2020 but is back on schedule
[74] Construction has started on speculative basis and FID expected mid 2016
[75] Was assigned to Columbia but gas not now available and awaiting new location
[76] On hold
[77] On hold. Excelerate Energy focusing their resources on FSRU market

Appendix 3 – FSRU Projects

Project	Country	Status	Start-up	Type	FSRU Contractor
Gulf Gateway	USA	Retired	2005	SRV	Excelerate Energy
Teesside	UK	Retired	2007	SRV	Excelerate Energy
Bahia Blanca	Argentina	Operating	2008	FSRU	Excelerate Energy
North East Gateway	USA	Operating	2008	SRV	Excelerate Energy
Pecem	Brazil	Operating	2008	FSRU	Golar LNG
Guanabara Bay	Brazil	Operating	2009	FSRU	Excelerate Energy
Mina Al-Ahmadi	Kuwait	Operating	2009	FSRU	Golar LNG
Dubai Supply Authority	UAE	Operating	2010	FSRU	Excelerate Energy
Neptune	USA	Operating	2010	SRV	Höegh LNG
GNL Escobar	Argentina	Operating	2011	FSRU	Excelerate Energy
Livorno OLT	Italy	Operating	2011	FSRU	Owned by OLT
Hadera	Israel	Operating	2012	FSRU	Excelerate Energy
West Java	Indonesia	Operating	2012	FSRU	Golar LNG
All Saints Bay	Brazil	Operating	2013	FSRU	Golar LNG
Tianjin	China	Operating	2013	FSRU	Höegh LNG
PGN Lampung	Indonesia	Operating	2014	FSRU	Höegh LNG
Klaipedos Nafta	Lithuania	Operating	2014	FSRU	Höegh LNG
EGAS - Ain Sokhna 1	Egypt	Operating	2015	FSRU	Höegh LNG
Engro - Port Qasim	Pakistan	Operating	2015	FSRU	Excelerate Energy
Aqaba LNG Terminal	Jordan	Operating	2015	FSRU	Golar LNG
EGAS - Ain Sokhna 2	Egypt	Operating	2015	FSRU	BW Gas
WGA – Tema Terminal	Ghana	Development	2017	FSRU	Golar LNG
Gas Sayago	Uruguay	Construction	2017	FSRU	MOL
Bay of Bengal	Bangladesh	Development	2017	FSRU	Excelerate Energy

Bibliography

Ledesma, David: Floating Liquefaction (FLNG): How far will it go? 20th World Petroleum Congress

IGU (2015): IGU World LNG Report 2015, page 7 'LNG Trade': http://www.igu.org/sites/default/files/node-page-field_file/IGU-World%20LNG%20Report-2015%20Edition.pdf

List of FSRUs – IGU World LNG Report 2015 pp 79-82

Ledesma, David: Floating Liquefaction (FLNG): How far will it go? 20th World Petroleum Congress

Ledesma, Palmer and Henderson (2014): 'The Future of Australian LNG Exports – Will domestic challenges limit the development of future LNG export capacity?', D. Ledesma, N. Palmer and J. Henderson, OIES September 2014, NG 90, https://www.oxfordenergy.org/publications/the-future-of-australian-lng-exports-will-domestic-challenges-limit-the-development-of-future-lng-export-capacity/

Quinn (2016): Fortuna Article by Oliver Quinn – LNG Industry March 2016, pp 29-32

Songhurst (2014): LNG Plant Cost Escalation, Brian Songhurst, OIES, February 2014, NG83 https://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/02/NG-83.pdf

Talib and Price (2013): OTC Paper LNG Barges: The Offshore Solution for Export of US Pipeline Gas by Talib and Price, 2013, OTC-23939-MS. https://www.onepetro.org/conference-paper/OTC-23939-MS

Other articles

Floating LNG: Revolution and evolution for the global industry, KMPG, Nov 2014 www.kmpg.com/energy

Nitrogen Cycle Article by Air Products – LNG Industry March 2016 pp 17-22

Side-by-Side LNG Loading Article by FMC – LNG Industry March 2016 pp 41-44