

**PLAY IT FORWARD:** RPM ADVANCES INVIGORATE QUEST FOR THE HOLY GRAIL

# Offshore Engineer

Reservoir  
of hope

LNG terminals  
take off

Soft landings  
in the Med

[www.offshore-engineer.com](http://www.offshore-engineer.com)

DECEMBER 2003



## Poetry in motion

**PLUS:** EDWARD HEEREMA ON STOCK OPTIONS, LAWYERS AND OTHER ILLS

# Making the concrete case

Significantly increased local content, greater topside flexibility, superior stability and enhanced cryogenic temperature performance are among the advantages claimed for a concrete-hulled FPSO concept currently targeting floating LNG application in West Africa's relatively benign waters. Here, **Brian Raine**, **Al Kaplan** and **Gordon Jackson** discuss the technical issues associated with the integration of LNG production and storage facilities on a floating concrete substructure.

**G**overnments and offshore oil and gas field operators are researching means by which natural gas from associated and stranded gas fields may be monetized. In addition, governments are legislating to limit or prohibit the flaring of gas associated with oil production. The result is an increasing interest in the development of offshore gas liquefaction installations, in particular the development of floating liquefied natural gas (LNG) production facilities.

The primary focus of floating LNG proposals has been directed toward steel hulled FPSOs which may be procured from established shipyards and fitted out at an offshore fabrication and assembly facility. Established fabrication and assembly facilities are located in East Asia, Northern Europe and North America. Construction of the hull and topside facilities in a shipyard offers a number of benefits including contractor competition at bid stage. However, shipyards generally do not have the dock facilities to construct large concrete substructures. An alternative procurement strategy that incorporates local construction in purpose built graving docks is better suited to both the concrete substructure option and a procurement strategy that seeks to assemble the production facility locally.

Major onshore developments such as LNG production facilities inevitably include a significant proportion of local participation due to the high civil engineering content and a stick-build approach typical of LNG production facilities constructed to date. Offshore developments typically have a reduced local content due to the more specialized nature of offshore construction and the complexities that modularisation of the facilities introduces. Floating concrete substructures supporting LNG facilities have the potential to significantly increase local content by ensuring participation of both the local civil engineering industry and by encouraging the construction of the facilities in country as well.

The concrete hull will also contribute to the technical performance of the facility by providing enhanced cryogenic



temperature performance, impact resistance and increased vessel displacement leading to reduced operational motions.

This article considers a two-train floating LNG CFPSO concept and discusses the critical technical issues associated with concrete and the proposed hull. An indicative engineer, procure, install and commission (EPIC) cost and schedule estimate for West African application is included to demonstrate the feasibility of the concept.

## Project criteria

The project criteria considered for the concept is a two-train LNG facility. Production rates would be based on a production rate at approximately 4.5 million tonnes per annum (tpa) of LNG, and associated LPG and condensate production per train. The concept is limited to two trains due to the limited availability of the single LNG carrier berth for offloading.

The CFPSO would typically be positioned over the gas field but separate from the well production facilities. Significant cost savings would result if the well production facilities could also be supported on the CFPSO. The potential of such an arrangement has not been quantified but is worthy of further study.

The two train facilities would gas treating for heavy hydrocarbons, CO<sub>2</sub>, H<sub>2</sub>S and mercury removal; 2 x 4.5 million tpa LNG production; associated LPG (0.80

million tpa) and condensate production (1.40 million tpa); utilities; accommodation; and loading systems.

The refrigeration equipment for each LNG train would be driven by the equivalent of two Frame 7 gas turbines. However, larger trains could also be considered, thereby increasing total facility production.

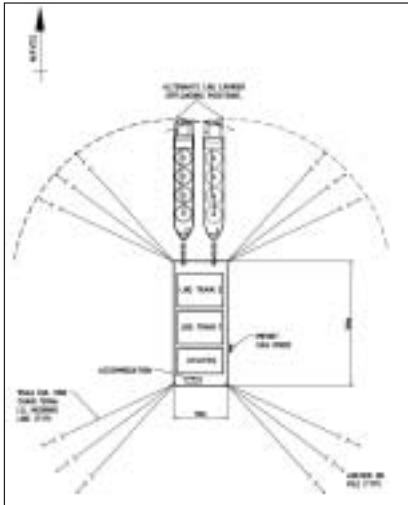
Utilities associated with this would typically be three Frame 7s for power generation along with other typical offshore utility requirements such as desalination units, wastewater treatment and plant/instrument air.

The requirements for water production and water treatment could be reduced by bringing water from shore and piping water for treatment to shore. This could reduce opex costs, depending upon the distance from shore.

The accommodation will be between 150-300 personnel depending upon the owner's operating and maintenance philosophy. Personnel transfer will be by either helicopter or boat, depending upon the facility distance offshore.

Loading systems for the LNG would comprise a boom to tanker type system that must be able to accommodate large motions relative to the CFPSO and the LNG carrier in order to achieve acceptable availability and minimize storage. Condensate and propane/butane loading would be achieved using either a typical single point mooring (SPM) unit located 1-2 miles distant from the CFPSO or at the

**Brian Raine** and **Gordon Jackson** are with Arup Energy. At the time of writing **Al Kaplan** was with Foster Wheeler; he joined Marathon Oil as VP major projects on 1 December. This article is based on a paper presented at OTC 2003, Houston.



Typical spread-mooring arrangement for an LNG CFPSO in West African conditions.

CFPSO. The selection of which concept to pursue would depend upon detailed berth availability studies and weather conditions in the area.

A C<sub>3</sub>MR liquefaction process LNG production facility has been used as the basis of the study. However, any of the liquefaction processes could be used for the facility. Some, such as those not using propane, offer safety advantages, as will be discussed later in this article.

In addition, some of the processes offer advantages and disadvantages due to the motion characteristics of the CFPSO. The advantages arise due to the processing equipment being shorter and the disadvantages arise from fluid flow characteristics. However, all of the problems are believed to be solvable with additional study.

The topside layout philosophy assumes single level facilities grouped into discrete functional areas including: accommodation, utilities, LNG trains (2), flare, product offloading.

In a typical two-train process facilities layout for a CFPSO application, the level of modularization of the facilities would be tailored to suit the constraints of the hull plan dimensions, local content requirements, schedule and cost issues. All of these could have significant effects on project economics, positive or negative. It may be advantageous for modularization to be limited to allow for final assembly and hook-up in country.

These issues will all require additional study when a specific project location is identified.

Dry weight of the two-train LNG CFPSO topside, excluding storage, is estimated at 75,000t while operational weight is 100,000t.

Product storage requirements are generally a function of ship capacity, berth availability and production rate. Assuming that the CFPSO to LNG/LPG carrier loading system has sufficient flexibility

not to impose undue demurrage time then the following two-LNG train storage requirements would typically apply:

- 330,000m<sup>3</sup> gross LNG storage;
- 100,000m<sup>3</sup> gross LPG storage in twin tanks.

For the purposes of this study it is assumed that condensate would be stored in a separate FSO vessel moored at a suitable distance from the CFPSO and connected via a flexible export line. The option to include condensate storage in the CFPSO hull is typically also available but not specifically here. The advantages and disadvantages of increased storage requirements, cost of the FSO and safety issues, need to be carefully assessed before a final decision is made.

Separate FSO for condensate (C<sub>5</sub>+ and propane/butane (C<sub>3</sub>/C<sub>4</sub>) are also possibilities. The cost and operational issues of the additional vessels located in the area of the CFPSO and the resulting reduction in storage requirements and potential berth availability increase must all be assessed carefully due to their interdependent relationships. The actual site of the facility, ie its metocean conditions, proximity to shipping lanes and the like, will also be key criteria to be considered.

The CFPSO should be capable of containing either the membrane or the prismatic self-supporting tankage system. The selection of the LNG storage tankage system is deliberately left open to encourage vendor competition at EPIC bid stage.

LNG product loading to LNG carrier would need to be by state-of-the-art LNG loading arms in a side-by-side or bow-to-stern arrangement. This is to achieve a reasonable availability for loading of ships without having excessive storage requirements. This equipment can accommodate relative motions up to 10m range between the CFPSO and the LNG export carrier. Consideration of the technical merit of state-of-the art loading arm technology is outside the scope of this article.

LPG product loading to LNG carriers would be through the LNG loading arms.

Condensate loading would be through flexible pipes to either a FSO or directly to a tanker.

The CFPSO would preferably be spread moored but could be configured for turret mooring. The proposed solution is configured for spread-moored operation.

For the purposes of conceptual study, limiting motions would be assumed to be combined roll and pitch motions not exceeding 1.75° amplitude in a three hour operational sea state. This criterion is determined by the production facility operational limit.

A significant advantage of a concrete hull is its relatively large mass, compared to a steel hull. This will act to dampen the relative motions and will be beneficial to

the design and operation of the process facilities.

A vessel drift limit of 15% of water depth is assumed. The connecting gas import riser may require tighter limits on mooring system displacement. The limit would be determined by the water depth and riser diameter.

The CFPSO concept has been targeted toward the West African gas fields where metocean conditions may be described as benign but with persistent swell. Extreme design environmental criteria have been assumed to be:

- significant wave height: 4.5m
- spectral peak period: 17s
- hourly wind speed: 20.0m/s
- surface current: 1.0 m/s

The CFPSO would be moored in at least 150m water depths to provide for economical mooring and riser design.

## Regulatory standards

Both the American Bureau of Shipping (ABS) and Lloyd's Register of Shipping (Lloyd's) have published draft guidance notes<sup>[1, 2]</sup> for the design of offshore LNG production and storage installations. In each case the guidance notes recommend the inclusion of both offshore installation and ship standards in the design of the facility. The Lloyd's guidance notes include more specific discussion on issues associated with concrete structures, both fixed and floating, and as a consequence these have been used as first point of reference in this article.

Specific criteria included in the Lloyd's guidance notes relating to concrete structures and LNG containment include a requirement for durable concrete designed to internationally recognised standards.

A number of internationally recognised frameworks such as the DnV Rules for Fixed Offshore Installations<sup>[3]</sup> in conjunction with national standards such as British Standards<sup>[4]</sup> have been successfully applied to offshore concrete substructures.

A presumption that LNG storage be either self-supporting prismatic tanks or membrane tanks has been made. This is reasonable given the number of available proprietary LNG storage systems is limited and the likely geometric unsuitability of alternative primary container systems such as cylindrical tanks and the Moss spherical containers.

There is an expectation that the LNG containment system for a floating LNG plant will be essentially similar to the requirements for storage on LNG carriers. However, the containment incorporated into modern LNG carriers may only be described as 'partial' double containment since the system caters for only minor leakage from the inner tank. Significantly, Lloyd's expect that the containment system requirements for a concrete gravity based LNG terminal would include double

## LNG offshore

or full containment in accordance with BS EN 1473<sup>6</sup>.

The rationale for a difference in LNG containment philosophy between a floating and a fixed offshore LNG production facility is not clear. In each case, the installation would likely be sited remote from areas of public access such that the overriding concern should be for the safety of the operational staff and the integrity of the facility. Partial double LNG containment of the LNG carrier type would likely provide for sufficient time for operating staff to evacuate the facility but would leave the facility at risk. In the authors' opinion the potential for loss of the entire facility in the unlikely event of a catastrophic loss of containment of a single cryogenic tank or due to a cryogenic pipe failure should be considered unacceptable.

It follows that LNG storage with true double containment systems should be considered the minimum performance criteria for all LNG tankage in both fixed and floating LNG facilities.

The guidance notes recognise that the deck of a CFPSO will have superior capability to resist the effects of LNG spills and provide superior dropped object protection.

The guidance notes also include an expectation that the concrete hull would include a vapour barrier applied to the concrete structure that could otherwise allow moisture to permeate into cryogenic tank insulation. The notes also require that the concrete structure would include heating elements to limit freeze/thaw conditions in the concrete that could lead to unacceptable thermal strains and surface spalling.

In other respects the guidance notes are not specific to concrete. A CFPSO would be expected to include the normal range of design criteria and systems to ensure floating stability for intact and damaged conditions and a reasonable level of flexibility in its design to account for possible tank filling sequences and accidental conditions.

### Design for construction

The CFPSO should be constructible in a purpose built dry dock and should use normal strength concrete formed into flat panels that are not so highly reinforced that potential construction difficulties arise. Slipformed concrete should be used wherever possible for speed and to reduce the number of construction joints. The form of CFPSO should enable duplicate use of formwork and falsework systems for economy and speed of construction.

The CFPSO concept also utilizes relatively modest strength concretes. Characteristic compressive cube strengths would be limited to 50-60N/mm<sup>2</sup> at 28 days. These strengths are considered to be an achievable concrete strength in those countries of West Africa considered to be

most applicable to the CFPSO application.

Topside assembly would most likely be carried out adjacent to the proposed CFPSO hull construction, though an offshore installation, either in protected waters or at site, are also possibilities. This will require more detailed review and will be dependent upon the in-country capabilities where the CFPSO hull is constructed as well as the proximity of other module fabrication yards. While many of the modules will require cryogenic materials of construction, others will not. These will also need careful review and an assessment of cost, schedule and local requirements.

The effects of relative motions during tow to site and at site for the total project duration, on both process and large rotating equipment, must be examined. The potential increase in topside structure weight and the effects on long-term reliability and maintenance are also both significant factors to consider in the availability of the facility and its full lifecycle cost.

The assembled modules would then be loaded onto the CFPSO after completion of the roof construction.

LNG and LPG tankage would either be carried out within the CFPSO hull during the topside assembly or prior to erection of the roof structure.

### CFPSO concept

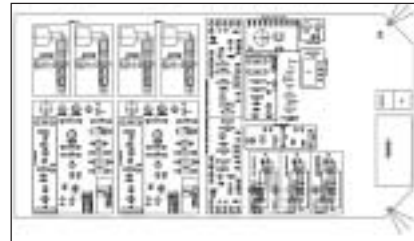
The CFPSO design criteria has defined a vessel that requires a large deck area on which to layout the facilities, a significant hull space for product storage and double wall structures to the sides and soffit to provide for accidental impact resistance, damaged stability and separation of tankage spaces. The CFPSO structure must also have sufficient structural continuity to adequately resist transportation and in-place forces.

Principal dimensions for the two LNG/LPG storage options considered in this article – the membrane tank and the self-supporting tank – are indicated in *Table 1* below.

The topside facilities will most likely need to be modularised in order to achieve acceptable cost and schedule for the project. As most of the likely sites for a CFPSO are in relatively remote areas, the availability of significant local fabrication facilities is low. In addition, the use of a 'stick-build' method is not thought feasible as in excess of 3000 personnel are likely to be required in a relatively confined space,

Dimensions	Membrane tankage	Self-supporting tankage
Hull length	300m	300m
Hull width	128m	130m
Hull depth	34m	38m
Concrete volume	165,000m <sup>3</sup>	165,000m <sup>3</sup>

Table 1.



Typical CFPSO process layout.

unlike an onshore facility. This is believed to add 10-15% cost and approximately one year to the schedule compared to modularisation.

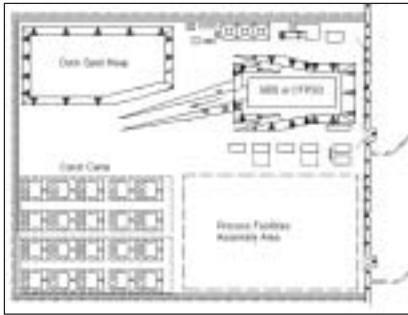
Modularisation also offers the opportunity to build the facilities in controlled environments, thus improving both quality and productivity.

Design requirements would incorporate both LNG process and marine environment considerations. In addition, a potential remote locations impact on operability and maintainability of major rotating equipment will also need careful review in order to achieve the facility availability requirements. A typical onshore LNG facility availability is in excess of 93%; an offshore facility most likely would be lower. The additional cost required to achieve high facility availability will need significant work and both reliability, availability maintainability (RAM) and life cycle cost models are recommended to be established early in the project to aid in making critical decisions.

The membrane tank CFPSO includes a tank base slab within the hull to provide structural support to the insulation and membrane. The membrane system includes a secondary LNG liquid barrier within the insulation space that is designed to prevent LNG from directly contacting the concrete. The structure would include embedded wall heating elements within the tank walls to maintain the structure temperature above 0°C.

The concept includes double wall and base structure to ensure that water pressure is not applied to walls supporting membrane tankage. This reduces the potential for water liquid or vapour transmission through the structure into the insulation space. The intent of such an arrangement is that water transmission into the load bearing insulation will be sufficiently low for it to be removed by the membrane nitrogen purging system. It is assumed that the limited concrete permeability and the fact that it is not being subject to permanent water pressures will negate the requirement for an applied water vapour barrier. Additionally, the CFPSO hull void space may require a purging system to remove hydrocarbons that may permeate through the tank structural walls.

The membrane system's provision of a secondary LNG liquid barrier within the



CFPSO graving dock and topside assembly yard.

insulation ensures that the theoretical spill condition is not an onerous design condition for the concrete hull. The secondary barrier prevents extreme cold from permeating to the concrete and the concrete is not required to be liquid tight in that condition. Consideration must be given to the effects of the cold on the concrete substructure but these effects would not lead to catastrophic loss of structural integrity.

The alternative CFPSO has been configured with self-supporting prismatic tankage. The hull base structure includes structural walls spanning longitudinally between transverse bulkheads. The structural walls provide support to the base slab and support the prismatic tanks. There is no need for a slab beneath the tank. The elimination of that requirement greatly simplifies the hull construction. The LNG/LPG tanks are configured transversely to maximise the storage volume and to fit within a notional 30-35m span of the under tank walls and roof structure. The void space under the tanks provides buoyancy and is able to contain LNG in the unlikely event of tank rupture.

Self-supporting LNG tankage has, to date, been configured with a partial liquid barrier surround to the tank insulation. In the unlikely event of a significant spill the liquid barrier is believed to retain liquid for a period before failure. Complete loss of the tank would result in significant quantities of LNG contacting the CFPSO hull. Rectilinear concrete structures with significant degrees of restraint, such as the proposed CFPSO concept, are unable to redistribute internal forces without significant cracking that would lead to leakage and loss of structural integrity. The authors have concluded that a partial double containment system without the provision of insulation to the CFPSO hull would not provide sufficient protection to the installation.

The potential of placing insulation to the base and walls of the CFPSO to protect the hull from extreme cold has been investigated. Insulation of the base slab is practical due to the heating effect of the seawater. However, internal walls would experience the most adverse temperature gradients leading to structural distress and leakage. It has been concluded that

insulation of the CFPSO hull to accommodate a full spill condition can only be contemplated in conjunction with significant wall heating. Such an arrangement is considered to be impractical to construct.

The conceptual alternative to insulating and heating the CFPSO hull is to specify a true double containment self-supporting prismatic tank. Such a concept has advantages in packaging the complete LNG containment function into a pre-assembled unit and liberating the CFPSO from additional construction complexities. The CFPSO solution presented in this article assumes that the prismatic LNG tanks will include a primary LNG container, an insulation layer and a secondary LNG liquid container. The secondary liquid container would be constructed from either stainless steel or some form of flexible membrane similar to the secondary container material proposed in the Technigaz membrane solution.

Clearly, such a solution will require significant technical development to allow it to be considered for project application.

The CFPSO hull would be configured in response to the storage and topside area requirements. The hull depth is limited by the maximum float-out draft from the dry dock, notionally assumed to be 14m but lesser or greater drafts could be considered if dry dock site characteristics are known. While it is the case that a deeper graving dock will allow a more efficient CFPSO hull solution, the relatively large CFPSO deck area required for the shallower dock construction site is beneficial in allowing greater facility separation distances and lesser topside modularisation. Both aspects are advantageous and also relevant to the proposed CFPSO construction in country.

The CFPSO concept is globally configured to provide the required topsides area with internal structural compartments configured to suit the LNG/LPG tankage requirements. Internal compartments are typically limited to 35-40m clear spans to reduce the size of the secondary hull and roof structure.

The design lateral pressures that may arise from tank operation and maximum seawater or ballast water hydrodynamic pressure loading would determine the bulkhead wall thicknesses.

Hull longitudinal and transverse cross-section properties would be checked for both serviceability and ultimate load performance in the transport and in-place conditions. The relatively long, wide and shallow hull structure may be subjected to critical bending, torsion and shear stresses during its transportation and in-place service. The concrete structure will require prestressing by post-tensioning to avoid tensile stresses in the concrete. Typical transportation and operational stresses in the structure would approach

the maximum concrete capacity and limiting prestressing system capacity in the longitudinal walls and base.

The CFPSO solution could be configured with either a spread mooring, a CALM and hawser, or a single point turret mooring. The simplest and most economical system for a CFPSO moored in offshore West African conditions is spread-mooring.

The mooring system response is most influenced by current and wind loadings in the beam or quartering seas where drift can approach the limiting design criteria for both the mooring and for the gas riser. The mooring system shows least response to head and quartering seas conditions where for West African conditions long period swell would dominate.

Mooring lines may be chain or steel fibre rope secured to conventional drag or suction anchors installed in the seabed in the traditional manner.

An analysis of a large CFPSO, 770,000te maximum displacement, showed that in extreme 100 year return period conditions, roll and pitch motions would be less than 2° and, in most cases, would be less than the limiting design criteria.

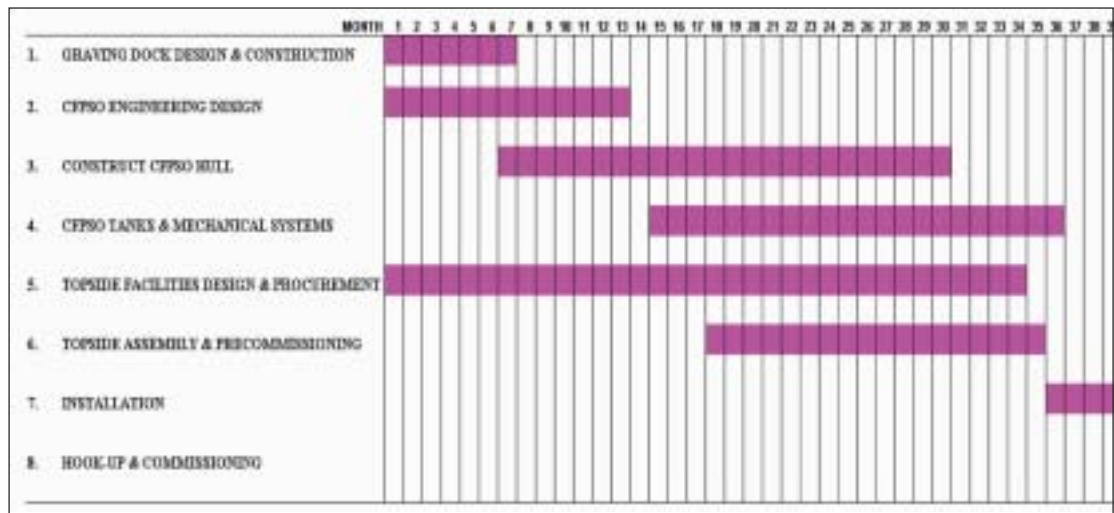
A twin LNG train production facility producing up to 9 million tpa LNG and other associated hydrocarbons will demand up to 1600 million standard cubic feet of gas supply per day. The gas intake pipeline would be a significant diameter and must be flexible to accommodate both the CFPSO motions and mooring system displacements. Assuming a 36in diameter riser were required, it can be shown that the minimum water depth for a single drape catenary riser is of the order of 200m. Alternative, multiple risers or flexible riser systems could also be considered.

The CFPSO concept requires a flexible offloading system for LNG and LPG product. Such systems are under development with a limited number of the concepts having being subjected to model testing. The more advanced concepts are configured for bow to stern loading. Assuming LNG CFPSO concepts will be installed in the coming years, then a fleet of LNG carriers fitted with bow loading systems will be required. Receiving terminals at the product destination could also be fitted with bow offloading systems or the LNG/LPG carriers could be included with traditional midships loading systems capability in addition to the bow systems.

However, this will decrease the flexibility for both parts of the supply chain, which could affect project economics and must be carefully assessed before a final decision can be made. In addition, risk assessments and the views of local regulatory authorities must also be evaluated.

The LNG/LPG carriers may require tug assistance or dynamic positioning during offloading to keep within the operational

## LNG offshore



EPIC construction schedule for a concrete FPSO.

limits of the loading arms and to avoid impacting the CFPSO vessel.

Key LNG hazards normally associated with an onshore facility may be considered within a limited number of general groupings; toxicity, cryogenic, fire, vapour cloud, vapour cloud explosion and rapid phase transitions. Many of these hazards are similar to those present in an onshore LNG production facility. Particular issues to be addressed in an offshore facility are:

- The current unavailability of industry accepted marine based LNG facility design codes.
- The inappropriate application of onshore LNG facility design codes to marine LNG production facilities
- Maintenance and emergency access/egress to a marine LNG production facility
- LNG facility operational requirements during severe weather conditions
- The establishment, with regulatory approval, of the LNG storage tank containment specifications (single, double or full containment) for offshore installations
- The hazards associated with placement of living quarters, with associated heliport access, adjacent to the LNG production and storage facilities.

### Schedule and cost

The preliminary EPIC project schedule shown above serves to illustrate the typical duration and sequence of the works. The membrane tank CFPSO has been presented due to the greater certainty at

Element	CFPSO with membrane tankage	CFPSO with prismatic tankage
CFPSO hull	\$370 million	\$380 million
Tankage	\$90 million	\$130 million
Mooring and installation	\$40 million	\$40 million
Total	\$500 million	\$550 million

Table 2.

present of the duration of the tankage works. The CFPSO with self-supporting prismatic tank has the potential to shorten the EPIC schedule by up to six months.

A preliminary estimate of the EPIC cost of the proposed schemes has been undertaken for the alternate CFPSO and tankage arrangements for a West African built facility. The costs are summarised in *Table 2*.

The cost estimate is based on West African construction close to a major population center such as Lagos, Nigeria. The level of accuracy is estimated to be  $\pm 30\%$ . No contingency has been applied. Accommodation, flare, quarters and LNG/LPG loading systems are common to both schemes and have not been priced in the estimate.

The estimate shows that the CFPSO scheme can deliver a reasonably priced LNG plant substructure and tankage solution at between \$1100/m<sup>3</sup> and \$1300/m<sup>3</sup> of LNG/LPG stored.

The cost of LNG production facility has not been explicitly estimated. The cost of LNG production facility is estimated at approximately \$1.6 billion, with an accuracy of  $\pm 20\%$ . The cost of the loading systems has not been estimated.

Key technical issues requiring additional effort are:

- LNG loading systems;
- codes/regulations to be used;
- safety issues/mitigation measures for facility design;
- tankage design; and
- impact of motion on LNG process and mechanical design requirements

### Conclusions

CFPSO LNG developments are feasible and offer significant advantages by being able to locate the facility in close proximity to large, offshore stranded gas reserves. These advantages are the reduction of offshore pipelines, onshore facilities and marine jetty. In addition, the facility could ultimately be moved to another location in

the future. LNG in itself offers a proven method to monetize stranded gas with large market access on both a dedicated and spot cargo basis.

The use of concrete for such a facility also offers several advantages. These are:

- reduced operating cost;
- enhanced safety for dropped objects and spills;
- increased vessel impact capability;
- significantly increased mass to reduce facility motions;
- better storage safety for possible tank leakage; and
- ability to increase local content.

Technical issues remain with regard to the facilities as well as safety considerations. These are believed to be solvable, but will require more effort before a firm case can be put before the appropriate local and international regulatory authorities. Unique site conditions (metocean, soil, etc) will also require careful review for impact on the design and cost and project economics.

The necessity or desire to have such a facility funded by outside lending agencies, especially on a non-recourse basis as is typical for LNG plants, will also need more care and nurturing before it can most probably be brought to fruition.

### References

- [1] *Guidance notes on building and classing offshore LNG terminals*, American Bureau of Shipping, 2002.
- [2] *Classification of offshore LNG production and storage installations: Guidance Notes*, Lloyd's Register of Energy & Transportation, Report No GN 02015, Revision 01, October 2002.
- [3] *Rules for fixed offshore installations*, DnV, 1989 (plus Amendments).
- [4] *BS8110, Structural use of concrete*, British Standards Institution, 2000.
- [5] *Installation and equipment for liquefied natural gas – design of onshore installations*, British Standards Institution BE EN 1473:1996. **OE**