GOLAR LNG: DELIVERING THE WORLD'S FIRST FSRUs

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Golar LNG Ltd

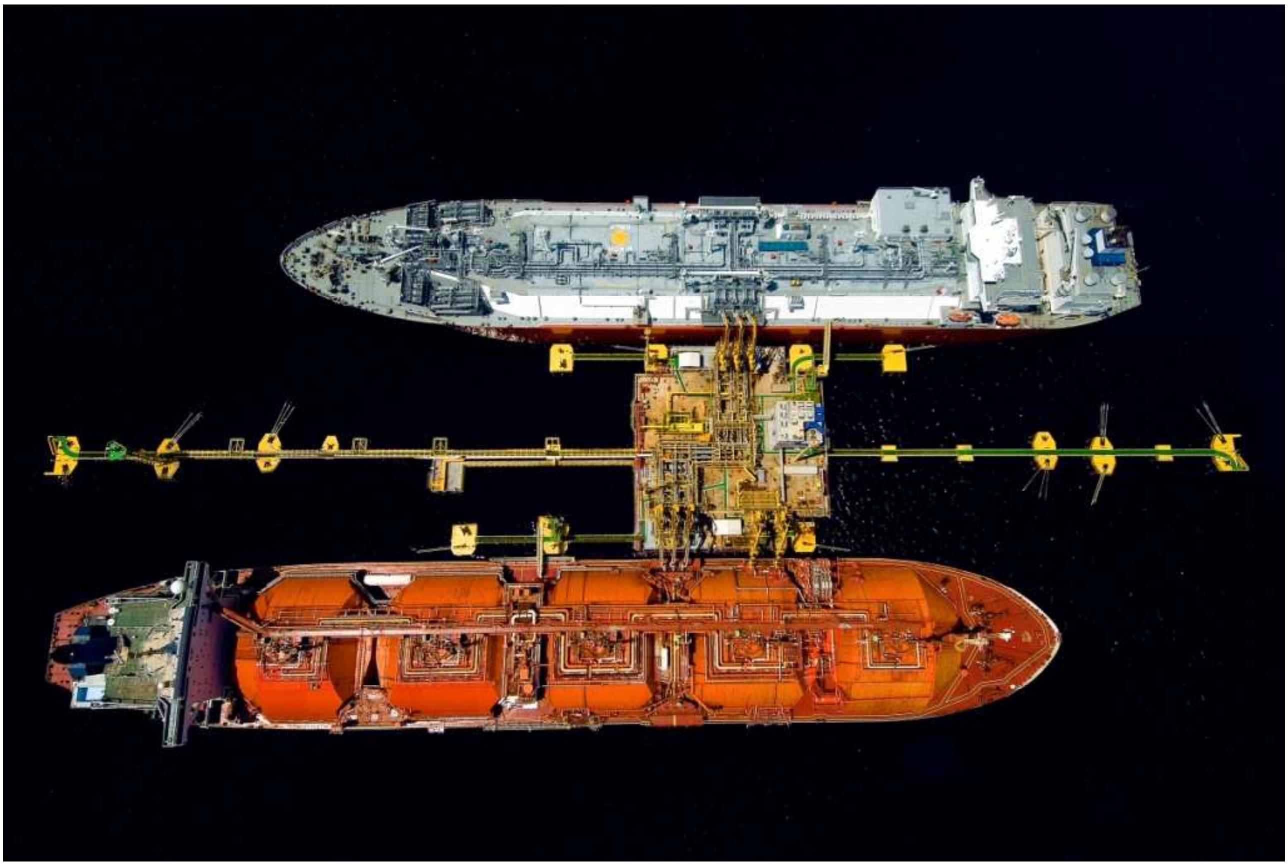

Photo courtesy of Petrobras

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1. SUMMARY

- There is firm demand for new LNG import projects, particularly from developing economies.
- The business case for floating storage and regasification is compelling: the concept is economic, flexible and proven.
- Floating storage and regasification is a reality: there are more than 10 floating storage and regasification projects operational or committed around the world.
- The process of converting an LNG carrier into a floating storage and regasification unit (FSRU) is simple in principle but complex in execution – a wide range of project, technical and operational skills are required.
- Customers are seeking tailored, fast-track solutions that use capital efficiently.
- Experience and the ability to innovate will be essential to the success of future projects.

2. INTRODUCTION

Strong LNG market fundamentals

The long-term outlook for liquefied natural gas (LNG) is bright – the market fundamentals are strong. It just requires the industry to weather the difficult market conditions that seem likely to persist for the next few years.

The global economic downturn has hit demand for energy of all types and from all quarters. At the same time, the world's capacity to produce LNG is surging. CERA has estimated that by the end of the year there will be an additional 48 million tonnes per annum (MTA) of LNG coming onto the market.[1] Further, CERA forecasts that global production capacity, currently around 190 MTA, will rise by an unprecedented 50% over the next three years. Much of this increase will be in Qatar, although Russia, Indonesia and Yemen will also play significant parts in sustaining the glut in supply. A further factor in the supply and demand equation is the upsurge in the production of gas in the USA (9.1% in 2008), which is the result of technology advances that have unlocked shale gas reserves in the region.

Most leading analysts expect that it will be 2012 at the earliest before the market recovers and prices begin to strengthen. Thereafter, the market is expected to swing right around. Many believe that the reluctance to commit funds to new LNG plants in the present economic climate will inevitably lead to a capacity squeeze in the years beyond 2012.

A new proven approach with further growth potential

Economic jolts of the magnitude experienced last year are always going to cast a shadow over a business that, until now, has been characterised by massive capital investments in highly integrated, long-term projects spanning the entire value chain from wellhead to consumer.

[1] Midwest Power Market Fundamentals, 2009–13, CERA, 29 April 2009.

Floating storage and regasification provides a striking contrast with this traditional, complex LNG business model. Arguably, it is this contrast that is the prime reason for the interest that the new concept has generated, and continues to generate even during the current severe downturn. Golar is responding to new enquiries about floating storage and regasification from across the globe. Since April 2008, over 20 new enquiries have been received from South America, the Caribbean, the Mediterranean, Southeast Asia and Africa. When it comes to floating storage and regasification projects there appears to be no strong regional bias. As a further indication of the extent of the interest, numerous parties have formally announced feasibility/consulting studies or have firm tenders planned. Activity of this kind is building in, for example, Uruguay, Israel, Indonesia and Vietnam.

Interestingly, to complement the dozen or so committed or operational floating storage and regasification projects today, expressions of interest are increasingly coming from non-OECD countries. This is in line with the statistic that energy demand from non-OECD countries outstripped that from OECD countries for the first time in 2008. Though not among the world's major demand centres, these countries are developing economies for which floating storage and regasification provides a 'fast-track' way of opening their energy market to natural gas, thus increasing diversity of supply, reducing costs and introducing environmental benefits.

Figure 1 – Completed and ongoing projects
There are currently around a dozen floating LNG storage and regasification projects completed or ongoing around the world – four of these (marked in blue) involve the conversion of Golar LNG carriers.

A compelling business case for floating storage and regasification

The case for floating storage and regasification centres on three issues: its economic attractiveness, its technical acceptability and its flexibility. FSRUs cost much less than land-based schemes of a similar size. General cost comparisons must be treated with caution, as the circumstances surrounding floating and land-based developments can affect the cost of both significantly. However, experience to date indicates that FSRUs of the order of 2–4 MTA are likely to be roughly 50% cheaper than equivalent land-based plants. Certainly, there are those in the industry that quote a greater cost differential than this.

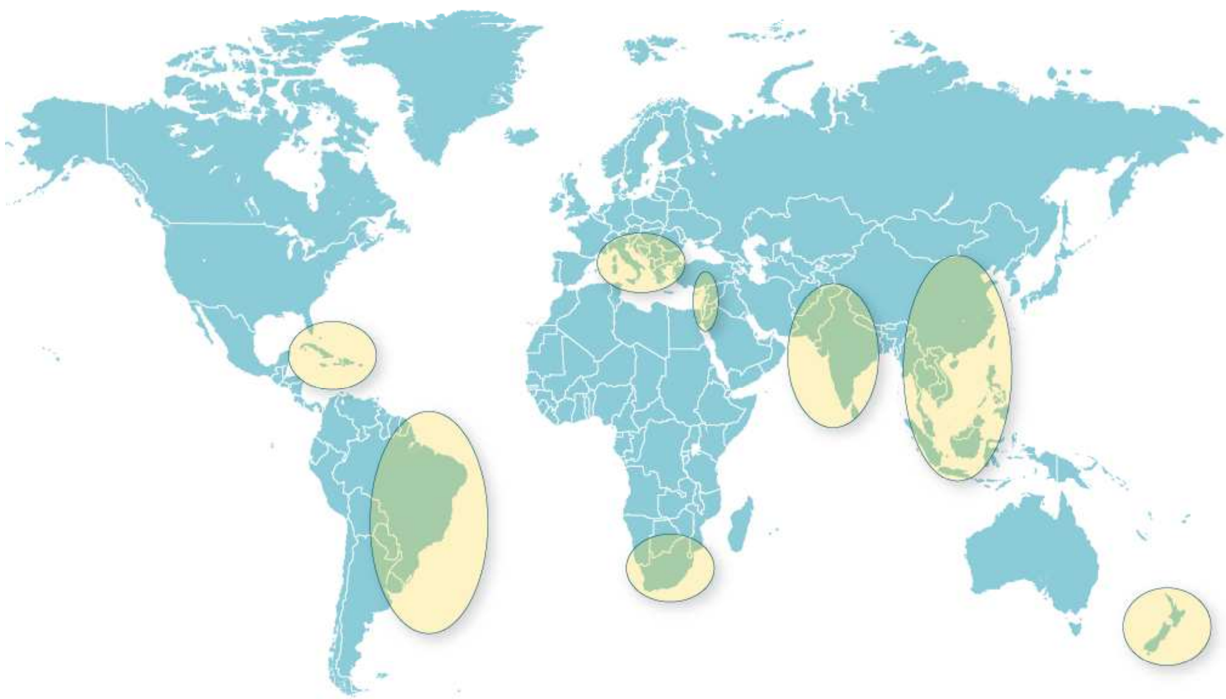

Figure 2 – Interest in the concept
Interest in floating storage and regasification of LNG is being sustained even during the current economic downturn. The marked areas are where most of the enquiries to Golar are coming from.

Just as importantly, FSRUs provide a faster return on the capital invested: time is saved by not having such an extensive planning and permitting process as that normally associated with onshore developments; and the construction time is reduced, assuming the conversion of an existing LNG carrier, because much of the required equipment (storage, power and utilities) is already available and in place. The conversion projects carried out on the *Golar Spirit* and the *Golar Winter* suggest two years from the final investment decision to the delivery of the vessel: 18 months for engineering and procurement, and six months for the shipyard work.

The ability of FSRUs to establish quickly new markets for LNG benefits suppliers and customers alike. Suppliers get the benefit of access to new markets and greater trading flexibility; and customers gain from increased diversity of supply, which can improve negotiating positions with their existing energy providers. Overall, the conditions are created to stimulate economic growth more rapidly than with traditional energy infrastructure projects. That most of the technology involved in the floating storage and regasification of LNG is proven in related applications is an added inducement to investors in these schemes.

What appears to seal the arguments for FSRUs with potential investors is the flexibility that they provide in terms of location and use. Depending on their design and configuration, FSRUs can be moved from one demand centre to another and may retain the ability to trade as LNG carriers. This flexibility makes an FSRU an interesting option in countries where energy demand is particularly seasonal or where there is an intermittent market. Equally, the attraction is obvious in areas where economic growth is uncertain or where there is an element of political or economic instability.

"NIMBY" – not in my backyard!

Interest in floating storage and regasification is not coming exclusively from the developing economies. The concept has not gone unnoticed by developed nations seeking to enhance the diversity and security of their energy supplies. Part of the attraction of floating storage and regasification seems to lie in the fact that the residents of such countries, while supporting the idea of enhancing their energy supply position, tend to favour solutions that are situated as far away from where they live as possible – that are not in their backyards.

Opposition to onshore LNG regasification plants has certainly been fierce in many places. Floating storage and regasification offers a way of distancing the energy solution from possible LNG opponents and potentially avoiding a lengthy and difficult approvals process.

Golar's midstream strategy

For a company like Golar, with 35 years of experience as a vessel owner and operator and currently controlling 14 LNG vessels, floating storage and regasification provides an undeniable business opportunity. It is a way of enhancing shareholder value by extending the lives of older vessels and maximising the overall value of the fleet.

Golar decided to pursue floating storage and regasification in 2002 as part of the company's Midstream strategy, which was initiated to enhance core margins across the entire LNG value chain and to create a more diverse, balanced business portfolio.

Floating storage and regasification represents the main downstream part of this strategy and became a reality in 2005 with the award of a contract to Keppel Shipyard Ltd, Singapore, to convert the *Golar Spirit* into an FSRU. Today, Golar is the established world leader in the conversion of LNG carriers into FSRUs. Three long-term FSRU charter agreements have been signed: two with Petrobras (*Golar Spirit* and *Golar Winter*) and one with the Dubai Supply Authority (*Golar Freeze)*. Others are in the pipeline.

In the upstream area, Golar has two major initiatives. It has established a partnership with Thailand's PTT Exploration and Production plc (PTTEP) to develop floating LNG (FLNG) production technology and pursue projects on a worldwide basis. In June 2009, Golar signed an agreement with PTTEP whereby the two companies will carry out front-end engineering and design studies for a proposed FLNG project in north-western Australia. Additionally, an agreement in principle was reached on the commercial structuring of the project that provides for Golar to participate in the gas value chain on a 50:50 basis with PTTEP. It is intended that Golar will farm into the gas reserves held by PTTEP as a result of its recent acquisition of Coogee Resources Limited.

In addition, Golar has become the largest shareholder in Liquefied Natural Gas Ltd (LNG Ltd), an Australian company committed to the development of small- to medium-scale LNG trains using modular construction techniques. In February 2009, Golar signed a Heads of Agreement with LNG Ltd covering the joint development of a mid-scale (1.5 MTA) LNG plant in the port of Gladstone, Australia. The plant will purify and liquefy coal seam gas sourced from the Arrow Energy Ltd gas fields, located in central Queensland. Golar and LNG Ltd have agreed to each take an equity position of 40% in the joint venture. First production is currently scheduled for 2012. Golar will be the sole LNG offtaker and up to two of Golar's existing LNG carriers will be used to deliver the gas.

3. PROJECT EXPERIENCE

Converting an LNG carrier into an FSRU is simple in principle – most, if not all the technology has been proved elsewhere. Add vaporisers, loading arms and extra pumps to the LNG carrier, upgrade its power, electrical and control systems, and you have an FSRU. The experience of two completed projects plus those in progress has shown that this could not be further from the truth: converting an LNG carrier into an FSRU is a complex exercise requiring a wide range of technical and commercial skills. Further, it is clear that, although the lessons learned on one project can be applied to the next, each conversion creates its own set of challenges. Put simply, there is no such thing as a generic FSRU project.

Completed conversion projects

Golar Spirit

Use:	FSRU, with retained capability to trade as an LNG carrier
LNG storage capacity:	129,000 m^3
Regasification capacity	2.5 bcm/y
Location:	Moored at an existing upgraded jetty at Pecém, Ceará, northern Brazil
LNG transfer:	Over the jetty via loading arms fixed on the jetty
Gas transfer:	Via high-pressure loading arms fixed on the jetty
Vaporisation system:	Direct steam in a closed loop

Built in 1981, the *Golar Spirit* was the first LNG carrier built in Japan; it has a Moss tank containment system. The *Golar Spirit* was contracted for LNG shipments between Indonesia and South Korea from 1986 to 2006. The decision to convert the vessel was taken in 2005, and Moss Maritime was chosen as the main engineering contractor. The vessel entered the Keppel shipyard in Singapore in 2007 and emerged in June 2008.

Figure 3 – *Golar Spirit*
The *Golar Spirit* FSRU (right) and an LNG carrier berthed at the Pecém terminal jetty, in Brazil. (Photo courtesy of Petrobras)

Golar Winter

Use:	FSRU, with retained capability to trade as an LNG carrier
LNG storage capacity:	138,000 m^3
Regasification capacity	5.1 bcm/y
Location:	Moored at a new purpose-built jetty at Guanabara Bay, Rio de Janeiro, Brazil
LNG transfer:	Over the jetty via loading arms fixed on the jetty
Gas transfer:	Via high-pressure loading arms fixed on the jetty
Vaporisation system:	Two-stage propane and seawater in closed or open loop

The *Golar Winter* was built in 2004 and has a GTT NO96 membrane tank containment system. The vessel was selected for conversion in 2006, and the engineering and procurement activities started in 2007. Moss Maritime again acted as the lead contractor. The vessel entered the Keppel shipyard in Singapore in September 2008 and emerged an FSRU in May 2009.

The decision to convert the first vessel, the *Golar Spirit*, was taken without a contract on the vessel. However, subsequent negotiations with Petrobras resulted in a charter arrangement signed in April 2007 under which Petrobras will charter the vessel for 10 years with options for up to a further 5 years. The *Golar Winter* is similarly contracted to Petrobras.

Petrobras's decision to take the two vessels is largely founded on the flexibility of the floating storage and regasification concept. LNG demand in Brazil is seasonal and depends partly on the contribution made by the country's hydroelectric power stations to the grid. In the rainy season, when hydroelectric power is plentiful, the FSRUs will be able to sail to overseas loading ports to secure LNG cargoes. During the dry season, when hydroelectric power output falls, the vessels will remain in Brazil and receive cargo from LNG carriers.

Both FSRUs are designed to operate at either of two terminals, at Pecém, in northern Brazil, or at Guanabara Bay, Rio de Janeiro, although the *Golar Spirit* is earmarked for Pecém and the *Golar Winter* for Guanabara Bay. The jetty at Pecém already existed and only required modification to turn it into a receiving terminal; Guanabara Bay is a new, purpose-built terminal. Each of the terminals has three sets of marine loading arms: two sets for LNG and one set for high-pressure gas. LNG carriers discharge LNG via one set of arms across the jetty to the second pair connected to the FSRU. Transfer of LNG and gas export can take place simultaneously.

Figure 4 – *Golar Winter*
The *Golar Winter* FSRU moored at the Guanabara Bay terminal in Brazil and transferring cargo to the *Golar Spirit* FSRU (Photo courtesy of Petrobras)

On leaving the shipyard in June 2008, the *Golar Spirit* first sailed to Trinidad, where it loaded a partial cargo of LNG, and then onto Pecém. The vessel was commissioned in January 2009. In March 2009, the *Golar Spirit* transferred temporarily to Guanabara Bay to assist in commissioning the new terminal. *Golar Winter* departed Keppel Shipyard following its conversion in June 2009. Initial commissioning tests began in mid-July at Guanabara Bay.

New committed projects under development

Golar Freeze

Use:	FSRU
LNG storage capacity:	125,000 m^3
Regasification capacity	4.0 bcm/y
Planned location:	Moored at a new purpose-built jetty at Jebel Ali, Dubai
LNG transfer:	Side by side via loading arms on the FSRU
Gas transfer:	High-pressure loading arms fixed to the jetty
Vaporisation system:	Two-stage propane and seawater in open loop

The *Golar Freeze* was built in 1977 and has a Moss tank containment system. The final investment decision for the conversion was made in April 2008 and work on the vessel is due to start in late 2009. Delivery is planned for the second quarter of 2010.

The Dubai Supply Authority has taken a charter on the vessel for 10 years, with an option for a further 5 years. The vessel will be used to import gas during the very hot, six-month summer season, when the load on the electricity grid from air conditioning systems is greatest. The vessel is not expected to trade.

Figure 5 – *Golar Freeze*, an artist's impression
The *Golar Freeze* will operate at Jebel Ali in Dubai, and is designed to be berthed side by side with an LNG carrier at a purpose-built jetty. Transfer of LNG will be directly from ship to ship. (Image courtesy of Shell/Dubai Supply Authority)

Golar Frost

Use:	FSRU
LNG storage capacity:	137,000 m^3
Regasification capacity	3.75 bcm/y
Planned location:	Turret moored 20 km offshore Livorno, Italy
LNG transfer:	Side by side via loading arms on the FSRU
Gas transfer:	Via a riser to a subsea gas pipeline
Vaporisation system:	Open loop

The *Golar Frost* is a 2004-built vessel with a Moss tank containment system. A lump-sum turnkey contract to convert the vessel was awarded in February 2008 and conversion work started in June 2009. The first commercial gas delivery is targeted for 2011. The vessel will be turret moored approximately 20 km offshore and will receive gas from an LNG carrier moored alongside. The two vessels will weathervane together. LNG transfer will be via loading arms designed for offshore operation and mounted on the FSRU. Ownership of this vessel has transferred from Golar to a new operating company consortium, Offshore LNG Toscana SpA.

Positioning for the next opportunities

Gandria

Use:	FSRU
LNG storage capacity:	126,000 m^3
LNG transfer:	Ship-to-ship via a tandem loading system using flexible cryogenic hoses
Gas transfer:	Via a riser to a subsea gas pipeline
Vaporisation system:	Closed loop

In 2008, Golar entered a partnership with Dutch-based FPSO and mooring specialist Bluewater Energy Services to purchase the 1977-built Gandria. The objective is to develop an FSRU capable of operating in harsh offshore environments (wave heights > 6 metres). The Golar/Bluewater harsh environment FSRU will be permanently stationed using a turret-mooring system and thrusters. LNG will be transferred using a tandem loading system from the bow of an LNG shuttle carrier to the stern of the FSRU via flexible cryogenic hoses. The Golar/Bluewater cooperation offers strong evidence of the industry responding via technological innovation to address more challenging project requirements.

Hilli

Use:	FSRU
LNG storage capacity:	125,000 m^3

An indication of Golar's confidence in the floating storage and regasification concept is the recent decision to convert the 1975-built *Hilli* into an FSRU on a speculative basis. To further shorten the delivery time for the *Hilli* as an FSRU, Golar has already placed orders on certain items of equipment that have long lead times.

3. FSRU PROJECTS – ESSENTIAL CONSIDERATIONS

Contracting – are we dealing with a ship, a floating production system or an LNG terminal?

Even for Golar, which has been involved in the LNG vessel business for 35 years, floating storage and regasification has initiated a serious review of industry contracting strategies, as there are several new questions to consider. Will the vessel be the subject of a charter agreement? Will it be purchased outright by an operating company? Could a joint venture be involved? And, more fundamentally, are we dealing with a ship, a floating production system similar to an oil industry floating production, storage and offtake facility, or is it better to view the vessel in the same light as a land-based LNG terminal?

So far, most interest has been from end-users that want to charter FSRUs and leave ownership and responsibility for vessel operations and maintenance with Golar. This means that two contracts need to be developed and managed simultaneously: one with the contractor chosen to assist with converting the vessel, and the other with the time-charter party, the client.

The conversion contract carries risks: the suitability and quality of the design; the quality of the construction; and the on-time delivery of the vessel in a technically acceptable condition. These are the normal risks associated with any large construction project. But here they are exacerbated by the high level of technical integration involved in creating an FSRU from a carrier; the very long lead times for specialist equipment; and the fundamental business objective of creating a very flexible vessel very quickly.

The charter contract carries its own complications. As the charter will probably be long term (so enabling the vessel owner to recoup a proportion of the capital invested), getting the terms right and allowing for the flexibility demanded by both sides are particularly important. A similar set of risks to those for conversion is also involved here. These risks relate to the vessel's ability to meet the basic functional specification, its local regulatory and environmental acceptability, vessel importation and customs requirements, and, not least, on-time delivery. Key questions in this last regard include when is the vessel deemed to have been delivered, and when does the vessel pass from the conversion party to Golar and then on to the client?

Set against this background, clear measures need to be taken to minimise and manage the risks. On the conversion side, great care needs to be taken to select engineering and construction contractors that, together, will provide the right project development capability. Also the key equipment suppliers need to be involved as early as practicable and integrated into the engineering and construction activities. On the charter side, it is vital that the end-user has a clear mandate for the project, the support of governments and authorities, and an energy partner. Permitting also needs to be dealt with at an early stage and the responsibilities of the charter-party and the vessel owner clearly established. A potential issue here is the interface between the vessel at the jetty and the shore: just which party is responsible for permitting, and with which authorities has the process to be pursued?

The vessel's functional requirements need to be established clearly and at an early stage. Environmental requirements must be properly understood to enable the permitting process to proceed smoothly. In addition, assurance should be sought that the associated infrastructure requirements are being dealt with in parallel with the vessel conversion.

One point that must not be forgotten is that financiers and insurers need to be involved from the outset.

FSRU technology and integration – Tailoring the solution

There is no single overwhelming factor affecting which kind of LNG carrier makes the best FSRU. Indeed, availability and cost have to be prime considerations when seeking a candidate vessel. The technical community tends to favour older Moss tank vessels, especially if the intention is to moor the FSRU permanently. Moss tanks have a strong reputation for structural integrity and longevity. Additionally, an older vessel is likely to have been more conservatively designed and hence will be more robust, so providing an easier foundation for major engineering modifications. A more modern membrane tank vessel, however, which will probably have a more efficient propulsion system, may be more attractive if the intention is to continue using the vessel to trade LNG.

It makes economic sense to use as much of the existing equipment aboard the LNG carrier as possible during the conversion process, but the list of potential modifications can be daunting. As well as the addition of the regasification unit, the most fundamental modification, there are numerous other aspects of vessel design to consider. These include changes to the

- LNG transfer system
- cargo handling equipment
- gas export and metering systems
- power and utilities
- process controls and communications
- emergency shutdown and fire and gas detection systems
- vessel's mooring arrangement.

As the conversion of the *Golar Spirit* to an FSRU was the first project of its kind, and also because the vessel did not have a contract when the work started, the general philosophy was to keep the design as simple as possible. This was certainly behind the choice of regasification plant. The unit, designed by Moss Maritime, operates in closed-loop mode – a decision based on its universal environmental acceptability – and uses saturated low-pressure steam as the heating medium. The maximum flow of gas from the unit is 7.0 million m^3/d (in a pressure range of 57–98 bar), which equates to roughly 2 MTA of LNG. The plant can be turned down to 10% of its maximum flow.

The plant, which is built into a single compact skid, is arranged in three trains each capable of delivering 50% of the maximum required gas flow to ensure a high level of production flexibility, operability and redundancy. Each of the regasification trains is fed by a high-pressure booster pump that draws LNG from a common suction drum. LNG is fed to the suction drum by new cargo pumps in the storage tanks.

The unit would ideally have been located on the open deck at the bow of the vessel to maximise the distance from the accommodation. However, to maintain the option to fit the vessel with a turret-mooring system, the unit sits between the two foremost tank covers.

Although the overall steam generation capacity of the *Golar Spirit* was sufficient for its new use as an FSRU, the existing power plant was upgraded by adding a new steam turbo generator; steam desuperheaters were also required to supply saturated, low-pressure steam to the regasification plant.

A new integrated automation system was installed on the vessel. This covers the control and monitoring of the regasification plant and other main FSRU functions, notably the emergency-shutdown and fire-and-gas-detection systems.

Figure 6 – The regasification unit aboard the *Golar Spirit*
The *Golar Spirit's* regasification unit – a close fit between the vessel's two foremost tank covers.

The conversion of the *Golar Winter*, which was immediately after the *Golar Spirit* and in the same shipyard, obviously benefited from the systems developed and the lessons learned from the first project. Interestingly the major difference between the two vessels – the *Golar Winter* has a GT NO 96 membrane tank containment system in contrast to the *Golar Spirit's* Moss tanks – was not a serious issue for the conversion. In fact, it was the desired gas send-out rate that led to the biggest differences between the work scopes. Petrobras required the vessel to be capable of delivering double the volume of gas of the *Golar Spirit* and for the regasification unit to operate in either closed- or open-loop mode.

This difference in the functional specification led to the decision to equip the *Golar Winter* with a regasification unit designed and supplied by Hamworthy. The unit, which has a maximum gas send-out rate of 14 million m^3/d (equivalent to roughly 4 MTA of LNG), is similar to that on the *Golar Spirit* in that it comprises three individual trains, each capable of sending out 50% of the total design capacity of the vessel. The unit differs in the heating medium: instead of direct steam heating, the LNG is vaporised in a two-stage process using propane and then seawater. High-capacity pumps have been fitted in the engine room to circulate the seawater through the vaporiser and through a second exchanger to reheat the propane.

Upgrading the existing boiler and adding a new boiler and a steam turbo generator have satisfied the increased power and heat requirements of the FSRU, especially when operating in closed-loop mode. Both of these occupy a newly provided machine space created above the vessel's poop deck.

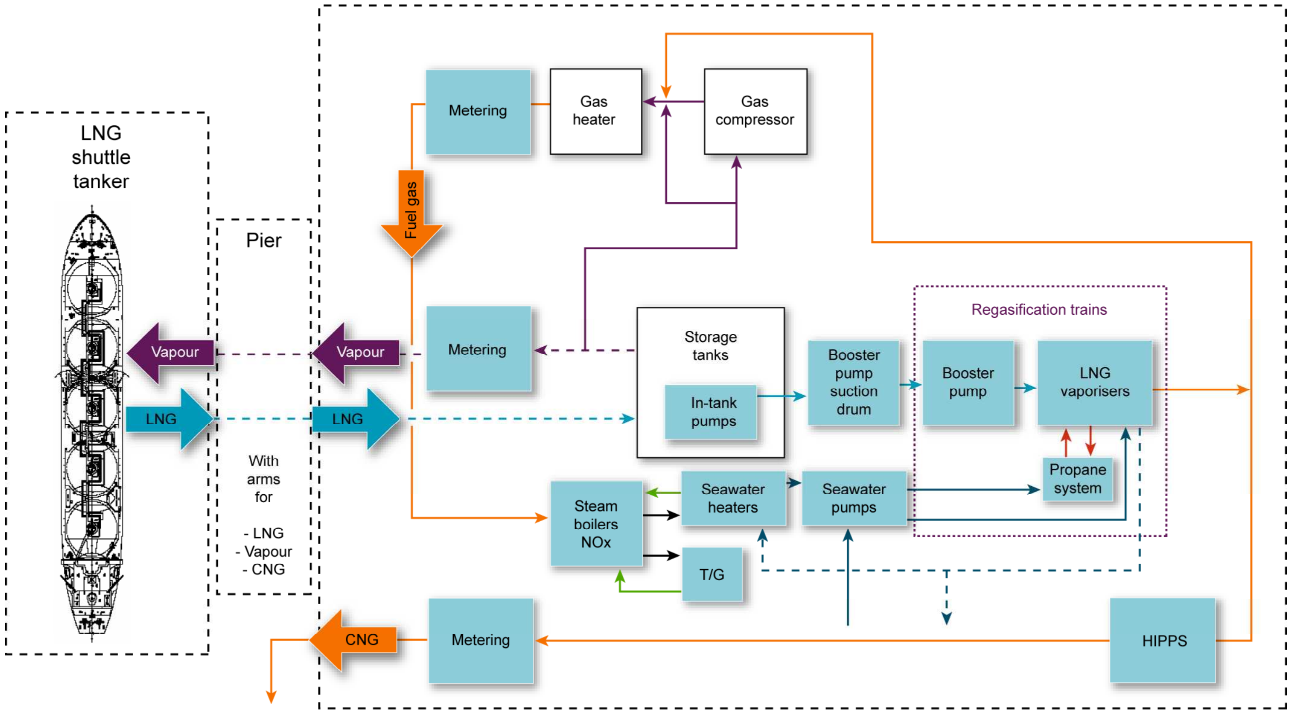

Figure 7 – Process outline
The basic regasification process outlines for the *Golar Spirit* and *Golar Winter* are the same. However that for the *Golar Winter* (shown here) is slightly more complex owing to it having a two-stage vaporiser that may be operated in either closed- or open-loop mode.

FSRU commissioning, operations and maintenance – Experience counts

Under the agreement with Petrobras, Golar is responsible for operating and maintaining the *Golar Spirit* and the *Golar Winter* throughout the charter periods. (A similar arrangement exists for the *Golar Freeze*, which is to be chartered by the Dubai Supply Authority.) Based on Golar's long experience as a vessel owner and operator, the preparation for this role started early for each vessel.

A commissioning engineer joined each vessel in the shipyard and assumed full responsibility for taking it from the yard through commissioning and into routine operation. Items of equipment were functionally tested individually in the shipyard, and all the process systems were nitrogen pressure and tightness tested. The first phase of commissioning the vessels' LNG systems was carried out after they left the shipyard at an LNG loading terminal in Trinidad. There, the normal cool-down, gas-up and loading processes associated with conventional LNG carriers were performed. The second phase, which involves start-up of the regasification unit, testing the key interfaces with the shore systems and the final send-out capacity acceptance tests, has been completed in Brazil for the *Golar Spirit*. Commissioning the *Golar Winter* is scheduled for July 2009.

The vessels' senior officers remained onboard while the conversion process was carried out in order to familiarise themselves with the regasification operations. As well as attending Golar-developed courses, the officers took advantage of training provided by the main equipment suppliers and also spent considerable time working with a process simulator designed specifically for these first two vessels. As a result of these efforts and those devoted to the commissioning process, the transition from shipyard to full operation has so far been trouble-free for both vessels.

FSRU classification – Setting new industry standards

It is the role of international organisations such as DNV to provide classification systems that can be used to demonstrate that a given ship, plant or structure complies with defined rules and standards, especially those concerning safety. However, these FSRU conversion projects were the first of their kind, and when they started there were no specific rules and standards to refer to; there was no classification notation for FSRUs.

Figure 8 – Commissioning
Commissioning the *Golar Spirit* in Brazil. Dealing with the interface between the ship and the shore is a key issue for a vessel which is part LNG carrier and part LNG terminal. (Photo courtesy of Petrobras)

Golar's approach was, first, to ensure that the FSRUs complied with the class rules for LNG carriers. Second, the vessels were designed with reference to all the offshore industry standards relevant to the high-pressure processing of oil and gas. The entire design process was subjected to rigorous quantitative risk assessment (QRA). Key studies underpinning the QRA included vent stack dispersion analysis; a risk assessment focusing on heat radiation levels; a risk assessment of the steam-heated LNG vaporiser and its condensate return system; a fire integrity study of the regasification plant equipment and piping; and separate verifications of the abilities of the regasification unit and the storage tank covers to withstand accidental loads resulting from fire or explosion.

DNV was heavily involved in the conversions of the *Golar Sprit* and the *Golar Winter*. Partly as a result, DNV released *Classification Notes for Regasification Vessels No. 61.3* in June 2008. These define classification notations REGAS-1 and REGAS-2 and are intended to supplement the well-established DNV rules and standards for LNG gas carriers. Unsurprisingly, given the level of cooperation between Golar and DNV, these notations strongly reflect the approach taken during the two FSRU conversion projects.

REGAS-1 is the safety standard for on-board regasification plants intended for occasional use in connection with cargo discharge. It lists the basic standards for the vessel and calls for risk-based hazard identification (HAZID) and hazard operability (HAZOP) studies to be performed. REGAS-2 applies to regasification units designed for continuous operation. To achieve this notation, all the rules and standards contained in REGAS-1 must be complied with; in addition, the vessel must be subject to a full quantitative risk assessment (QRA) exercise carried out by an independent party.

The *Golar Spirit* achieved REGAS-2 class notation in January 2009; at the time of writing, the same class notation for the *Golar Winter* is pending the completion of the commissioning process.

4. LESSONS LEARNED

A number of lessons have emerged from the projects completed so far. The first relates to project definition: time spent with the vessel's end-user is well spent. This effort will not be wasted if it is used to define as closely as possible the operational requirements of the vessel and to convert these into a robust technical specification against which detailed engineering can be performed and the procurement process started early. With lead times on the specialised equipment needed by an FSRU running into many months and space for extra equipment on the vessel severely limited, any shortcomings in these early project stages are bound to result in major difficulties and delays later on.

A second major lesson is about integration. Although this is a factor in the success of most large engineering projects, converting an existing LNG carrier into an FSRU presents an extreme example of the effort needed. Appointing one strong main engineering contractor is essential, in view of the limited space available for additional equipment, the additional power demands, the requirement to make best use of existing equipment and the interdependence of the regasification unit, the utilities and the storage and transfer systems. It is perhaps worth noting that at the height of the conversion of both the *Golar Spirit* and the *Golar Winter* there were around 500 people working simultaneously on each vessel.

Contracting offers a third lesson, as some serious new issues arise related to the long-term charter of an FSRU. The form of agreement typically used for the charter of a ship is a Time Charter Party (TCP). Depending on whether the FSRU is to be permanently moored or to retain the flexibility to operate as an LNG carrier, an FSRU may adopt the characteristics of (i) an LNG carrier, (ii) a land-based regasification facility, and/or (iii) an offshore floating crude oil storage and production unit. Each of these options needs to be considered when negotiating the TCP. Additionally, there are questions related to the agreed delivery and testing protocols; the position in the event of the vessel receiving off-specification gas (the FSRU no longer only delivers LNG); permitting roles and responsibilities; and the allocation of costs should rules or regulations come into force after delivery that affect the FSRU's design or operation.

A fourth lesson involves commissioning and testing. Upon delivery of the FSRU, the charterer and the owner need to agree and execute a test protocol to ensure the charterer accepts the condition of the delivered FSRU. For the charterer, this a critical time when some initial adjustments to the vessel are inevitable. It is vital the charterer has people with sufficient experience and capability to see this aspect of the agreement through.

Finally, not to be overlooked is the issue of the operation and maintenance of the vessel. Golar has relied largely on using vessels' existing marine crews to operate and maintain them after conversion to FSRUs. However, FSRU operations present many new challenges for those onboard and so appropriate training and development become very important.

5. CONCLUSIONS

Floating storage and regasification has made a strong impact on the LNG industry: enquiries about the concept have not fallen off, despite the recent severe economic downturn. Much of the new interest in floating storage and regasification is coming from countries with developing economies rather than from the traditional major demand centres.

Cost, speed of delivery and flexibility are the main advantages of FSRUs. In this respect, FSRUs contrast strongly with traditional land-based LNG developments.

The two successful Golar conversion projects demonstrate the viability of the technologies needed for floating storage and regasification of LNG. These conversions have played a vital role in the development of DNV class rules for FSRUs that will provide valuable design and safety guidelines for future projects.

Projects being planned will push the technology further: one case will introduce a turret mooring system and another a tandem LNG transfer system for application in harsh environments.

In Golar's view, the conversion of an LNG carrier into an FSRU is far from being a standard exercise – there is no such thing as a generic FSRU. If you add the challenge of integrating the various new and existing items of equipment on a vessel with space at a premium to the various separate technology issues, then it is clear that each conversion is an individual project; every FSRU is a tailored product.

The FSRU business is challenging. It involves the sound aggregation of shipping and energy technology, LNG market awareness, commercial skills and marine operating experience. Success depends on having a deep understanding of both the technical requirements of the FSRU and the surrounding commercial issues from the project's outset.

Golar's wealth of experience as a vessel owner–operator, its project management skills, its financial strength and a culture that promotes speed and flexibility have combined to establish the company as one of the world leaders in floating storage and regasification of LNG.