John Sheffield and **Rod Dean** look at the progress of off-shore LNG production

THE development of liquefied natural gas (LNG) is very much related to the second half of the 20th century. That said, methane, the overwhelming component of dry natural gas, was first liquefied in 1820 by one of Britain's most revered scientists, Michael Faraday and later in 1873 the first compressor refrigeration machine was built by the German engineer Karl Von Linde. However there was no real practical application, as far as natural gas was concerned, until almost 100 years later. Commercial use of natural gas commenced in the 1930s in the US and in the late 1950s in the UK, where LNG imports began in 1956.

In 1959 there was only few thousand tons exported from the US to the UK on a trial basis. By 2011, world trade in LNG was about 245m t/y, and growing at an annual rate of 5–10%. The industry has come a long way and is now looking to sea.

All of the LNG traded in 2012 was produced by land-based processing but this is about to change as floating LNG (FLNG) developments currently under construction in the Far East start to produce LNG.

The concept of producing LNG on a boat has been around for almost as long as the LNG business itself, indeed the LNG produced in that inaugural trans-ocean LNG shipment to the UK came from a small barge-mounted plant moored alongside a pier near Lake Charles in Louisiana. However it soon became clear that despite the apparent advantages and benefits offered by an off-shore option there were numerous difficulties in realising LNG liquefaction plants on an economically-viable scale.

The perceived benefits of LNG production on an off-shore floating platform were:

- it should be lower cost as the flow-lines to shore would not be needed;
- it should also be lower cost as the plant

could be modularised and built in controlled conditions; and

- it would be re-useable and could be relocated to a new location once the field was exhausted.

But weighed against these apparent advantages were a number of real difficulties.

Perhaps the major problem was that the potential buyers regarded the overall risk as too high

Overall the cost was not lower; the available plot size, the deck area of the ship, meant that the plant equipment was congested and only a limited scale of operation could be achieved, losing the benefit of scale and multiple trains possible on an on-shore facility.

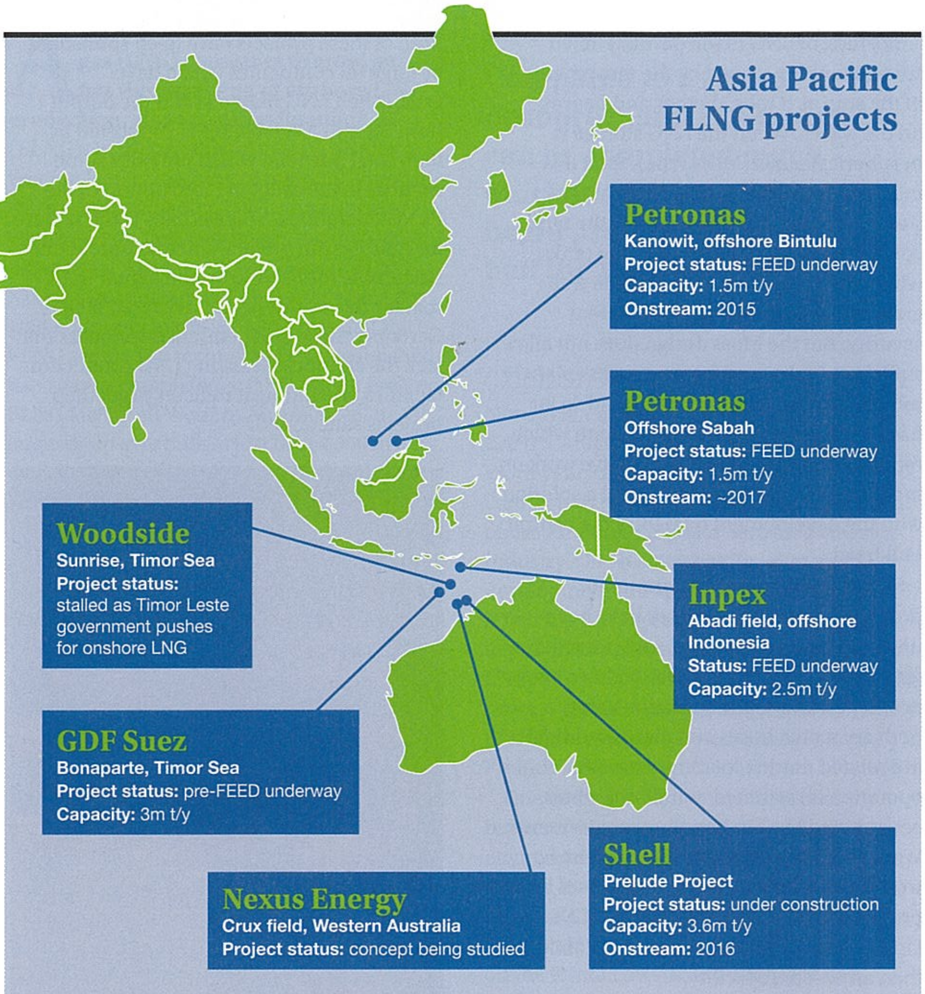
Moving the facility before the field was completely exhausted was resisted by some authorities who were also nervous about the whole concept of a 'national' asset hauling up anchor and moving on.

There were severe technical problems when operating in the open sea caused by the movements of the vessel, this not only affected the performance of the process plant but 'sloshing' in LNG storage tanks was likely to damage them, and LNG transfer to a shuttle carrier was restricted to very mild sea states.

However, perhaps the major problem was that the potential buyers regarded the overall risk as too high and so long as LNG was available from onshore-based plants, this was always going to be the preferred option.

So, at the turn of the last century, while there were many potential opportunities (some with robust technical options), there was no coherent strategy to pull the strings together and tackle the outstanding challenges.

Against this challenging background, many companies continued to develop the concept to reality, spending many millions of dollars on studies and prototype experiments to realise the goal. The driver for this was the availability of many potentially-developable small off-shore gas reserves (less than 5tn ft^3) which were too small and too disparate to develop a gas-gathering and pipeline network to deliver the gas to a shore-based plant. Some of these were associated gas, where it is necessary to re-inject the gas to avoid flaring if the oil is to be recovered. Whilst some are gas fields, a number had a high level of liquids which add to the value of the asset.



The majority of FLNG projects are planned for the Asia Pacific, though there are tentative plans for smaller projects in the Americas

But first the technical challenges had to be overcome and significant work was undertaken by major oil companies such as Shell, the ship operators such as Hoegh, and off-shore developers such as SBM. Ship builders and equipment manufacturers also used their creative skills to address some of the key issues. Many other companies also saw potential in off-shore LNG production and perhaps the work by Flex LNG was the most interesting and showed a strong innovative and entrepreneurial approach (see also KANFA Aragon's article, p49).

Work has focussed on making the process plant layout more compact, safe and resilient to the motions of the vessel and developing new onboard storage concepts

This work focussed on:

- making the process plant layout more compact, safe and resilient to the motions that the vessel is subjected to;
- developing storage concepts that could accommodate the forces generated by sloshing and still provide sufficient deck space;
- addressing the LNG transfer question and developing solutions which would work in more severe sea states and, more importantly
- finding investors and consumers who would fund the development and ultimately a project.

Making the plant more compact relied on the skills and experience developed for off-shore oil and gas platforms. Oil FPSOs provided a useful experience base to address the challenges of motion and a few LPG production units proved that columns could be designed to work effectively.

The safety issue was exacerbated by the compactness of the designs and this resulted in most developers eliminating propane from the refrigerant mix. Some developers have completely eliminated hydrocarbons from the refrigerant mix and use expanding nitrogen as the refrigerant, tolerating the marginal loss in efficiency, which is not significant on trains of less than 1.5m t/y. Train size, or capacity, is an issue and those developers seeking a higher capacity do find it necessary to use single or dual mixed refrigerant processes to achieve a higher efficiency.

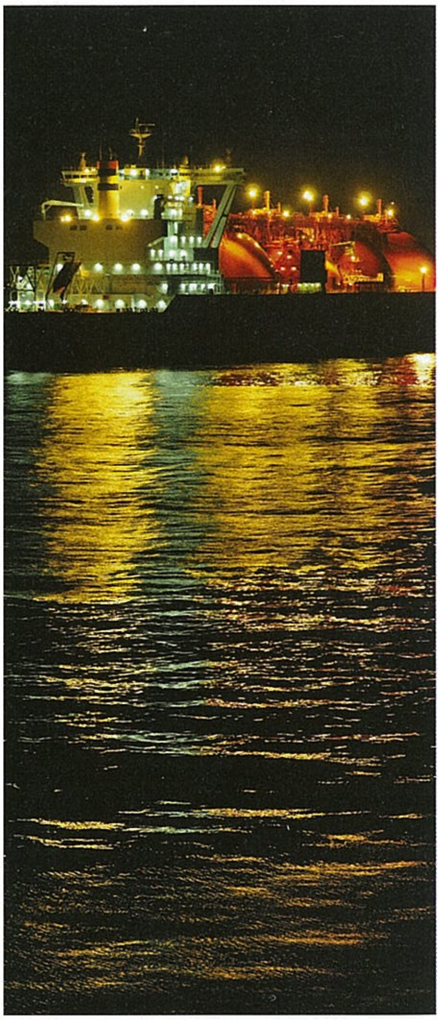
Sloshing of LNG in the partially-filled storage tanks is caused by the movements of the ship as it rolls, picthes and heaves on the waves. When the LNG storage is in spherical tanks (Moss type), then this movement causes few problems as the surface waves roll up the sides of the tank, compared to the cubic membrane tanks where the wave slams into the side walls gradually damaging the containment security. But the Moss design does not allow sufficient deck space for the process plant required for liquefaction trains and so far has only been used for regasification which requires less equipment. Innovative work on membrane tank design has found a solution with the development by GTT of the central bulkhead.

Systems to transfer LNG from the production vessel to a tanker have been under active development, and procedures for side-by-side (SBS) operation have been developed and are in operation using both cryogenic hoses and marinised rigid articulated marine loading arms. SBS operation is restricted to mild sea states, constrained by ship handling requirements. Work to develop tandem systems which would extend the operating window is in progress, but the reality is that an FLNG facility is likely to have a lower availability than an on-shore facility.

With robust technical solutions now available, the race was on to launch the first FLNG project, with several developers favouring a mid-scale 1.5m t/y operation and one major company, Shell, pioneering a larger unit with a capacity of more than 3m t/y. Shell eventually approved the development of its Prelude project off-shore Western Australia in May 2011. This is a leviathan of a vessel, with an overall length of 490m, weighing 600,000 t and with a capacity of 3.6m t/y of LNG and 1.3m t/y of condensate which uses the Shell DMR (double mixed refrigerant) process. The Prelude facility is scheduled to be on stream in 2016, but the proposed FLNG facility announced by Petronas in June 2012 may yet be first, as it is targeted to be on-stream in 2015. The Petronas facility is smaller at 1.5 m t/y and uses the APCI nitrogen cycle installed on a hull similar to a large LNG carrier.

Those independent developers that lack the support of existing LNG production facilities are finding it difficult to get their projects sanctioned.

Both of these projects have been sponsored by large oil companies which have established LNG markets, and the output from their FLNG facilities is supported by their total portfolio which provides some security in the event of interruption to the FLNG operations. This perhaps is the secret for a successful project, since its operational risk profile for FLNG must be higher than that for the equivalent shore-based facility. Certainly those independent developers that lack the support of existing LNG production facilities are finding it difficult to get their projects sanctioned.



The costs of the FLNG projects which have so far been approved are comparable to shore-based facilities, but it is confidently expected that with experience and further developments lower capital costs will be possible. This however is unlikely to have a major impact on the price of LNG produced from an FLNG vessel, particularly in the Pacific Rim market area where LNG is priced against crude oil. However, there may still be an option for specifically-focussed trades.

The FLNG concept might find a niche in the further development of the Australian reserves. There have recently been severe-cost blow-outs on both the west and east coast LNG projects. So much so that serious proposals are now being made to use FLNG technology as a more cost effective alternative for the Browse basin project, thus enabling the complete facility to be fabricated and constructed in lower cost areas.

The other end of the LNG chain is the receiving terminal for storing and regasifying LNG, and the off-shore version is the FSRU (floating storage and regasification unit). There are already some 15 FSRUs deployed around the world and one company, Excelerate Energy, has a fleet of nine vessels with four more under construction available for short- or long-term charter. In the past few years the seasonal deployment of these vessels to supply gas to South American countries during the southern hemisphere winter is an interesting development.

With two major companies having made the commitment to FLNG deployment we can expect more developments in the next few years

The future for off-shore LNG developments is looking very promising: the technology is now considered mature for deployment in a variety of situations. With two major companies having made the commitment to FLNG deployment we can expect more developments in the next few years as others seek to develop stranded gas reserves economically.

It is highly unlikely that FLNG will ever overtake the volumes produced at land-based plants; however the coming growth of alternative LNG production does promise added flexibility in production and supply.
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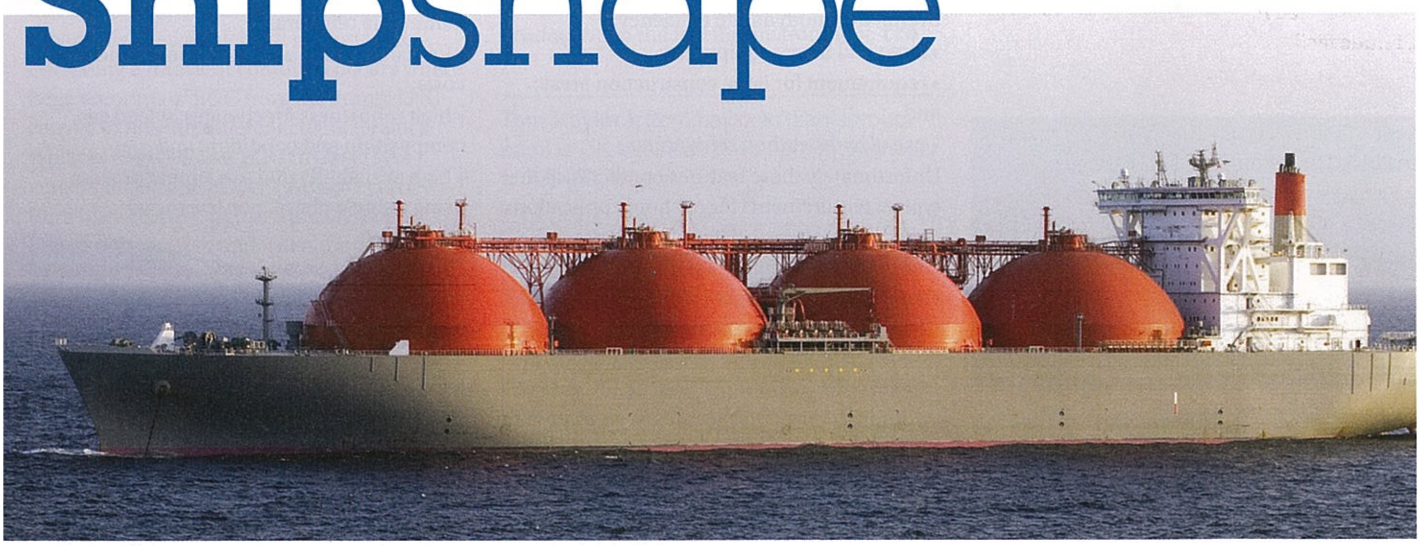
further reading

1. Kennett, AJ, Limb, DI and Czarnecki, BA, *Offshore Liquefaction of Associated gas – A suitable process for the North Sea*, 13th Annual Offshore Technology Conference, Houston, May 1981.

2. Jones, N, *Overall FLNG Development Philosophies and Strategies*, FLNG Rio Technical Masterclass, Rio de Janeiro, September 2010.

Shipshape

Tom Haylock examines the key technical challenges of producing LNG at sea



AS demand for liquefied natural gas (LNG) continues to grow, so has the attraction of offshore LNG production, also known as floating LNG (FLNG). In theory, the concept is simple: a floating facility, capable of treating, liquefying, storing and offloading LNG at sea, located wherever you find natural gas in abundance.

However, although the concept of FLNG has been evaluated and discussed since the 1980s, it's only in the last ten years that the FLNG sector and technology has established itself. Once completed in 2016, Shell's Prelude FLNG facility off Western Australia will be the largest ship ever built at just below 500 m long, with a target production of 5.3m t/y of liquids including 3.6m t/y of LNG.

Compared to a typical onshore plant, FLNG projects can be completed much quicker, with some able to begin production in up to half the time required for a typical onshore LNG plant. This is because the whole plant can be built into modules and installed on a ship in a shipyard which is fully prepared and staffed with the necessary skilled labour, unlike onshore plants where the ground and infrastructure must be built from scratch and the workforce brought in.

So far, FLNG has only been considered for offshore gas fields where it's too expensive to install the infrastructure needed to transport the gas onshore (as in Shell's Prelude project). But it is now also now being considered as an alternative to *onshore* LNG plants. By piping the gas to a ship anchored off the coast, or moored at shore, onshore fields in areas with poor infrastructure or even pipeline gas can be liquefied for export. This option is expected to be popular in countries where populations have shown themselves averse to large onshore industrial plants, or where permanently-installed LNG plants aren't suitable.

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offshore technology criteria

Norwegian engineering company KANFA Aragon, along with Costain and WorleyParsons in the UK, have recently completed the front end engineering design phase for FLEX LNG and Samsung Heavy Industry's FLNG concept for an at-shore development in Papua New Guinea (PNG). A floating LNG solution has been selected to provide a faster route to begin producing LNG. Since 2006, KANFA has been developing process topsides and liquefaction technology to rival those championed by Shell on the Prelude development.

Due to the fundamental differences between the onshore and the offshore environments, there are different selection criteria for FLNG projects compared to onshore LNG projects. Floating facilities must be more compact and lighter to fit on the limited available deck space and offer high inherent process safety due to limited methods of escape. Other important constraints include operation under vessel motions as the ship rises and falls on the waves, the need for modular prefabrication before installation, offshore maintenance and operation challenges, and limitations on logistics and available manpower in operation.

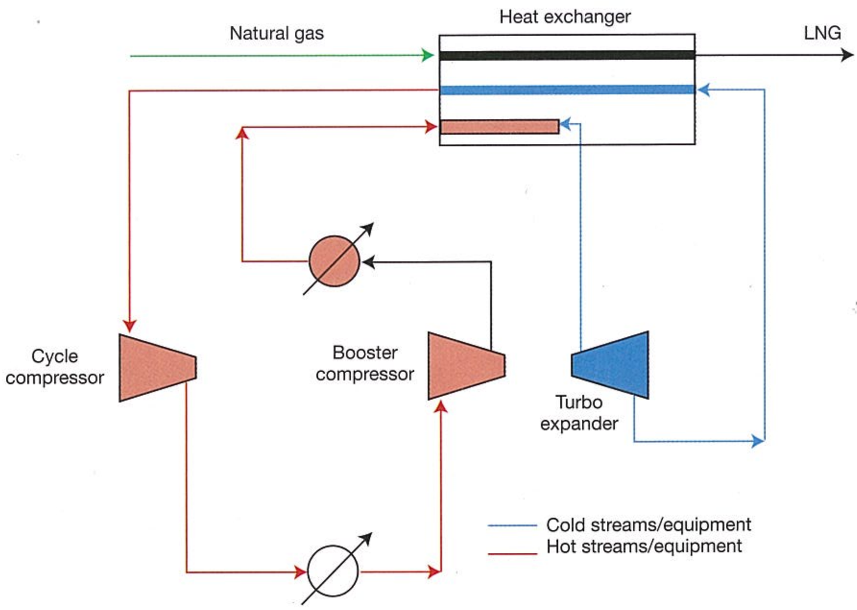

Figure 1: The nitrogen expansion cycle – simplified

From the experience gained in offshore oil and gas, a highly reliable offshore plant is more desirable than trying to optimise process efficiencies.

From the experience gained in offshore oil and gas, a highly reliable offshore plant is more desirable than trying to optimise process efficiencies. High uptime ensures reliable production and income. Finding the correct balance between optimum process efficiency and increased complexity is one of the key challenges for FLNG.

Technology selection should also take into consideration the robustness of the process, its sensitivity to variable feed gas compositions and conditions, and the time it takes to start up and shut down.

liquefaction technology

Most onshore large LNG projects apply mixed refrigerant processes with high process efficiencies. Common for all these technologies are:

- ultra-large train size (a train is one stand-alone LNG producing process system);
- high process efficiencies (in terms of power used per kg of LNG produced) but variable overall thermodynamic efficiency;
- large and heavy equipment;
- requirement for large construction areas; and
- use of hydrocarbon refrigerants.

Unfortunately these features conflict with the typical requirements for offshore applications. To date, three types of liquefaction process have typically been considered for FLNG: single mixed refrigerant (SMR) and optimised double mixed refrigerant (DMR) cycles; optimised cascade cycles; and nitrogen-based expansion cycles.

Although mixed refrigerant cycles have the highest process efficiencies, the nitrogen expansion process has been acknowledged by many as most suitable for FLNG, even as far back as 1981[1]. All nitrogen expansion processes are based on the Reverse Brayton-Claude Cycle where high-pressure nitrogen is pre-cooled and then expanded over turbo-expanders to approximately -160°C. The expansion is near isentropic so the use of turbo-expanders lowers the gas temperature more than using a Joule-Thomson valve, and is hence more efficient (and leads to more LNG production).

After the expansion, cold, low-pressure gas streams are returned to the cryogenic heat exchanger refrigerating the natural gas (see Figure 1).

Using high efficiency aero-derivative gas turbines as drivers in the nitrogen cycle increases the overall efficiency of the system. Such gas turbines available for the offshore environment are limited in size, limiting production per nitrogen liquefaction train to approximately 1.2m t/y. Although nitrogen technology is expected to be primarily suited to medium-scale projects (<3m t/y), it is competitive with single train mixed refrigerant processes (such as is being used on Shell Prelude). Due to the lower equipment count, up to three nitrogen cycle trains can be competitive with the capital cost of a single mixed refrigerant train[2]. Using multiple trains compared to one train also results in better overall availability due to the added operational flexibility, where shutdown will only limit output, not halt it altogether.

A nitrogen expansion cycle offers several features suitable for offshore:

- high inherent safety level due to non-flammable refrigerant;
- low complexity, weight and investment costs;
- high robustness for changes in feed gas composition and condition; and
- high availability due to a simple process using a single phase, non-corrosive refrigerant.

Dual nitrogen expander cycles offer improved power consumption by approximately 30% compared to single expander cycles. This is because the use of two expanders at different temperatures allows for a closer match of warm and cold streams, giving reduced temperature differences and reducing the thermodynamic loss.

KANFA's optimised dual nitrogen expander cycle, whose additional features make it

The Shell Prelude FLNG concept requires the world's largest ship; in comparison, multiple nitrogen cycle liquefaction trains can be installed on a ship the size of the LNG carrier next to the Prelude vessel highly suitable for offshore, was selected for use on the FLEX LNG project as it offers optimised part load operation, integrated heavy hydrocarbon removal, and flexibility to changes in feed gas compositions and pressures. All while maintaining the simplicity of the nitrogen expansion cycle.

marinisation and safety

Experience from both FPSO design and cryogenic engineering is crucial as the plant needs to handle vessel motions and accelerations together with cryogenic operation. This is especially important if applying a mixed refrigerant style process due to its multi-phase (vapour and liquid) nature. It can be expected that production will be much more vulnerable to an offshore environment as a result. Two key issues for mixed refrigerant cycles are:

- pipe sloping requirements complicate the layout of large cryogenic piping systems and reduces access space in what is already a very limited area; and
- changes in the compositions and/or phases require special care and fine tuning to ensure optimal production.

These are issues that a nitrogen cycle avoids. However, vessel motion effects on liquids in other systems remains a challenge but can be dealt with through solutions applied offshore already.

Challenges certainly exist for the nitrogen cycle, such as large pipe sizes, but by using equipment that is already proven in offshore oil and gas environments the risks can be minimised.

To produce LNG the gas must always be pre-treated and systems such as CO_2 and water removal require a lot of energy. Comprehensive understanding of the overall process topside is essential to reach successful integration of all systems. A good example is integrating the overall fuel gas balance and boil off gas (BOG) balance of the ship into the overall process. BOG is LNG that has vapourised in the storage tanks. It is typically used as fuel, but during cargo offloading a transient condition occurs where large amounts of BOG from the empty LNG carrier, often with different characteristics, replaces the LNG and BOG in the FLNG vessel's tanks. The BOG in the LNG carrier from its previous cargo is typically at a higher temperature and when transferred to the LNG FPSO during cargo loading, the amount of BOG on the LNG FPSO increases significantly compared to normal; this causes a transient condition/upset that the plant must be designed to handle.

As space and escape options are limited offshore, FLNG has more safety concerns than onshore LNG production. Care must be taken to ensure a floating plant is uncongested and meets both fire loads and escape route requirements. Loss of cryogenic containment is another new risk offshore, when LNG leaks it causes cold shock on whatever it touches which can lead to material failures (eg causing pressurised lines to rupture) and also creates an explosive vapour cloud when exposed to the atmosphere. The risks are injury, loss of life and damage to equipment. If things go wrong offshore it is not easy to get away.

The liquefaction system itself takes approximately half of the size of an FLNG vessel. By using nitrogen the risks are significantly reduced as it is non-flammable and minimises the amount of cryogenic liquids. Hydrocarbon refrigerant processes require inventories of hazardous liquid hydrocarbons on board which also require larger flare systems in a limited offshore area.

KANFA has studied FLNG solutions over many years. Although there are challenges, the conditions for FLNG are favourable, and the desire in the US to become an LNG exporter presents new opportunities in particular.

These are exciting times as LNG production takes to the sea. It will open up new opportunities for chemical engineers as any FLNG development will need experienced capable engineers who understand the unique challenges of applying LNG production to the marine environment. **tce**

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Image courtesy of Samsung Heavy Industries

The FLEX LNG producer concept, developed for offshore and at-shore projects using KANFA Aragon's technology

further reading

1. Kennett, AJ, Limb, DI and Czarnecki, BA, *Offshore Liquefaction of Associated gas – A suitable process for the North Sea*, 13th Annual Offshore Technology Conference, Houston, May 1981.

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