



LNG SHIPPING AT 50

SIGTTO
at 35 &
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at 43



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LNG Shipping at 50

A COMMEMORATIVE SIGTTO/GIIGNL PUBLICATION

October 2014



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Published by:
Riviera Maritime Media Ltd
Mitre House
66 Abbey Road
Enfield EN1 2QN
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riviera 

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It all started here ... Methane Princess discharges the first ever commercial cargo of LNG at the Canvey Island terminal on 12 October 1964



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LNG shipping – one continuous golden age

Jointly sponsored by SIGTTO and GIIGNL, *LNG Shipping at 50* is a celebration of the first half century of commercial LNG carrier and terminal operations. The publication also marks the 35th and 43rd anniversaries of the Society of International Gas Tanker and Terminal Operators (SIGTTO) and the International Group of LNG Importers (GIIGNL), respectively.

The two organisations and their memberships have done a sterling job of developing guidance on safe operations; promulgating industry best practice; and providing forums for the airing of concerns and discussion of topical issues. The exemplary safety record built up by the LNG shipping and terminal industry over the past five decades owes much to the central roles played by SIGTTO and GIIGNL.

The LNG industry has an exceptional

story to tell and *LNG Shipping at 50* contributes to the telling of that story. The publication starts with a review of the early days to show how the industry developed the innovative solutions needed to ensure the safe transport of LNG by sea. The articles in this section then describe how these solutions were then continuously improved upon as more countries turned to seaborne natural gas imports to meet their energy needs.

Pioneering people, ships, shipyards, containment systems, class societies and equipment suppliers are reviewed to highlight the key role they played in facilitating the safe and smooth operation of the LNG supply chain, including at the critical ship/shore interface.

Safety is the No 1 priority in the LNG industry and the safety regime section of the magazine examines the cornerstones that underpin an unparalleled safety

record. Quite aside from the IGC Code and the work of SIGTTO and GIIGNL, there are the contributions of class, training establishments, vetting programmes and escort tug services.

LNG Shipping at 50's survey of progress to date is followed by a look at the many innovations introduced by the industry in more recent years, not least floating LNG production vessels, regasification units, Arctic LNG, small-scale LNG and LNG bunkering. These pages show that the LNG industry is not only innovating at a faster pace than ever before but also beginning a major new era of expansion that will encompass a range of players, places and applications undreamt of 50 years ago.

*Mike Corkhill, Editor
September 2014*

The authors

Mike Corkhill has been editing *LNG World Shipping* for 10 years and writing about oil, gas and chemical tanker shipping for the best part of four decades. Following qualification as a naval architect and an inaugural few years as a Lloyd's Register structural surveyor, his first writing job was the compilation of a book, *LNG Carriers: The Ships and Their Market*, for Fairplay in 1975.

Fifty years ago Syd Harris was a young naval architect designing LPG carrier tank and hull structures at UK shipbuilder Hawthorn Leslie. His career has focused solely on LPG and LNG ships, including early LNGC pioneering plan approval with ABS. He formed his own consultancy firm in 1978 and is the

author of *Fully Refrigerated LPG Carriers* as well as a regular contributor to *LNG World Shipping*.

Andrew Clifton is the current general manager of SIGTTO, having been appointed in November 2012. His pre-Society career includes 19 years at sea, mainly on liquefied gas carriers, a first class honours degree, three years at the UK's Marine Accident Investigation Branch and 30 months in the SIGTTO Secretariat as a technical adviser. Prior to his present role, he spent six years in Indonesia as LNG shipping operations manager for the Tangguh LNG project.

Prior to his appointment as general delegate to GIIGNL in 2010 Jean-Yves Robin worked for Gaz de France and GDF Suez in a range of jobs. These included heading one team analysing economic

and strategic aspects of new exploration and production targets and another responsible for the company's economic intelligence activities. Presently seconded from GDF Suez, Jean-Yves is working fulltime for GIIGNL.

Bill Wayne became general manager of SIGTTO in May 2007 on retirement from Shell. His five-and-one-half-year tenure, which ended in November 2012 when he handed over the reins to Andrew Clifton, coincided with a time of great change during which the Society's membership experienced unparalleled growth. His involvement with SIGTTO actually goes back much further, to the early days of the Society when he represented Shell on the General Purposes Committee and participated in many of the early working groups devoted to technical issues.



Mike Corkhill (MC)



Syd Harris (SH)



Andrew Clifton (AC)



Jean-Yves Robin (J-YR)



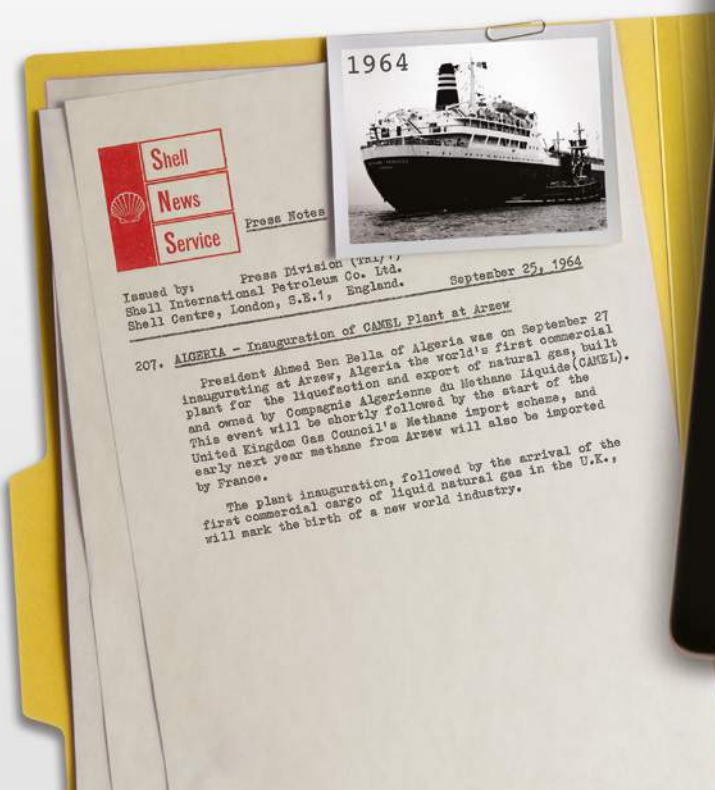
Bill Wayne (BW)



Fifty years ago, Shell was proud to have been involved in the world's first commercial liquefaction plant in Algeria and the voyage of the first commercial liquefied natural gas (LNG) cargo. Now, Shell is at the forefront of the next first for the LNG industry: floating LNG (FLNG), which will allow gas to be liquefied at sea.

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HALF A CENTURY OF FIRSTS





Andrew Clifton
General Manager, SIGTTO

Hail to the pioneers and their foresight!

An introduction from the Society of International Gas Tanker and Terminal Operators (SIGTTO)

It is a great pleasure and honour for the Society of International Gas Tanker and Terminal Operators (SIGTTO) to be jointly producing this commemorative publication along with our good friends and colleagues at the Group of Liquefied Natural Gas Importers (GIIGNL).

It really is quite remarkable that liquefied natural gas has been transported by sea for 50 years, but it is an unmistakable fact that *Methane Princess* discharged the first ever commercial shipment of LNG on 12 October 1964.

Today is a very exciting time to be involved with LNG shipping and terminals and there has never been a period quite like it. Today's growth is completely unprecedented, with more ships, terminals and SIGTTO members than ever before. I often wonder if the pioneers of half a century ago ever thought about what the future held in store for LNG, indeed about whether an international trade in LNG would establish itself or not.

It is unlikely that the pioneers would have dreamed about LNG carriers the size of today's Q-max ships or vessels like *Prelude* that will be able to produce large quantities of LNG while floating at a remote offshore location.

While the increased activity in our industry is to be welcomed, it does bring with it further challenges which need to be tackled. Not least of these is the provision of an adequate supply of properly trained and competent ship crews, shore support staff and trainers to meet the requirements of a rapidly expanding global fleet.

The LNG shipping sector's safety record is something we are all very proud of and many reading this article will have contributed towards it over the years. This outstanding

performance, however, remains our industry's license to operate and we all have a 'collective responsibility' as an industry to maintain it despite the steadily increasing levels of activity.

When mentioning the safety record, we also need to give credit to the pioneers for their contributions to the early days of LNG shipping and to the development of the International Gas Carrier (IGC) Code, with its healthy safety margins and robust design, equipment and construction provisions. I believe that these contributions are directly responsible for the excellent and unprecedented safety record that the LNG industry has achieved over 50 years of commercial operation.

SIGTTO was formed 35 years ago and the Society is as strong now as it has ever been. We remain the industry leader for the provision of best practice guidance and technical support across the liquefied gas shipping and terminal sectors.

Our membership includes companies responsible for around 97 per cent of the world's LNG vessels and terminals and around one-half of the LPG market. Furthermore SIGTTO's membership is a committed membership, supplying staff to working groups and SIGTTO's General Purposes Committee (GPC) in a timely and consistent manner.

SIGTTO Panel Meetings are very popular and well attended and the Society now has Regional Forums across the world, engaging with the membership and ensuring that any concerns are addressed for the benefit of the industry as a whole. Our recent publications have addressed topics such as the gas carrier transits of the Panama Canal, human factors and competencies in the workplace. The Society is also further developing its library of publications with new documents and updated versions of existing ones.

I find the history of liquefied gas shipping fascinating and this publication has many very interesting articles about the early days. I hope you enjoy reading this publication and retain a copy as a keepsake for future reference. Here's to the next 50!



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Jean-Yves Robin
General Delegate, GIIGNL

An achievement worth celebrating

An introduction from the International Group of Liquefied Natural Gas Importers (GIIGNL)

The development of energy resources and the exploration and production of hydrocarbons represent one of the epic accomplishments of the modern industrial world. Within this field of endeavour the emergence of the LNG industry over the last 50 years stands out as a success story of exceptional merit.

One of the reasons behind the success of LNG is the excellent body of technical and operational guidance established by those responsible for processing, transporting and handling the product. The strong demand for plentiful, clean-burning natural gas and the infrastructure that has been established for moving it around the globe as LNG are poised to support the continued, impressive growth of this sector well into the future.

Reinforcing this belief, the consensus view among experts is that global LNG trade flows are likely to double within the next 20 years. Trade growth will be accompanied by an increasing number of players and the emergence of new sources and destinations worldwide, especially in Asia but also in Africa and South America.

At this stage – on the occasion of the industry’s 50th anniversary – it is fair and fitting that we pay tribute to all those men and women who have made this adventure possible. These are the ones who faced up to the many technological and business challenges encountered in liquefying natural gas for the mutual benefit of buyers and sellers separated by the world’s oceans.

The pioneers developed and constructed the first LNG supply chains and subsequent generations built on these foundation stones with larger and more sophisticated liquefaction plants, regasification terminals and LNG carriers. We also need to acknowledge the entrepreneurial and innovative spirit of the current players who are helping to extend the LNG supply chain into new realms, namely offshore and small-scale LNG, and to develop new market opportunities, not least the use of LNG as marine fuel.

The industry can be justifiably proud of the exemplary safety record that has been built up over its first half century. So far some 77,000 LNG cargoes have been discharged without any major accident attributable to the cargo.

The International Group of Liquefied Natural Gas Importers (GIIGNL) – the worldwide association of importers established in 1971 – has consistently supported the development of the industry and has provided a forum for senior executives of importing companies to meet and contribute to its continued growth. Today GIIGNL has 74 member companies in 24 countries worldwide. The three main regions are well represented, with 10 members in the Americas, 32 in Asia and 32 in Europe. The strength, geographical spread and long-term commitment of this membership are indicative of GIIGNL’s support to the LNG adventure to date and of its confidence in the continued success of the industry.

The LNG industry and GIIGNL have good stories to tell and we are pleased to be part of this commemorative magazine and the celebrations of 50 successful years of LNG transport and handling. We hope you enjoy the stories.

Methane Pioneer sets the scene

Methane Pioneer made history in January 1959 when it departed Louisiana with the first ever seagoing cargo of LNG and opened the door to a whole new world of energy transport

Even *Methane Pioneer*, the first ship to carry a seagoing cargo of LNG, had a vessel that preceded it. William Wood Prince, president of Chicago's Union Stock Yard and Transit Co in the early 1950s, is acknowledged as the father of LNG and he pioneered the *Pioneer*. But he didn't get there right away.

In 1951, irked at a proposed price rise by his local gas supplier, Prince had the idea of liquefying natural gas in Louisiana and barging the LNG up the Mississippi River to his stockyards. Here the fuel could be used in various meat-processing operations, including in freezing and preserving meat products.

The plan called for liquefaction equipment to be mounted on a barge which could be moved around to remote fields along the Gulf Coast where the cost of gas was very low. Willard Morrison, an engineer, inventor

and one of William Wood Prince's consultants at the time, played a key role in developing the various elements of the project.

In 1954 a barge-mounted liquefaction plant and a 5,500m³ transport barge, *Methane*, were ordered at the Ingalls Shipbuilding yard in Pascagoula, Mississippi to carry out test work and enable the scheme to move forward. At about this time Prince decided to seek the involvement of a company familiar with gas processing and found a willing partner in Continental Oil Co of Oklahoma.

Continental Oil reviewed the work of Union Stock Yard's research team and carried out its own investigations of LNG transport by river barge. The consensus view was that shuttling LNG up the Mississippi River by barge was not an economical proposition but that the ocean transport of LNG was. In 1955 the partners came together to establish

Constock International Methane Ltd.

Although the original barging scheme was abandoned, it was decided to use the liquefaction and transport barges building at Ingalls as pilot plants. The vessels were completed in late 1955 and moved to Bayou Long in Louisiana for extensive testing throughout 1956. *Methane* had been built with five vertical cylindrical tanks internally lined with balsa wood. Amongst the test results, the balsa proved not to be up to the job as an internal tank liner.

It was realised from the outset that the shipment of LNG by sea would pose special technological challenges. For a start the design of the cargo tanks would be complicated by factors such as ship motions and the need to keep tanks firmly in position; independent expansion and contraction; ship hull deflections; and substantial temperature gradients during tank filling and emptying.

Constock Liquid Methane Corp, a subsidiary of Constock International Methane, embarked on an ambitious research programme to verify the commercial feasibility of LNG transport by sea. The investigative work encompassed innovations in gas processing and liquefaction techniques, the evaluation of materials, ship designs, cargo-handling systems and storage tanks.

Consultants from universities were employed on a part-time basis to translate the research results into design



At its Calcasieu River jetty *Methane Pioneer* loads the historic first LNG cargo

criteria for practical applications. One of the lead consultants on the project was Dr Cedomir 'Cheddy' Sliepecevic, a chemical engineer and the son of an immigrant from Bosnia-Herzegovina. Dr Sliepecevic received the 1986 Gas Industry Research Award from the American Gas Association in recognition of his work in coordinating work on the overall project.

Specific assignments involving more detailed work were contracted out to industry specialists, as follows:

- J F Pritchard – focusing on gas processing, liquefaction and plant construction
- Gamble Brothers – wood and insulation
- J J Henry – naval architects and marine engineers
- A D Little – storage and cargo-handling methods.

By 1957 complete designs, specifications and drawings for the liquefaction plant, oceangoing tanker and terminal facilities had been completed. It was at this point that the British Gas Council entered the picture.

The UK was seeking to reduce its heavy reliance on coal, not least by increasing its commitment to gas. At the time, the discovery of North Sea gas was still a decade away and the country had no known natural gas resources. It had to rely on town gas processed from coal for its supplies and this accounted for 6 per cent of the country's energy mix in the 1950s.

The UK's predicament had come sharply into focus in December 1952 when the Great Smog hit London. Over a period of five days a combination of coal smoke and the climatic conditions produced a smog so thick that it brought road, rail and air traffic to a halt and literally choked people to death. Some 4,000 fatalities were directly linked to the smog and it is likely that a further 8,000 deaths recorded in the following weeks and months could be attributed to exposure to the Great Smog.

That episode is one of the key reasons the UK Parliament passed the 1956 Clean Air Act. Amongst its many measures, the legislation encouraged the use of gas for domestic heating and cooking. The search was on for other sources of gas as the process of producing town gas from the distillation of coal gave rise to considerable air pollution in its own right and town gas possessed only one-half the calorific heating value of natural gas.

As part of the search the North Thames Gas Board sent Dr James Burns, its chief engineer, and Leslie Clark, its development engineer, to the US to evaluate the ship design work JJ Henry was carrying out on behalf of Constock. The pair were sufficiently impressed to recommend that a project be mounted to send trial shipments of LNG from the US to the UK on behalf of the British Gas Council (BGC). The trials would be a precursor to the country signing up to buy 100 million ft³/day of natural gas from a suitable source. This volume is equivalent to about 700,000 tonnes per annum of LNG and about 10 per cent of the UK's gas consumption at the time.

To enable the trials to be carried out Constock agreed to provide a barge-mounted liquefaction plant on the Calcasieu River near Lake Charles, Louisiana while the British Gas Council would construct a receiving terminal on Canvey Island near the mouth of the River Thames. Constock and the Gas Council agreed to share the cost of converting a dry cargo ship into the required pilot LNG carrier and British Methane Ltd was established as a joint venture company to own and operate the vessel.

Constock moved its original Bayou Long liquefaction barge to the Calcasieu River to serve as the liquefaction facility for the trials. A flat-bottomed, double-walled, cylindrical tank with an inner shell of aluminium, 1m of perlite insulation and a capacity of 5,500m³ was built by Chicago Bridge & Iron for the storage of LNG in a fully refrigerated condition.

The ship chosen for the conversion was *Normarti*, a World War 2 Victory dry cargo ship of the C1 type, and the work was carried out at the Alabama Drydock & Shipbuilding yard in Mobile, Alabama. A dry cargo ship was chosen because it offered large double bottom and wing tanks for the substantial amount of ballast the ship would be required to carry to achieve a suitable degree of hull immersion with the low-density LNG cargo.

The result of the conversion was the 5,000m³ *Methane Pioneer*, a landmark vessel in the annals of LNG shipping. The ship was fitted with five prismatic tanks of aluminium, and balsa wood insulation was fitted to the ship's inner hull to a thickness of 0.3m. Balsa was the only material available at the time able to meet the required, stringent performance criteria.



Methane Pioneer at the receiving end - Canvey Island

Besides providing good insulating properties, *Methane Pioneer's* insulation had to be able to perform as a secondary, liquid-tight barrier in case an aluminium cargo tank should fail. The balsa at the bottom of the tank had to bear the tank's laden weight and withstand the stresses induced by the ship's motions in a seaway. It also had to accommodate the thermal stresses associated with ambient temperature on one face and -162°C on the other without yielding. Finally, it had to be able to maintain its structural integrity in a fire situation for a period of four hours.

Methane Pioneer departed the Constock terminal on the Calcasieu River with its first trial shipment on 28 January 1959 and arrived at Regent Oil's deepwater jetty on Canvey Island on 20 February after a trouble-free, 27-day voyage. The North Thames Gas Board had built two aluminium, single-containment, perlite-insulated storage tanks, each with a capacity of 2,200m³, to receive the LNG. A temporary aluminium cryogenic pipeline had been installed linking the Regent Oil jetty to the nearby LNG tanks.

Over the next 14 months, to March 1960, *Methane Pioneer* carried a further six trial shipments across the Atlantic. In 1960 Shell joined Constock as a 40 per cent shareholder and the company was renamed Conch International Methane. Shell had been carrying out its own research into LNG transport by sea in the 1950s but broke off the work following the Suez Crisis in 1956.

The *Methane Pioneer* project and the groundbreaking research and development work carried out by Constock during the 1950s had proven the viability of the carrying LNG on long international voyages by sea. In November 1961 the UK government approved the purchase of 700,000 tonnes per annum of LNG from Algeria for 15 years, commencing in 1964.

The scene had been set for the birth of the commercial LNG industry and the realisation of William Wood Prince's vision. **MC**



HÖEGH LNG



Höegh LNG is listed on the Oslo stock exchange and has established presence in Oslo, London, Singapore, Miami, Jakarta and Lithuania. The company employs approximately 100 office staff and 500 seafarers.

Höegh LNG is a provider of floating LNG infrastructure services, offering regasification, transportation and production services under long-term contracts. The company operates a fleet of five floating storage and regasification units (FSRUs) that act as floating LNG import terminals, and four LNG transportation vessels. In addition, Höegh LNG has new FSRUs under construction. The company has also developed a solution for floating LNG production (FLNG).

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FSRU flexible, low cost and efficient
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The official ceremony for the delivery of the first commercial cargo of LNG, by Methane Princess, was held at Canvey Island on 12 October 1964

The sisters that launched an industry

Methane Princess and *Methane Progress* went into service 50 years ago carrying cargoes from Algeria to the UK on the LNG industry's first long-term project

Contracted in February 1962, the 27,400m³ *Methane Princess* and *Methane Progress* were the first LNG carriers to go into commercial service. The UK, having no known natural gas reserves of its own at the time, was anxious to secure an overseas source of the clean-burning fuel and ease its heavy reliance on coal. Algeria had just discovered the Hassi R'Mel gas field in the Sahara desert and was anxious to monetise this windfall. The two sisterships were the link that established the first LNG supply chain and enabled the needs of the two parties to be met.

Methane Progress and *Methane Princess* were built following a series of successful transatlantic trial shipments of LNG by the test vessel *Methane Pioneer* in 1959. These voyages convinced the British Gas Council (BGC) of the viability of transporting LNG by sea and prompted orders for the two sisterships. *Methane Pioneer* and the background to that historic series of trial cargoes are described on page 10.

In November 1961 the UK Parliament granted approval for BGC's plan to import Algerian LNG. Algeria agreed to

build a pipeline linking the Hassi R'Mel field with a liquefaction plant that the Algerian Liquefied Methane Company (CAMEL) would provide in the port of Arzew. The CAMEL terminal is described on page 18.

For its part BGC would construct appropriate receiving facilities at a site on Canvey Island in the River Thames estuary to the east of London. The Canvey Island import terminal would be erected on land owned and utilised by the North Thames Gas Board. *Methane Pioneer* had discharged its trial shipments to two small, hastily erected storage tanks at this same site. The facilities that were provided for the Algerian LNG project were of an altogether greater magnitude. Five storage tanks able to hold a total of 22,000 tonnes of LNG were constructed and these were later augmented by four inground LNG tanks.

France also wanted to commence LNG imports and agreed its own gas supply deal with Algeria. As a result CAMEL was designed with a liquefaction capacity of 1.1 million tonnes per annum (mta) of LNG, 0.7 mta of which was for the UK and 0.4 mta for France. The

French cargoes were transported by the 25,500m³ *Jules Verne*, which, when completed in March 1965, was the third LNG carrier to go into commercial service. *Jules Verne* discharged its cargoes at a new import terminal at Le Havre.

Both the UK and France signed 15-year LNG purchase agreements with Algeria. For the UK each of the *Methane Princess* and *Methane Progress* was able to carry a 12,000-tonne cargo from the CAMEL terminal and to complete a round trip in 12 days, travelling at 17 knots. Between them, the pair were able to deliver a volume equivalent to 10 per cent of the UK's gas consumption at the time.

The newbuilding contract for *Methane Princess* was placed with the Vickers Armstrong shipyard at Barrow-in-Furness in northwest England while Harland & Wolff in Belfast, Northern Ireland won the order for *Methane Progress*. The vessels were sisterships, and Vickers Armstrong, as the lead yard, took responsibility for drawing up the working plans and placing material orders for the pair. Each ship was to cost £4.75 million to build.

The cargo containment system on the two ships was designed by Conch

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International Methane Ltd. The system was based on that utilised on *Methane Pioneer* and for which Conch held the design patents. JJ Henry, the New York-based consulting naval architect firm, was closely involved with the hull design of the two vessels while Shell supervised their construction. The main particulars of *Methane Princess* and *Methane Progress* are shown in the accompanying table.

Each ship was fitted with nine 5083 grade aluminium, free-standing cargo tanks, installed three to a hold in three holds. Each tank weighed about 130 tonnes and was lifted in as a complete unit. 'Keys' were fitted to the top of the tank to locate the unit and allowed for expansion and contraction. Each tank had a full height centreline bulkhead with two separate cross-flooding valves near the bottom.

A single JC Carter submerged electric cargo pump, with a capacity of 200 m³/hour and a 82m head, was placed at bottom of each tank on the port side. This was the first marine application of submerged electric cargo pump technology.

Only one side of each tank had a filling connection. As a result it was necessary to have the cross-flooding valves open throughout loading and discharge operations but closed at sea, for stability reasons.

The tanks were insulated primarily with prefabricated balsa wood panels faced with maple leaf plywood, which was impervious to LNG. On the tanks' vertical sides the panels were supplemented with glass fibre. The top of the tank was insulated with a loose-laid mineral wool material called Rocksil. The insulation system was also designed to act as a secondary barrier in event of



Captain WS Atkinson, master of *Methane Princess*, with UK minister of power Frederick Lee on the occasion of the delivery of the first commercial LNG cargo

leakage from the primary aluminium tank. In modern parlance these would be described as IMO Type A tanks.

The ships' cargo-handling system was very similar to that found on a modern LNGC. A single header ran along the main deck pipe rack while tank filling and discharge connections branched off at each tank. The vapour system was different to modern designs in that no vapour return compressors were fitted. During cargo loading operations the vapour was free-flowed to an onshore compressor installation. In practice it was difficult to keep to the required tank pressures during loading without venting vapour from the forward of the two risers on each ship.

Two vapour compressors were installed in a compressor house on deck. They had three duties, the principal one of which was to act as fuel gas compressors for cargo boil-off gas being fed to the boiler plant. Their secondary duty was part of the emergency discharge and cargo tank stripping system. This system served the cargo tanks and the hold spaces in event of cargo tank leakage. It was described as a vapour lift system. The tertiary duty of the vapour compressors was to warm up the cargo tanks by circulating vapour through a heater.

Two liquid nitrogen storage tanks were installed below the forecastle head. These supplied vaporised nitrogen to the hold spaces, which were kept under

nitrogen pressure, to the compressors and to the purging arrangements for the fuel gas system. The ships had no inert gas generators. Instead prior to docking at Canvey a temporary steam-heated nitrogen vaporiser was set up on the jetty and liquid nitrogen was delivered by road tanker.

Since inerting following refits was done with pure nitrogen, cooling down operations were performed by directly spraying LNG into the tanks. No LNG vaporisers were installed.

Cargo fill levels were determined by float gauges, one per tank. Back-up level readings were provided by two sets of two sighting ports in each cargo tank dome, one pair on each side of the centreline bulkhead, looking down on an inclined board with ullage markings. Crew would shine a torch through one sighting port and read the level through the other. The sighting ports could only be used for topping off operations.

A comprehensive data-logging system which was state-of-the art for the time was also installed. It was an electromechanical device which covered some 300 points around the ship and included extensive temperature monitoring of the inner hull and cargo tanks. A comprehensive fixed gas detection system was also provided.

Methane Princess and *Methane Progress* were propelled by steam turbines supplied with steam by dual-fired boilers. The Pametrada turbine on each ship was rated at 12,500 shp (9,325 kW) at 107 rpm while each of the two Foster Wheeler ESD II boilers supplied 20.4 tonnes/hour in normal operating mode. Electrical power was derived from two 600 kW back-pressure turbo generator sets while a 100 kW emergency diesel generator was also provided.

The boilers were front-fired and fitted with three dual-fuel burners. Gas was supplied from the compressor and heater to the boiler front through a pipe in a swept air trunk. The last sections from the



Methane Princess takes shape on the slipway at the Vickers Armstrong yard

METHANE PRINCESS AND METHANE PROGRESS MAIN PARTICULARS

Methane Princess: Vickers Armstrong (Shipbuilders) Ltd, Barrow-in-Furness, Hull No 1071, delivered June 1964

Methane Progress: Harland and Wolff Ltd, Belfast, Hull No 1653, delivered May 1964

LOA	199.37m
LPP	175.26m
Breadth	24.84m
Depth	17.88m
Draught	7.92m (summer)
Draught	10.67m (scantling)
GRT	21,876
Cargo capacity	27,400m ³
Service speed	17 knots

LNG Shipping at 50 | the early years

air trunk up to the burner nozzles were fitted with nitrogen-pressurised jackets. A hood with its own extraction fan system was positioned over the burners.

Methane Princess and *Methane Progress* predated engine control rooms. All control of the machinery was from the 'plates' forward of the boilers. Automatic combustion control was pneumatic with a 10:1 burner turndown ratio.

The gas-burning system was interlocked such that the gas would automatically trip in the event of a failure of either the forced draft fans or the flame. There was a gas flow control valve and an automatic shutoff valve in series, with a bleed-off to the vent mast in between. In event of a trip both valves closed and the valve to the vent mast opened, thus ensuring a tight shutoff of gas.

A single flame detector was mounted looking through the side wall of the furnace of each boiler. The technology of the period was such that detectors could only discern bright luminous flames such as those generated by fuel oil. They could not detect the gas-only flame. As a result it was stipulated that a minimum of 10 per cent fuel oil should be burned at all times and that the gas could not be supplied to a burner without the fuel oil being on first.

The IGC Code was mainly written in the late 1970s and early 1980s and reflected the best practice at the time of its adoption in 1983. Its development is described on page 64. It is remarkable that the two *Methane* ships, designed in the early 1960s, stand up well to assessment against the Code requirements. It is a credit to the ship designers that the final Code should reflect much of their thinking. In particular the design of the cargo containment system would satisfy the cargo tank IMO Type A designation. The gas-burning system would seem to stand up well to the requirements of Chapter 16 of the IGC Code.

The *Methane* ships fell short of the Code requirements in a few areas. First, there was a lack of any secondary means of disposing of excess boil-off gas, i.e. a steam dump system. In addition, although the ships had a pneumatic emergency shutdown (ESD) system, it would not have complied with the Code's requirements for overfill protection. It was linked to shore.

Methane Princess and *Methane Progress* operated successfully throughout their service lives. They were easy to operate and popular with their crews, although one or two problem areas came to

light. The data-logger, for example, was never very reliable and needed frequent attention from the manufacturer's representative to keep it working. Both vessels also suffered fatigue cracks in their inner hulls, leading to water ingress to the insulation. Repair techniques were developed for this problem, and accounts at the time claimed that the insulation properties of balsa wood did not seem to degrade when it became soaked.

A more frequent problem was cracks developing in the insulation system. These were indicated by areas of frost on the inner hull, or 'cold spots'. An in-service technique was developed involving drilling through the inner hull at the site of a cold spot and injecting a resin adhesive to seal the crack. This seemed to work well, but it did mean that there had to be a regular inspection routine for the inner hull to check for cold spots.

In addition there was no way of assessing the ability of the insulation system to act as a secondary barrier. It can now only be a matter of conjecture as to how effective it would have been after these repairs if there had been a leakage of LNG. Fortunately there was no instance of such leakage during the time the pair were in service.

When it comes to LNGC newbuildings today, steam turbine ships have largely been eclipsed by diesel-driven vessels. However, it is interesting to compare *Methane Princess* and *Methane Progress* with the latest designs of steam LNGCs built up to about six years ago. Obviously ship size is the biggest change, as modern steam turbine LNGCs have a cargo-carrying capacity which is about five times that

of the *Methane* ships. Service speeds are now a little higher at about 19 knots.

Since the adoption of the IGC Code, no LNG ships have been built with Type A tanks. All new LNGCs are fitted with shipboard inert gas generators and vapour return compressors. Nitrogen generators have replaced liquid nitrogen storage. The steam propulsion concept has remained much the same, with two boilers, now roof-fired, supplying steam to the main turbine and, typically, to two turbo generators. These generators are now condensing sets rather than back-pressure sets.

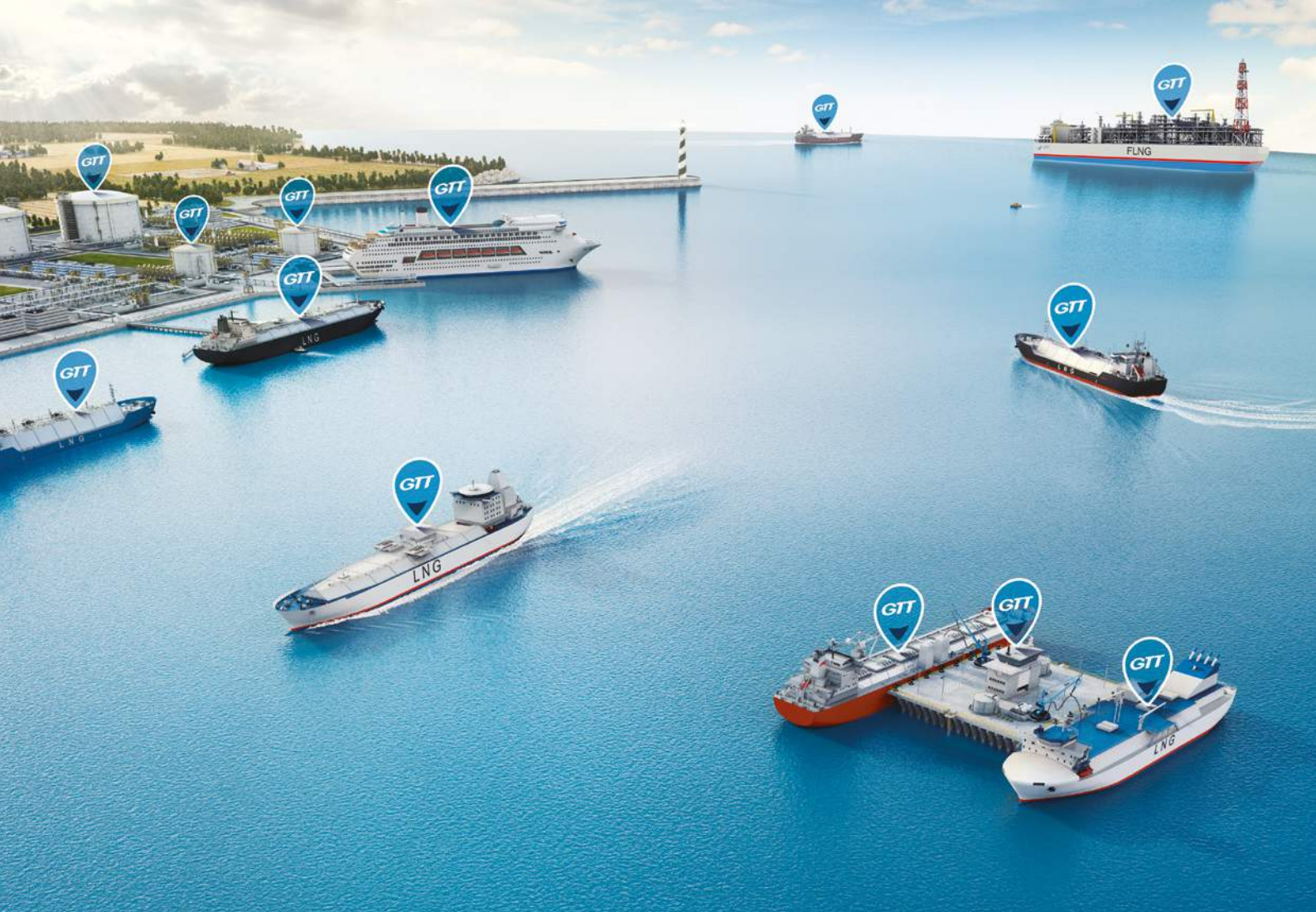
All steam turbine ships are fitted with steam dump systems to provide a secondary means of disposal for cargo boil-off gas. The gas-firing system on modern vessels is very close in concept to that of the *Methane* ships, with the exception that many have a forcing vaporiser since modern cargo boil-off rates do not supply enough gas to achieve service speeds on gas only.

It still seems amazing that only five years after the successful *Methane Pioneer* trial shipments and three years after the UK government approved the project, the first two purpose-built LNG carriers should enter service. This start-to-finish timetable compares very favourably with all subsequent LNG projects!

Another indicator that the maritime industry was confident in the ability of these ships to perform as required, despite their novel design and the challenging cargo, was the fact that the insurance market insured *Methane Princess* and *Methane Progress* with no additional premium or deductible compared with the going rate for clean product tankers. **BW**



Although built 20 years before the IGC Code was adopted, the *Methane* ships anticipated the Code's requirements to a startling degree



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CAMEL – the first LNG export terminal

Fifty years ago, when several of the Atlantic Basin's leading economies realised they would need to begin importing natural gas, Algeria was the go-to country

The history of Algerian hydrocarbons began in 1956 with the discoveries of the Hassi Messaoud and Hassi R'Mel fields by French oil companies. The development of these deposits, deep in the Sahara desert, was made first within the framework of a Petroleum Code and then with the help of an organisation established to develop the region's resources. The group included not only Algerian interests but also the French oil companies involved in the exploration work.

The recoverable reserves of the Hassi R'Mel, which is Arabic for 'sand well', were determined to be over 50 trillion ft³ (1,400 billion m³) of gas, with the methane content of the gas at about 85 per cent. At the time of discovery, these figures put Algeria in fourth place in the world league table of natural gas reserves, after the US, the USSR and Iran.

A first step to amend Algeria's hydrocarbon legislation was taken following the country's independence in 1962. Amongst the initial measures was the creation of Sonatrach, the state oil and gas company, at the end of 1963.

A key Sonatrach senior officer

during those early years was Nordine Ait-Laoussine. Having completed his studies in 1963 and worked in the country's Department of Mines for a short period, he joined Sonatrach. By 1969 Ait-Laoussine was the company's vice-president hydrocarbons and in 1971 he was appointed marketing vice-president. In this position he negotiated various of the gas sale and purchase agreements behind his country's pioneering LNG export projects.

Looking back at these challenging times, Nordine Ait-Laoussine states, "Following independence a few of the persons in charge of developing the Algerian economy, including Belaid Abdessalem, were particularly keen to exploit Algerian gas resources. And, when appointed the first president of Sonatrach, Mr Abdessalem fully supported the then Algerian president Houari Boumedienne in his drive to build Algeria's oil and gas exports and increase their value to the country in the process. Sonatrach's control of Algerian gas development, as enshrined in gas policy agreements concluded in 1965, and the improvement of its management resources provided the

company with the necessary means to accomplish this task.

"In the early 1960s subsea pipeline technology was not very advanced and negotiations with neighbouring countries on the construction of, and commercial arrangements for, a transit pipeline appeared complicated," continues Mr Ait-Laoussine. "Although the commercial liquefaction of LNG was still considered as experimental at that time, Algeria's Compagnie Algérienne du Méthane Liquide (CAMEL) project in the early 1960s was to prove its viability on an industrial scale. Gas for the new liquefaction plant at Arzew was supplied from the Hassi R'Mel field via a 500km pipeline."

The CAMEL project had four participants: Conch International Methane, the Algerian Development Bank and two oil companies, one Algerian and one French. The Algerian body was the National Society of Exploration and Exploitation of Oil in Algeria (SN Repal) while the other, the Bureau de Recherches Pétrolières (BRP), was a subsidiary of Elf Aquitaine.

"While CAMEL was a modest-size project compared to the liquefaction trains of today, it was a pioneering initiative and the largest industrial undertaking in the LNG sector at the time," adds Mr Ait-Laoussine. "Launched in 1960 the project was initially managed by CAMEL itself but was taken over by Sonatrach following Algeria's 1965 gas policy agreements.

"On 14 September 1962 Ahmed Ben Bella, the first president of the newly established Algerian republic, laid the foundation stone at the Arzew plant, and construction work on the CAMEL facility began. The successful completion of the

Algeria's CAMEL project was realised at an estimated cost of US\$89 million



project owed much to the teamwork between French, British, American and Dutch engineers. The first Algerian gas engineers were also assigned to the team.”

The cascade technology developed by Technip and Air Liquide was chosen for the CAMEL liquefaction process. This process utilised three separate cooling cycles, employing propane, ethylene and methane as the respective refrigeration media. The liquefaction plant’s three trains had the capacity to produce about 1.2 million tonnes per annum (mta) of LNG. The CAMEL terminal had three 11,000m³ aboveground storage tanks, an inground tank with a capacity of 38,000m³ and an impressive 350km of pipework. Ahmed Ben Bella came back to inaugurate the plant on 27 September 1964.

The UK had signed up for two-thirds of CAMEL’s output and France one-third. To complete the two supply chains that would be served by the world’s first commercial-scale LNG liquefaction plant, reception terminals were built at Canvey Island in the UK and at Le Havre in France. In addition the 27,400m³ *Methane Princess* and *Methane Progress* were built to carry cargoes for the UK while the 25,500m³ *Jules Verne* was completed for the French shipments. The capacity of each ship was equivalent to roughly three days of LNG production at the CAMEL plant.

The Canvey Island facilities and the ships are described in other articles in this publication, but it is important to note that CAMEL started loading the first-ever shipment of LNG sold under a long-term contract on 26 September 1964. That milestone cargo was despatched to Canvey Island on *Methane Princess*.

The Le Havre regasification terminal featured three 12,000m³ aboveground storage tanks of 9 per cent nickel steel. *Jules Verne* delivered the first CAMEL cargo to the facility on 28 March 1965. Le Havre operated for over 20 years before being dismantled in the late 1980s.

Following the CAMEL project, the wider development of Algeria’s gas resources had to accommodate the choices of the government’s hydrocarbon policy. While French companies wanted to produce more oil, the Algerian authorities were anxious to better monetise the country’s condensate and natural gas resources, and to avoid gas flaring in the process.

“At this point Algeria implemented its Valorisation of Hydrocarbons (VALHYD) programme,” comments Nordine Ait-Laoussine. “The objective of this initiative



Le Havre served as a French LNG import terminal for over 20 years, until the late 1980s

was to optimise the production of Hassi R’Mel by selling all the gas that could be sold and to inject any excess gas volumes back into oil wells to enhance the production of oil and liquids.”

At the same time, the Algerians wanted to extend the customer base for their gas exports and to gain independence from their total reliance on French companies. This policy underpinned the construction of the country’s second liquefaction plant, at Skikda. With a capacity of 7.5 mta of LNG, this was a much larger complex than the CAMEL plant, and new contracts were negotiated with US buyers and other European customers, including the Italians and the Spanish.

The 25-year sale and purchase agreement with El Paso in the US was concluded at the ridiculously low price of US\$0.30/million British thermal units (Btu) – just enough to earn a decent return and make it a commercially more sensible option than flaring the gas. When Houari Boumedienne died in 1978, the new Algerian government immediately cancelled this contract. The famous El Paso project is covered in a separate article elsewhere in this publication.

During the 1970s the Algerian authorities sought to build LNG

production capacity to the 22.5 mta mark, a goal which was achieved through the construction of two new liquefaction plants at Arzew rated at an aggregate 16 mta. A series of sales contracts were agreed with the Italians as well as a new one with Gaz de France.

The development of LNG slowed down progressively from the early 1980s as emphasis was placed on the construction of trans-Mediterranean subsea pipelines and the development of new contracts for piped gas. At one point the Algerian government and Sonatrach had declared that they hoped to achieve total gas exports, including LNG and piped gas, of 80 billion m³ a year by the end of the century. However, this target was never reached.

By the late 1970s CAMEL, with its limited production capacity, had become a relatively minor LNG project. When the 15-year gas purchase contract with the UK came up for renewal, it was left to expire at the appointed date in 1979. The UK had discovered significant volumes of gas in the North Sea and no longer had need of LNG imports.

Maintenance work was carried out on the CAMEL plant at the end of the 1980s, with the principal focus on the renewal of the aboveground tanks. More extensive modifications were implemented in 1997–98, including the provision of a new control system. These changes necessitated some targeted training for the plant workers who were not accustomed to these new technologies.

CAMEL’s days were numbered, however, as the plant had become uneconomical to run and customer requirements had changed. In 2004 a decision was taken to decommission the facility. This necessitated, amongst other things, the complete removal of the inground storage arrangements at the site, a task carried out in 2007. The final curtain came down on the CAMEL LNG plant in 2010, some 46 years after it opened for business. **J-YR**



Nordine Ait-Laoussine in his early Sonatrach days



Marsa el Brega – the world's third LNG export terminal

The Mediterranean LNG crucible

The busiest and most intense LNG shipping arena since the industry's inception, the cross-Mediterranean trades show no signs of slowing down

The proximity of the gas-rich nations of North Africa to the gas-poor countries of southern Europe has ensured a busy Mediterranean trade in LNG over the decades. Due to the short distances involved Medmax LNG carriers, which are considerably smaller than a conventional deepsea vessel, consistently top the LNG shipping industry's Voyages Completed charts.

In November 1965 the Esso Libya LNG venture was initiated when affiliates of the oil and gas company agreed to supply 2.4 million tonnes per annum (mta) of LNG to customers in Italy and Spain, beginning in late 1968. Italy was to receive two-thirds of the volume and Spain one-third.

Four ships of 41,000m³ were deemed right for this cross-Mediterranean trade and Esso International developed its own independent cargo tank design for the ships. During 1969 and 1970 Italcantieri's Genoa Sestri yard in Italy completed three of the ships – *Esso Brega*, *Esso Portovenere* and *Esso Liguria*. The fourth vessel, *Laieta*, was delivered by the Astano yard at El Ferrol in Spain in 1970.

The hull and containment system of *Esso Brega* and her three sisters reflected the cautious approach of

the Esso designers, shipbuilders and class societies at a time when LNG transportation was just commencing. The result was a quartet of the most robust LNG carriers ever built. The four prismatic cargo tanks constructed by Chicago Bridge & Iron (CB&I) for each vessel had double walls of Type 5083 aluminium alloy and were fitted, one per hold, below the main and trunk decks.

The new LNG export terminal being built at Marsa el Brega in Libya was complemented by the Mediterranean's first LNG receiving facilities, at Panigaglia near La Spezia in Italy and at Barcelona in Spain. Delays in construction work at Marsa el Brega meant that exports did not begin until late 1971, at which point Libya became the world's third LNG export nation.

In 1969, in advance of the completion of the Esso ships and the start of the Marsa el Brega plant, the 5,000m³ *Aristotle* (ex-*Methane Pioneer*) delivered two cargoes from the CAMEL plant at Arzew in western Algeria to Panigaglia, where they were used to cool down the storage tanks and pipelines. The Enagas import terminal at Barcelona was also commissioned in 1969 and, similarly, was able to

take early LNG cargoes from Arzew, onboard *Aristotle* and *Methane Princess*.

In 1972 the CAMEL plant at Arzew added a new Mediterranean import terminal to its list of customers – France's Fos Tonkin facility near Marseilles. The Algeria-France cross-Mediterranean connection was also enhanced by the commissioning of a second Algerian export terminal, the three-train Skikda plant in the eastern part of the country, in November 1972.

Each country agreed to provide a new 40,000m³ ship for the Skikda-Fos Tonkin project. *Hassi R'Mel* was delivered to Compagnie Nationale Algérienne de Navigation (CNAN) in 1971 by Constructions Navales et Industrielles de la Méditerranée (CNIM) at La Seyne in France. France's contribution, *Tellier*, was handed over to Messigaz in January 1974 by Chantiers Navals de la Ciotat.

Hassi R'Mel, the first Algerian-owned LNG carrier, had six Gaz Transport No 82 membrane cargo tanks and loaded its first Skikda cargo in 1973. A five-tank ship with the Technigaz Mark I membrane containment system, *Tellier* joined *Hassi R'Mel* on the Skikda-to-Fos route in 1974. A look at *Tellier*'s logbook in 2012, as the vessel was taken out of service for despatch to the recycling yard, revealed that the ship had completed 1,956 loaded passages during a 38-year working life. It is a record that is unlikely to be broken, given the larger vessels employed on the cross-Mediterranean routes today. *Tellier* first made history in 1992, as the first LNG carrier to rack up 1,000 voyages.

Once the Skikda plant was in full operation, its output was sufficient to enable the supply of several customers. In addition to the Fos shipments cargoes were also directed to Barcelona

and buyers in the US. Algeria later consolidated its position as the world's largest exporter of LNG with the commissioning of two large export facilities at Arzew, the GL1Z plant in 1978 and the GL2Z in 1981. Each has a nameplate capacity of 8 million tonnes per annum (mta) of LNG.

As the cross-Mediterranean trades in general expanded on the back of Algeria's rising output, more tonnage was needed and the six ships purpose-built for the region were augmented with some of the early, pioneering LNG vessels. Deemed to be of a size eminently suitable for the relatively short routes involved, *Methane Princess*, *Methane Progress*, *Jules Verne*, *Annabella*, *Isabella*, *Century* and *Haofru* became common sights in the Middle Sea.

In 1991 the 35,500m³ *Annabella*, with accommodation in place for 25 additional personnel, was made available to the industry as the world's first LNG training ship. The ship was on long-term charter sailing between Algeria and Barcelona, a short passage which enabled trainees to experience both loading and discharge operations in the space of a week.

Spain's second receiving terminal, at Huelva, opened for business in July 1988 with the delivery by the 35,500m³ *Isabella* of a cargo of Algerian LNG. As it is located on the Atlantic side of the Strait of Gibraltar, whether or not Huelva qualifies as a Mediterranean port is a moot point.

Spain's third import terminal, at Cartagena to the south of Alicante, most definitely does, and it was commissioned the following year. The facility received most of its early cargoes from Algeria and, at 115 nautical miles (213km), the Arzew-to-Cartagena LNG route is the shortest across the Mediterranean. The country's complement of Mediterranean receiving facilities is completed by the SAGGAS terminal at Sagunto, near Valencia, where the first cargo was discharged in April 2006.

Turkey joined the ranks of the Mediterranean LNG import countries in 1994 when a new terminal was opened at Marmara Ereğlisi on the Sea of Marmara. The Turkish Petroleum Pipeline Corp (Botas) immediately commenced LNG imports under a contract with Algeria covering the delivery of up to 3 mta of LNG over 20 years. The 130,000m³ *Bachir Chihani*, a vessel belonging to Hyproc, the shipping affiliate of Sonatrach

in Algeria, delivered five cargoes from Arzew during 1994 to initiate the contract. Turkey's second import terminal, the Egegaz facility at Aliaga on the Aegean Sea, received its first LNG cargo in December 2006.

A new trade started in February 2000 when the 29,000m³ *Century* delivered the inaugural cargo, from Algeria, to the Revithoussa LNG import terminal in Greece. Revithoussa has recently received government permission for the construction of a third tank, which will boost the facility's storage capacity by 75 per cent.

By the mid-1990s shipowners were reviewing their fleets and considering their newbuilding requirements. To realise economies of scale in the growing cross-Mediterranean trades, it was decided that the optimum new Medmax size would be in the 65,000–75,000m³ range. SNAM of Italy made the first move, ordering a pair of steam turbine-driven, 65,000m³ vessels at the Sestri yard in Genoa. They entered service as *LNG Portovenere* and *LNG Lerici* in 1997 and 1998, respectively. Each ship is provided with four Gaztransport and Technigaz (GTT) No 96 membrane tanks.

Hyproc followed a decade later with a pair of 75,500m³ LNG carriers ordered at Universal Shipbuilding's Tsu yard. *Cheikh El Mokrani* was delivered in June 2007 and *Cheikh Bouamama* in July 2008. Mitsui OSK Lines is a joint owner of the steam turbine ships, each of which has four GTT Mark III membrane tanks.

Gaz de France (now GDF Suez) also contracted a new Medmax ship. Delivered in December 2006 by Chantiers de l'Atlantique, the 74,100m³ *GDF Suez Global Energy* is the first vessel to be ordered with a dual-fuel diesel-electric propulsion system, now the most popular power option amongst LNGC owners.

Over the past decade the cross-Mediterranean trades have continued to flourish. In 2005 Egypt commissioned two new export projects. In January the single-train SEGAS terminal at Damietta, 60km west of Port Said, opened. The plant's 5 mta capacity is provided by what was then the largest liquefaction train yet built. Four months later, in May, the two-train, 7.2 mta Egyptian LNG plant at Idku, 50km east of Alexandria, entered service.

Due to the location of these terminals in the eastern Mediterranean, some distance from the region's receiving terminals, it was always envisaged that conventional size LNG carriers would be used to load cargoes at the Egyptian sites. This is evidenced by the carriers chosen for the inaugural shipments. The 138,000m³ *Cádiz Knutsen* lifted the first cargo at Damietta while the 137,100m³ *Puteri Zamrud Satu* did the honours at Idku.

Unfortunately Egypt's days in the sun were short-lived. The tumult of the Arab Spring uprising and burgeoning domestic demand for gas have reduced LNG exports to a trickle, and the country is considering LNG imports.

Elsewhere in the Mediterranean, four new import facilities have commenced operations in recent years. Cavaou, the second Fos terminal, received its first cargo in 2010. Italy has brought two offshore facilities into service – Adriatic LNG in 2009 and *FSRU Toscana* in 2013 – while Israel also commenced imports using a regasification vessel in 2013.

The expansion of the Mediterranean's LNG production infrastructure also shows no sign of slowing. Algeria is bringing two new liquefaction trains – one at Skikda and one at Arzew – into service while Cyprus and Israel are both weighing up LNG export options for their large, newly discovered offshore gas fields. **SH/MC**

The Panigaglia terminal in Italy received its initial cooldown cargo from Algeria rather than the expected Libya



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The long-running story of Alaskan LNG

The Kenai terminal in Alaska began exporting cargoes 45 years ago, using a pair of pioneering ships and setting a number of Pacific Rim LNG precedents along the way

Marathon Oil discovered the Kenai gas field in the US state of Alaska in 1959 while Phillips Petroleum and other partners found the nearby North Cook Inlet gas field in 1962. With no local demand the companies looked to overseas markets for the natural gas. The customer search achieved success in March 1967 when Phillips and Marathon signed a 15-year agreement with Tokyo Electric Power and Tokyo Gas for the delivery of 1 million tonnes of LNG per annum.

To cover the transport of this gas, bids were invited for the construction of two 71,500m³ LNG carriers. At a hastily organised meeting at Phillips Petroleum headquarters in Bartlesville, Oklahoma, rival cargo containment specialists pitched their products. Representatives from Conch and McMullen promoted self-supporting tanks while Technigaz and Gaz Transport each espoused the merits of its particular membrane tank design.

The invar primary and secondary barrier concept won the day and Gaz Transport was awarded the contract to have the vessels built with its membrane cargo containment system. In July 1967 Kockums Mekaniska Verkstads of Malmö, Sweden secured the order to construct what were to become the first vessels in commercial service fitted with Gaz Transport membrane tanks. Kockums had quoted a price of US\$25 million for each ship.

Rather than the shipbuilder, Phillips Petroleum signed the license with Gaz Transport. The arrangement effectively gave Kockums permission to use the containment system and it was the only Gaz Transport license agreement not signed and paid for by the shipbuilder.

Polar Alaska was completed in August 1969 while sistership *Arctic Tokyo* followed in December of the same year. Each of the steam turbine ships had six cargo tanks, an ice-strengthened hull and a service speed of 17 knots. Both were

operated by Marathon Oil and both were provided with bow thrusters because it was expected that there would be no tug services regularly available at the Kenai terminal in Alaska to assist with berthing.

Polar Alaska arrived at the new Nikiski plant on Kenai peninsula in southern Alaska on 15 October 1970 and, after initial cooldown, testing and loading, departed for Japan on 26 October. The ship tied up at the Negishi terminal near Yokohama on 4 November and cargo discharge operations were completed on 11 November following an initial cooldown of the facility.

The shipment was the first export of LNG from the US and the first import of LNG into Japan and Asia. The second ship, *Arctic Tokyo*, completed discharge of her first cargo at Negishi on 11 March 1970.

During *Polar Alaska's* return ballast passage gas was detected in the inner barrier spaces in the forward No 1 cargo tank. The cargo heel in this tank, used to keep the tank cool on the return voyage, was in the 15-20 per cent fill range.

Following the emptying of the cargo heel and gas-freeing of the tank, it was found that the electric cable supports of one of the submerged cargo pumps had been damaged and debris moving within the liquid had punctured the invar primary barrier in several places.

No 1 tank was taken out of service and, with Gaz Transport personnel attending, a repair was completed in a few days at a Yokohama ship repair yard. *Polar Alaska* returned to full service following the invar repairs.

The cable damage on *Polar Alaska* at the outset of her working life introduced the LNG shipping industry to the phenomenon of cargo sloshing. Membrane containment systems, with the large free surface areas afforded by the open space inside the tank, are particularly susceptible to the large sloshing loads that can be generated while proceeding in a seaway.

The incident resulted in a major rethink on aspects such as the shape of membrane cargo tanks and filling limits. Following *Polar Alaska*, the size of the chamfered corners on membrane tanks was increased and filling limits were imposed. One condition that was introduced, for example, was that cargo heel should not exceed the 5 per cent fill level.

Aside from a short period in 2012-13 in which the facility was mothballed due to dwindling gas supplies, the Kenai liquefaction plant has remained in service for 45 years, making it by far the oldest such facility in the world. New gas discoveries have resulted in its recent reactivation and Kenai is scheduled to load six LNG cargoes in 2014. **SH**



Small but significant – the Kenai terminal in Alaska continues to load cargoes 45 years after its commissioning

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Brunei targets its own 50th anniversary

The Brunei-Japan project, the world's first large-scale LNG scheme, is now on a second contract extension and heading towards a half century of operations

On 15 December 1972 the 75,000m³ membrane tank LNG carrier *Gadinia* discharged a cargo at the new Senboku 1 terminal of Osaka Gas in Osaka Bay. This historic delivery marked not only the first shipment of LNG from Brunei to Japan but also the start of the world's first large-scale LNG project. At the same time, the sultanate became only the fourth country to export LNG.

The Brunei LNG dream started in 1968 when Shell discovered promising gas fields off the country's coast. Mitsubishi Corporation (MC) joined in the effort to prove the reserves and it soon became apparent that there was enough gas to support what was then still the rather unusual idea of an LNG export project. The demand for gas in Japan, a country without any indigenous resources, provided the incentive to overcome the challenges associated with mounting the project.

In August 1969 MC and Shell established Coldgas Trading, an LNG marketing company, as a 50/50 joint venture and in December 1969 Brunei LNG was created as the LNG production company. Shell and MC each took a 45 per cent stake in Brunei LNG while the Brunei government held the remaining 10 per cent.

Tokyo Electric, Tokyo Gas and Osaka Gas were quick to express an interest in the Brunei gas and in June 1970 the three utilities signed up for the delivery of 3.65 million tonnes per annum (mta) of LNG for a period of 20 years from a new liquefaction plant to be built at Lumut. Even before the Lumut plant started, the principals agreed to incremental volumes which



The 75,000m³ Brunei LNG carriers were originally fitted with a stern loading arrangement

pushed the aggregate sales total to 5.14 mta.

The sales agreements also prompted orders for seven 75,000m³ LNG carriers from shipyards in France. Five of the ships sported the original version of the Technigaz membrane containment system while the other two were built to the original Gaz Transport membrane design.

The Lumut complex was built with five equally sized liquefaction trains and a total production capacity of 7.6 mta. Shallow waters in the area required the construction of a 4km jetty and berthed ships took on cargo through a special stern loading arrangement.

By 1986, following agreement amongst the principals, the Brunei government's share in the venture had been increased to 50 per cent, while Shell and MC each retained a 25 per cent stake. Brunei LNG later absorbed the Coldgas marketing activities. The 1986 realignment also encompassed the establishment of Brunei Shell Tankers and the names of the seven ships were changed from the original Shell names to those beginning with the letter B. Each vessel was given a Malay name for one of the local fish species.

In March 1993 Brunei LNG concluded a 20-year extension contract with Tokyo Electric, Tokyo Gas and Osaka Gas, at a level of 6.01 mta, and in 1997 a long-term sales contract, for 0.7 mta and spanning 16 years, was also signed with Korea Gas

Corporation (Kogas).

Prior to the expiry of the first contract with the Japanese utilities the Brunei LNG plant was given a revamp. Two new storage tanks were built along with a new jetty able to accommodate conventional midships loading operations.

To meet its transport needs Brunei LNG has charter arrangements with both Brunei Shell Tankers and Brunei Gas Carriers. Brunei Shell Tankers provided the original seven B-class LNG carriers but this fleet of ageing vessels is slowly being replaced by new, larger A-class ships for which Brunei Gas Carriers is responsible.

The A-class ships, at double the size of the project's pioneering vessels, are enabling increased efficiencies in delivering cargoes, not least through a reduction in fleet size. There are now three A-class LNG carriers in service while a fourth is under construction at Hyundai Heavy Industries and due for delivery in 2014. As the new ships join the fleet, the old B-class ships are slowly being removed from service and sent to breakers' yards for recycling.

In March 2012 Brunei LNG agreed a new contract extension with its original Japanese customers, but at a reduced volume of 3.4 mta and a reduced duration of 10 years, from April 2013. The new arrangement has set the scene for 50 years of operations for this pioneering project. **MC**

Politics, misfortune and price sideline El Paso



Although the distinctively coloured El Paso ships cut a dash, their time in the sun in this guise was short-lived

El Paso ambitiously ordered nine 125,000m³ LNGCs in the 1970s to ship Algerian LNG to the US, only for the trade to cease spectacularly in 1980

In 1969 El Paso Natural Gas Company and Sonatrach, the national oil and gas company of Algeria, agreed a long-term contract calling for the shipment of Algerian LNG to the US. Cargoes would be transported from Arzew in Algeria to new terminals at Cove Point, Maryland and Elba Island near Savannah, Georgia.

El Paso recognised that it would require a fleet of nine steam turbine-driven LNG carriers to service its new venture. The company split the newbuilding contract equally between three shipyards, with each builder choosing a different containment system. There was fierce rivalry between the promoters of the Conch, Gaz Transport and Technigaz systems at the time and El Paso was assiduously courted by each of the designers before the ships were ordered. Triumphant “breakthrough” announcements followed the signing of each newbuilding contract.

El Paso ordered two LNGCs at Chantiers de France-Dunkerque in 1970 and a third carrier was later added to the original pair. At 125,000m³, the trio were the largest LNGCs ever ordered. The size quickly became the accepted norm for ‘conventional’ LNG carriers

and remained the industry standard until well into the 1990s when LNG trade volumes and ship cargo-carrying capacities began to increase markedly.

The three French-built ships were delivered as *El Paso Paul Kayser* in July 1975, *El Paso Sonatrach* in June 1976 and *El Paso Consolidated* in January 1977. The Gaz Transport No 85 membrane cargo containment system with invar primary and secondary barriers was chosen for the trio and each ship had six cargo tanks, including a smaller tank amidships.

Domestic US politics and funding from the US Maritime Administration (MarAd) helped determine where the remaining six 125,000m³ ships would be built. El Paso ordered three ships at Newport News Shipbuilding and Drydock in Virginia in September 1972 and the final three at Avondale Shipyards near New Orleans, Louisiana in July 1973. No LNG carrier had previously been built at a US yard.

The original Newport News contract was based on the use of a Chicago Bridge and Iron spherical tank design but the principals subsequently decided to opt for a Technigaz membrane Mark I

containment system before construction work began. This concept featured a stainless steel primary barrier and a maple plywood secondary barrier. The newbuilding price for each ship was US\$101 million, with a MarAd subsidy covering 25.74 per cent of the cost.

Newport News extended its capabilities by constructing a new shipyard adjacent to its existing building berths. The centrepiece of the new yard was a 76m-wide building basin dock with a 900-tonne gantry crane. The arrangement allowed for the simultaneous construction of one complete LNGC and part of another.

The overall layout of the Newport News vessels was similar to that of the French-built trio. Each ship had six cargo tanks, including a smaller tank used for pre-cooling the main tanks prior to loading. The Newport News ships were delivered as *El Paso Southern* in April 1978, *El Paso Arzew* in December 1978 and *El Paso Howard Boyd* in June 1979.

The Conch containment system was chosen for the Avondale newbuildings, with each vessel being provided with five aluminium alloy, self-supporting, prismatic cargo tanks. Each of the three

cost US\$103m to build and in this case the MarAd subsidy covered 16.5 per cent of the total outlay.

The ends and sides of the Conch cargo tanks were internally stiffened with vertical aluminium extrusions supported by horizontal ring stringers. A liquid-tight centreline bulkhead and a transverse swash bulkhead were fitted in each tank. The cargo tanks were insulated by means of layers of sprayed polyurethane foam (PUF) applied to the ship's inner hull. Bottom load-bearing balsawood/plywood composite panels supported the weight of the tanks and cargo. Centreline anti-rolling support keyways and transverse top keys held the tanks in place.

Kaiser Aluminum and Chemical Corp was subcontracted to construct the cargo tanks and supply and apply the insulation. Kaiser set up an assembly plant on Pinto Island near Mobile, Alabama to construct the tanks and used a facility at Wilmington, North Carolina for the prefabrication of panels of aluminium plate and stiffeners. These units were then shipped by barge to Pinto Island for the final tank assembly.

Once Avondale completed its work on the vessels, including spraying PUF insulation on the inner hulls, the open hulls were towed to Pinto Island for the installation of the tanks. As each cargo tank weighed, on average, 950 tonnes, the mammoth 1,550-tonne crane at the Kaiser assembly plant was able to position them onboard without any undue problems.

The three Conch ships - *El Paso Columbia*, *El Paso Cove Point* and *El Paso Savannah* - were all completed in 1979. Unfortunately, extensive cracking of the PUF foam was discovered throughout the insulation during the vessels' gas trials. As a result El Paso refused to accept the Avondale ships. After many years of claim and counter claim, extensive layup periods and much debate, it was decided that the ships could not be economically repaired for LNG trading. El Paso received a US\$300m insurance settlement.

El Paso Cove Point and *El Paso Savannah* were later sold to Coastal Corp and taken to the Hyundai Mipo repair yard in Korea to be converted to bulk carriers. The aluminium cargo tanks were removed and reused ashore and the boiler and steam turbine propulsion systems were altered to enable them to burn coal. In 1983 the ships began to trade commercially as *Jade Phoenix* and *Golden Phoenix*, respectively. In March

1987 *El Paso Columbia*, the first of the Avondale trio, arrived at Kaohsiung in Taiwan to be broken up for recycling.

The colour scheme chosen for the El Paso fleet, allegedly for safety reasons, gave the nine ships an eye-catching appearance. A research study to determine an external hull colour scheme which would allow maximum visibility under various atmospheric and sea conditions resulted in a distinctive beige-orange-dark brown colour combination.

El Paso suffered more ill-fortune in June 1979 when the fully laden *El Paso Paul Kayser* ran hard aground on rocks in the Straits of Gibraltar enroute to Cove Point from Algeria. The vessel was travelling at a considerable speed when the incident happened and the hull structure below the waterline was extensively damaged. The impact caused some upward movement of the inner hull supporting the membrane cargo containment system but the membrane remained intact and no cargo was lost. The ship was later refloated, thanks to part lightening of some cargo to the 25,500m³ *Jules Verne*. The remaining cargo was later transferred to sister ship *El Paso Sonatrach*.

Algeria stopped shipments under the El Paso contract in April 1980, after the US refused to accept a request that the price of gas be increased to a level close to that of crude oil. In February 1981 El Paso announced that "In view of the remote prospects for project resumption the company considers its LNG activities to be a discontinued operation."

Cove Point received 31 Algerian cargoes on the French-built trio and 29 on the Newport News ships. At Elba Island 22 cargoes were discharged by

the *El Paso Paul Kayser* series and 18 by the *El Paso Southern* series. Between 1978 and 1980 a neat, but somewhat disappointing, 100 cargoes of LNG from Arzew were delivered to the Cove Point and Elba Island import terminals. Both Cove Point and Elba Island were mothballed following the demise of the Algerian trade.

The French-built trio were all scrapped back in the 1980s. *El Paso Paul Kayser* was the first to be broken up, in Taiwan in 1986. The next year *El Paso Consolidated* ended her days at a Chinese breakers yard. *El Paso Sonatrach* was sold to the Kuwait Oil Tanker Company in 1983 for a storage project and renamed *Al Rawdatain*. The ship was sold for recycling as *Alar* in China in 1987.

Following the demise of the Algeria-US trade the three Newport News ships remained in lay-up for 18 years on the James River in Virginia. *El Paso Southern* and *El Paso Arzew* were reactivated in the late 1990s to load cargoes at Nigeria LNG's Bonny Island terminal under charter to Shell as, respectively, *LNG Delta* and *Galeomma*. The 35-year old pair were despatched to the Far East for dismantling in 2013. The third Newport News-built ship *El Paso Howard Boyd*, now *Matthew*, is the only one of the original nine El Paso ships still trading.

At the time the El Paso Algeria/US initiative was the most ambitious LNG project ever mounted. It also turned out to be the largest to be brought to a halt as a result of outside economic forces. Furthermore, the failure of the Conch insulation system on the three Avondale ships was the most expensive mishap in the history of LNGC construction. Still, the sheer enterprise of the El Paso scheme at the birth of the LNG trades. **SH**



Conch prismatic tanks being assembled at Kaiser's Pinto Island facility in the late 1970s, for installation on the LNG carriers building at Avondale for El Paso

Quincy takes early spherical tank lead

While Quincy's sojourn in the LNG spotlight was short-lived, the General Dynamics yard packed more into a few short years than any other shipbuilder at the time

The US, or more specifically the Quincy yard of General Dynamics, was the most prolific builder of Moss spherical tank ships during the early days. Between 1977 and 1980 the yard built ten 126,300m³ ships with spherical tank containment systems. At the time the 10th Quincy LNG carrier was delivered only five other Moss vessels of this size had ever been built.

Called the *Aquarius* class, the first eight Quincy ships were constructed for the carriage of Indonesian LNG to Japan under a long-term agreement. The vessels were bareboat chartered to Burmah Gas Transport, time chartered by the Indonesia state oil and gas company Pertamina and operated by Energy Transportation Corp.

The final two ships were built for Lachmar and a proposed project which called for the transport of Algerian gas to a new US terminal at Lake Charles in Louisiana. All the Quincy ships entered into service as US-flag vessels manned by American crews.

Moss spheres were the most popular

containment system during the early days of LNG transport. In 1969 the Norwegian shipowner Leif Höegh had asked Moss Verft, a local shipbuilder that had constructed many LPG carriers, to investigate the challenges of LNG transport. Moss, then part of the Kvaerner engineering group, decided that robust spheres offered the best option at the time.

After considering some earlier approaches to the design of small spherical tank ships, Moss opted to develop its own design for large LNG carriers. The work was assisted by the research department of Det Norske Veritas (DNV), and in mid-1970 the Moss spherical tank concept gained class society approval. By 1977 a total of 14 shipyards worldwide were licensees of the Moss system. General Dynamics Quincy was one of them.

The LNGC newbuilding contracts prompted some refurbishment work at the Quincy yard in Fore River, Massachusetts as well as a novel approach to the construction of the

five 36.6m diameter, aluminium cargo tanks required for each vessel. General Dynamics decided to construct the tanks as complete units at a new fabrication facility in Charleston, South Carolina and then to barge each individual 850-tonne tank up the US East Coast to Quincy. After a four-day, 1,400km barge journey the tank was lifted and installed in position in the LNGC's hull using the yard's 1,200-tonne capacity gantry crane.

The 5083 grade aluminium for the tanks was supplied by Alcoa from its Davenport, Iowa rolling mill. This facility, then the world's largest aluminium rolling mill, was capable of turning out finished plates 5.25m wide. Such large sections eased the sphere fabrication work at Charleston by reducing the number of pieces required and the amount of welding by 20 per cent.

Fabrication of the spherical tanks at Charleston was accompanied by an elaborate programme of weld testing. The non-destructive testing regime included 100 per cent X-ray, 100 per cent ultrasonic and 100 per cent dye penetrant checks as well as full visual and dimensional inspections. The plating thickness of the aluminium varied over the surface of the tank, from a maximum of 75mm at the more highly stressed equatorial ring section to a minimum of 34mm in the top half.

The Charleston facility was able to work on eight spherical tanks simultaneously: six under final assembly and welding in the assembly hall; one at the outside hydrostatic test station; and one in a building dedicated to the



LNG Libra was part of an eight-ship fleet that served on the Indonesia-Japan route unceasingly for a quarter of a century, the only time off being for scheduled repair yard visits

application of insulation. Each sphere on the Quincy ships was fabricated from over 100 formed and machined aluminium plates, and about 100km of precision welding was required to complete each tank.

Following assembly and prior to the hydrostatic test, each sphere was inspected by US Coast Guard and American Bureau of Shipping surveyors. The process of insulating the tanks in the dedicated building involved rotating a completed sphere and covering it with over 10,000 panels of polyurethane insulation to a thickness of 200mm. The unit was then sealed with coatings of rubber and polyurethane.

Quincy completed its first ship, *LNG Aquarius*, in June 1977. All 10 of the yard's LNG carriers were built to the same rigorous standard. The heavy hull scantlings, as typified by the 50mm thick high-tensile steel deck plating, were in excess of those mandated by class, and the powerful 43,000 shp steam turbine propulsion systems provided a service speed of 20.4 knots.

The eight *Aquarius*-class ships marked the entry of Indonesia into the LNG community. The fleet loaded at the new export terminals that had been built at Bontang and Arun and discharged at four receiving terminals in Japan on behalf of five utility companies. Bontang loaded its first cargo in August 1977 and Arun in September 1978.

Initially the Burmah Gas Transport fleet was contracted, on behalf of Pertamina, to supply the Japanese utilities with 7.5 million tonnes per annum (mta) of LNG for 23 years, until 1999. Three of the Japanese companies subsequently signed up for additional small and variable volumes as new LNG production capacity was added at Bontang and Arun. It was not long before the fleet was delivering 150-160 cargoes annually, or 8-9 mta of LNG. Indonesia proceeded to build upon this strong debut with other projects and it was not long before the country was the world's largest exporter of LNG.

Mitsui OSK Lines (MOL) is a Japanese shipowner that has enjoyed considerable success in the LNG sector through joint ownership ventures with a wide range of other shipping companies. In 1989 MOL acquired a 50 per cent stake in Burmah Gas Transport, the beneficial owner of the vessels.

In the mid-1990s, as the 1999 expiry date on the original Pertamina charter was approaching, the vessels were put through life extension programmes under the guidance of Lloyd's Register to



The assembly hall at Charleston, South Carolina enabled the simultaneous fabrication of up to six spherical tanks

give them a new lease of life. Pertamina renewed the charter on six of the ships, taking them for an additional 10 years. Alternative work was found for the remaining two vessels in the fleet. All the vessels were reflagged with the Marshall Islands registry in 2000. MOL, in tandem with LNG Japan, subsequently bought the 50 per cent of the company it did not already own and Burmah Gas Transport was renamed BGT.

By 2014 MOL had ceased its involvement with all but one of the BGT ships. One had been sold for scrap, one to Höegh LNG, two to a Singapore company and three to General Dynamics. As one of the original financiers of the eight-ship fleet, General Dynamics held the title on the three ships in question. MOL retains a holding in a joint venture operating *LNG Aquarius*, the original ship in the series. The vessel is being employed in shuttle duties in Indonesia.

The final two Quincy ships had a much less intensive working life than the *Aquarius*-class vessels, at least early on. The pair, *Lake Charles* and *Louisiana*, were built for Lachmar, short for Lake Charles Marine. Lachmar was a joint venture 40 per cent owned by Panhandle Eastern, 40 per cent by General Dynamics and 20 per cent by Moore-McCormack Lines.

Panhandle Eastern had signed a gas purchase agreement with Algeria covering the delivery of 3.4 mta of LNG from Skikda to Lake Charles. The new receiving terminal there was operated by Trunkline, a Panhandle affiliate. Unfortunately the project never became established. The Lachmar transportation agreement and the LNG

purchase agreement with Sonatrach of Algeria were suspended in 1984 due to unfavourable market conditions. A key factor was the discovery of large quantities of gas in the US following deregulation of domestic gas prices.

As a result *Lake Charles* and *Louisiana* spent 12 of their first 20 years in layup. Although their idle time was interrupted by short bursts of employment, by the end of 1999 each of the two ships had made less than 100 loaded voyages, under 20 per cent of the number logged by their Quincy sisterships.

However, in the latter half of the 1990s there was a global resurgence of interest in LNG, and the Lachmar pair caught the eye of Nigeria LNG (NLNG). The new gas exporter decided to charter the second-hand vessels as a way of quick-starting shipments from the liquefaction plant it was building on Bonny Island. The agreement included an option to purchase the ships.

After spending four months at EN Bazan in Spain in 1999 undergoing reactivation work, *Lake Charles* and *Louisiana* departed the shipyard as *LNG Abuja* and *LNG Edo*. The refurbishment project had set the vessels up for a further 20 years of active trading in the carriage of Nigerian exports and NLNG was quick to exercise its purchase option. The pair were flagged with the Bahamas registry, and Denholm Ship Management was appointed to undertake their operation.

Any LNG carrier approaching 40 years of age will have accumulated some notable history and the same is certainly true of the 10 Quincy ships. **MC**

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Cavalcade of LNG non-starters

Few in number, today's successful LNGC containment systems emerged from a myriad of competing ideas that did not make it to the high seas

No new LNG carrier cargo containment system has been introduced since 1987. The ships in today's fleet sport one of only five tried and tested types. They are IMO Type C pressure vessels, Moss spheres, IHI SPB tanks and the two Gaztransport & Technigaz (GTT) membrane tank systems.

The three principal tank systems for conventional size LNGCs – the Moss spheres, the Gaz Transport membrane and the Technigaz membrane – have been established since the early years of the industry. Delivered in August 1969, the 71,500m³ *Polar Alaska* was the first vessel to be fitted with the Gaz Transport membrane system while the inaugural Technigaz stainless steel membrane ship was the 50,000m³ *Descartes*, completed in September 1971. The 88,000m³ *Norman Lady*, which entered into service in November 1973, was the first LNGC with Moss spherical tanks.

That is not to say that the industry has been short of ideas. Over the 50 years since LNG was first carried by sea many containment system designs have been put forward as a means of transporting this challenging cargo.

However, as the designers of these concepts will be quick to point out, the path to commercial acceptance is a difficult one.

A number of obstacles have to be overcome before a new containment system can be considered as being viable for an LNGC newbuilding project. Designers will encounter considerable development costs, including those associated with a rigorous prototype testing programme. Approvals from class societies and regulatory authorities will then be required and any new system overcoming all these hurdles still has to convince the traditionally conservative shipowner of its merits.

The following paragraphs describe some of the LNGC containment systems that have been unveiled over the years but, for one reason or another, were never chosen to grace an LNGC newbuilding in commercial service. The vast majority were introduced during the industry's formative years.

To meet the needs of a 1952 proposal to ship Louisiana gas to Chicago, consulting engineer Willard S Morrison designed a Mississippi River barge with five 15m diameter, vertically mounted, mild steel, cylindrical tanks lined with balsa wood insulation up to 30cm thick. On the drawing board each tank



Never short of ideas, Cornelis Verolme settled on multiple vertical cylinders

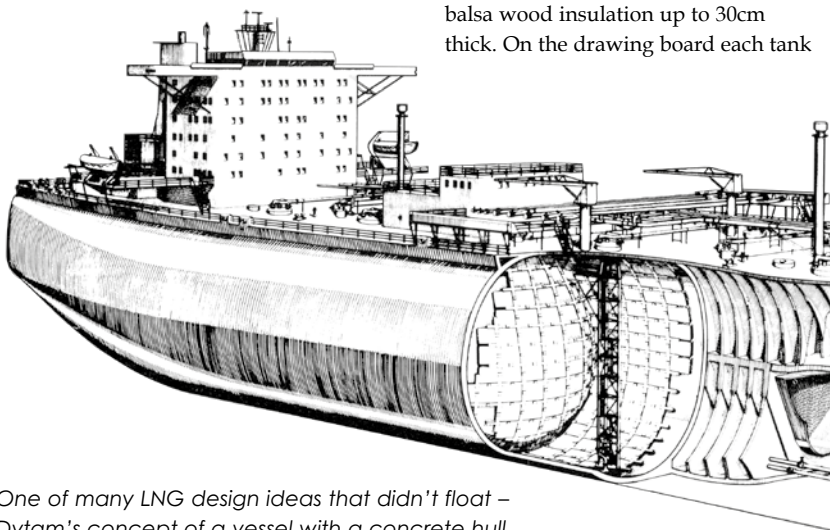
was provided with a 1.5m diameter central column in which regasification equipment was installed to enable the discharge of regasified cargo in Chicago. This project, and the others highlighted below, never materialised.

In 1954 the possibility of shipping LNG from Venezuela to the UK was investigated. Six ship designs were produced, all of which had an amidships bridge deckhouse over the cargo tanks. One design featured six spherical tanks while another sported four horizontal, cylindrical tanks. The other options were multiple horizontal cylinders, cork-insulated cylindrical tanks and two variations on the theme of balsa-lined cylindrical tanks.

A patent was taken out in 1955 by Norwegian shipowner Oivind Lorentzen of Oslo for a 7,500m³ LNG carrier with six aluminium spherical tanks. The four central tanks had 24m diameters while the two at the fore and aft ends had 20m diameters. The design showed a continuous weather cover over the six tanks, similar to the 'new' Sayaendo concept recently introduced by Mitsubishi Heavy Industries in Japan.

In 1958 British naval architect consultants Burness, Corlett developed two designs for a 4,000m³ LNGC as part of a study for Wm Cory & Sons. Eleven horizontally mounted cylindrical tanks were chosen for the first design, with six in the holds and five on the main deck. The second design had six vertically mounted cylindrical tanks in the holds, each with an upper cylindrical trunk. A trunk deck was fitted throughout the cargo area.

In 1969 Bridgestone Liquefied Gas (BLG) of Tokyo teamed up with Liquid Gas Anlagen (LGA) in Remagen, Germany to develop a semi-independent



One of many LNG design ideas that didn't float – Dytam's concept of a vessel with a concrete hull

LNG Shipping at 50 | the early years

membrane tank system for LNG carriers. The system was based on the semi-membrane design as installed on the 72,344m³ LPG carrier *Bridgestone Maru No 5*, which had been delivered by Kawasaki Heavy Industries in September that year.

Compared to the LPG arrangement, with tanks in pairs, the LNG design proposed cargo tanks extending across the full beam of the ship. Depending on the design of the ship, the 'metal' membrane primary barrier was to have a thickness in the 3-10mm range. The flat walls were supported by load-bearing insulation on the hull structure, with cylindrical edges and large ball corners to allow for thermal expansion and contraction. The secondary barrier was coated plywood panels.

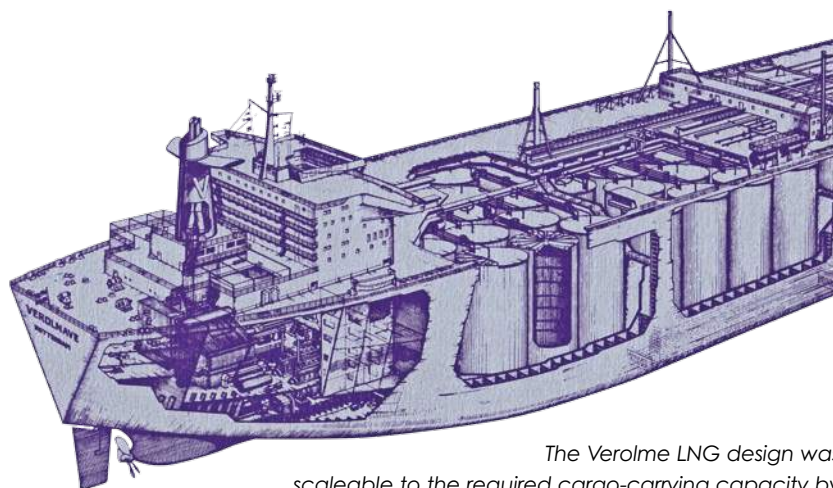
To be assembled separately before being lifted into the ship's hold spaces, the tanks would be held in position at the tank dome by a large hanger system. The lifting of a completed tank would necessitate a temporary internal frame support for the unstiffened membrane.

Dytam Tanker GmbH began research into the use of reinforced concrete for cryogenic applications in August 1972. Based in Kiel, Germany, Dytam was a joint venture between Dyckerhoff and Widmann, a concrete firm, and Tampimex, an oil trader.

Dytam developed a design for a concrete 128,000m³ LNG carrier. The 290m long vessel had a single hull made from concrete and 10 cargo tanks arranged in pairs. Internal insulation was either sprayed on or enclosed in stud-mounted fibreglass panels. The transverse bulkheads were dished in shape to allow for expansion and contraction. The thickness of the concrete was 60cm at the bottom hull, 45cm at the side hull and 20cm at centre. The concrete was reinforced longitudinally and transversely by stressed and unstressed steel rods.

As a solution for developing the remote Arctic gas fields Boeing of Seattle proposed a unique air and sea LNG solution in 1974. A fleet of up to 14 Boeing 747 freighters were to fly planeloads of LNG south to a marine terminal on the US Pacific coast for the onwards sea leg of this LNG distribution chain. Each aircraft would be capable of carrying up to 350m³ of LNG over a distance of 1,100km.

In 1976 Owens-Corning Fiberglass of Toledo, Ohio introduced an internal



The Verolme LNG design was scaleable to the required cargo-carrying capacity by specifying a greater or smaller number of same-size aluminium tanks

insulation LNG containment system called Perm-Bar II. The system was made up of prefabricated panels secured to the ship's inner hull by studs. The insulation was made up of two panels. The main flat panels were rectangular in shape and provided a primary and secondary barrier of glassfibre-reinforced plastic (GRP) with polyurethane foam (PUF) between. A third barrier labyrinth of FRP was fitted at the inner hull. Panels could be curved or tapered to suit the shape of the cargo tank.

Dutch entrepreneur and innovator Cornelis Verolme formed his Naval Project Development team in Rotterdam in 1976. This group produced designs for LNGCs, fitted with a multitude of vertically mounted, cylindrical, aluminium alloy cargo tanks of the same size, with capacities up to 500,000m³. A typical 3,500m³ tank for a 330,000m³ LNGC would have a height of 35.5m and a diameter of 11.8m.

A grid framework on the ship's inner bottom supported each tank and held it in place against ship movements. The cylinders were considered as IMO Type B tanks and had a maximum design pressure of 0.35 barg (135 kPa). Tanks could be positioned in three or five rows across the ship and in four or five holds, depending on the overall capacity. A 125,000m³ Verolme LNGC would have 38 tanks, a 165,000m³ vessel 50 and a 330,000m³ ship 93.

In 1978 Spain's Astilleros y Talleres del Noroeste (Astano) proposed a range of LNGC designs based on an internal insulation system called Metastano 20. Cargo capacities ranged from 130,000 to 300,000m³ while the 366m length of the largest design was similar to that of the

363,000 dwt very large crude carriers (VLCCs) built by the yard.

The individual cells of the Metastano internal insulation were made up of three components. The first consisted of two glassfibre-reinforced plastic (GRP) boxes with boundaries either curved or flat. These boxes were filled with rigid PUF, the second component. Adhesive was the third all-important component, as no studs were used to secure the cells. The system offered four GRP barriers and four PUF sealing barriers, with each designed to be impervious to cryogenic liquid leakage.

In 1981 General Dynamics in the US examined the feasibility of a 140,000m³ submarine LNG carrier for Arctic service. Nuclear and steam turbine propulsion systems were considered. The nuclear version would require a cargo reliquefaction plant while the conventional steam propulsion system would burn the cargo boil-off in the boilers.

The submarine design called for six cylindrical IMO Type B cargo tanks of equal size to be fitted along each side of the vessel. The tanks would be constructed of 9 per cent nickel steel and insulated externally with polyisocyanurate foam panels to provide a cargo boil-off rate of 0.2 per cent per day. Shipping routes from Prudhoe Bay in Alaska to the Canadian east coast and Europe were seen as viable.

The above paragraphs describe only a few of the LNGC containment system ideas that were considered over the past 50 years and that never came to fruition. Today's bright naval architects, when contemplating a new revolutionary LNGC design, should first check out these pioneering efforts to spot potential drawbacks early on. **SH**

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The people who put LNG on the map

The early momentum achieved by the LNG industry owes much to the commitment and ingenuity of a select band of key innovators and motivators

The early challenges posed by the quest to transport natural gas by sea drew in many enthusiastic engineers, naval architects, oil and gas executives, shipowners and innovators. Once smitten by the task at hand, many went on to forge real breakthroughs. These are the pioneers, visionaries and driving forces that established the foundations of today's LNG shipping industry. The soundness of those foundations is reflected in the success that has been achieved.

As described in the report on *Methane Pioneer* on page 10, the man who got the ball rolling was William Wood Prince, president of Union Stock Yard in Chicago. In the early 1950s he had the idea of bringing gas from Louisiana, where it was cheap and plentiful, to Chicago, where it was becoming increasingly expensive, for use in his meat-processing operations.

In the absence of a pipeline and to ensure deliveries of meaningful quantities, the gas would have to be liquefied and brought up the Mississippi River to Chicago by barge. The job of verifying the feasibility of such a concept was entrusted to Willard Morrison, a local Chicago inventor and refrigeration engineer of some renown that Prince had on his research team.

Prince also set up a partnership with Continental Oil of Oklahoma and, after much debate and research, it was decided that the future lay not with river barging but, rather, the ocean transport of LNG. The partners formed Constock International Methane in 1955 and specialists were brought in to move ideas forward. The effort culminated in the epic series of trial voyages by the 5,000m³ *Methane Pioneer* in 1959.

Who were the specialists who



For each of the pioneers that made the headlines, there were hundreds of people behind the scenes helping to establish the new industry

contributed to this breakthrough ship? Constock itself had vice-president John Murphy, director of engineering Chuck Filstead and engineers Jim Hunt, Carl Ritter and Elwood Crouse. It also had the services of Dr Cedimir 'Cheddy' Sliepceвич, a chemical engineer from the University of Oklahoma who served as Constock's lead consultant on the project.

The *Methane Pioneer* project made use of other outside expertise. The management consultants Arthur D Little of Boston were asked to investigate cargo storage and handling methods for the

vessel. The task of designing *Methane Pioneer's* containment system fell to Alex Pastuhov, one of the company's engineers. The result was this historic ship's self-supporting, aluminium tanks and balsa insulation-cum-secondary barrier. Alex went on to join the Gazocéan Group in Paris in 1972 and until 1975 was president of Gazocean USA, a role which included the promotion of Technigaz activities in the US.

The task of developing the specification for the ship and its overall design was assigned to the New York naval architect firm of JJ Henry.

After launching his own ship design consultancy in 1946, James Henry had become a prominent figure in US marine circles as well as a leading innovator for a wide range of specialist cargo ships. *Methane Princess* and *Methane Progress* were also designed by JJ Henry, as was the first purpose-built, fully refrigerated LPG carrier. This was the 28,837m³ *Bridgestone Maru* delivered from the Yokohama yard of Mitsubishi Nippon Heavy Industries in Japan in January 1962.

Also in the initial *Methane Pioneer* design team at JJ Henry were William duBarry Thomas, Alfred Schwendtner and Dick Eddy. The extensive knowledge of these pioneering gas ship naval architects was shared with the industry in later years through many notable presentations. Two which stand out are *LNG carriers: The current state of the art* by Thomas and Schwendtner and given to the Society of Naval Architects and Marine Engineers (SNAME) in 1971 and *Whither the LNG ship?* in 1974 by Thomas to the Royal Institution of Naval Architects (RINA).

Barry Thomas was also the compiler of SIGTTO's much-missed *LNG Log*, an annual publication which recorded voyages completed by LNG carriers and was packed with the author's delightful hands-on reminiscences. By the time Barry passed on the editor's baton in the late 1990s *LNG Log* in its original format had become virtually unmanageable, such was the size of the matrix of LNGC voyages completed and the speed at which it was growing.

North Thames Gas Board in the UK had some key personnel overseeing the *Pioneer Methane* conversion. These included chief engineer James Burns, development engineer Leslie Clark and a young engineer, Denis Rooke, who later became Sir Denis and chairman of British Gas. Amongst his many appointments Sir Denis was one of the early GIIGNL vice-presidents.

In 1960 Shell joined Constock as a 40 per cent shareholder and the company was renamed Conch International Methane. Continental Oil also owned a 40 per cent stake in the new company and Union Stock Yard the remaining 20 per cent. E M (Steve) Schlumberger, who had been seconded from Société Maritime Shell in Paris, was put in charge of the Conch R&D team. Steve was the engineer who introduced Gazocéan to refrigeration systems for LPG cargoes in 1955. Chuck Filstead, one of the original Constock engineers, was

appointed technical director to oversee the design and construction of *Methane Princess* and *Methane Progress*, the first LNGCs to go into commercial service.

Conch also seconded senior naval architect Roger Ffooks from Shell International Marine to join this small design team. Roger became a key and well-respected spokesman for Conch throughout the 1960s and early 1970s, promoting the company's containment systems based on the success of the two *Methane* ships.

During those early days Roger inevitably got caught up in the intense rivalry that existed between the promoters of the various pioneering LNGC containment systems, but he tended to be a calming influence. The protagonists came into the public spotlight at the regular Gastech and LNG series of conferences. The heated discussion periods, in which Roger would participate as a speaker or session chairman, have lived long in the memory of those present.

The ferocity of the various proponents' sales pitches and criticisms of competing systems was balanced by Roger's humour, poems, cartoons and thought-provoking responses. Many long-lasting friendships were born out of this rivalry. Roger's classic book, *Natural Gas by Sea*, covers the early years of LNGC development with insight and authority.

As far back as 1954 Gaz de France, with Algerian gas in mind, had begun its own studies into the transport of LNG by ship. One of the company's directors, Robert Labbé, was also a managing partner in the Worms Group. After a fact-finding visit to the US with Audy Gilles, Robert set up a research



Roger Ffooks found a gentlemanly path through the minefield that was the rivalry between competing containment systems



Dr Cedomir Slepcevic played a key role on the *Methane Pioneer* project

group called Methane Transport in 1959 to design a French LNG carrier. The experimental ship *Beauvais* and France's first commercial LNG carrier, *Jules Verne*, were the tangible results from that group's work.

There was a significant piece of equipment fitted onboard *Beauvais*. James Coolidge Carter of Costa Mesa in California provided a submerged electric motor pump (SEMP) for use in one of the vessel's three cargo tanks. More than any other individual shipboard component, the JC Carter SEMP made the large-scale transportation of LNG by sea possible.

In July 1962 members of the Methane Transport research group, along with several others, were invited to a tank test in Oslo. The invitation was from shipowner Øivind Lorentzen and Texas-based investor Carol Bennett who wanted to demonstrate the viability of a membrane tank system based on an idea developed by Det Norske Veritas (DNV) engineer Bo Bengtsson. Attending, and impressed with the tests carried out using liquid nitrogen, were Pierre Verret from Gaz de France, Audy Gilles from the Worms Group and Jean Alleaume and Gilbert Massac from Gazocéan.

Following these observations, Gazocéan acquired the Norwegian patents and set about making substantial changes to the original design and registering new patents. In time, and through cooperation with Conch Océan, the Gazocéan membrane concept was to become the basis for the Technigaz Mark I containment system.

Conch Océan was established as a 60/40 Conch/Gazocéan joint venture in 1967 to enable the marriage of the Technigaz waffled stainless steel membrane with the Conch balsa wood insulation system. Amongst those on the design team taking out patents under

the Conch Océan banner were Gilbert Massac, Michel Kotcharian and another ex-Shell man, Bob Jackson.

Going back to the evolution of the Gazocéan membrane itself, the next stage involved a seagoing trial. René Boudet, the company's president, and his friend Carol Bennett agreed to build a small prototype ship to demonstrate the soundness of the design for LNG and to show that it could also be used for LPG and ethylene trading. Delivered in May 1964, the ship was the 630m³ *Pythagore*.

René Boudet was one of the gas industry's larger-than-life characters. A formidable pioneer of LPG trading and transport by sea in the 1950s, he founded Gazocéan in 1957. Following the success of the *Pythagore* prototype vessel, Boudet then placed a speculative order in 1968 for the 50,000m³ *Descartes*, the first commercial ship with the Technigaz Mark I membrane. In 1979 René Boudet moved on from Gazocéan and created Geogas Enterprise, a Geneva-based LPG trading company.

One of the attendees at the Oslo test, Audy Gilles, had also been involved with the *Beauvais* project. The Worms Group man was investigating another potential membrane material. In particular he was considering a 36 per cent nickel steel alloy which the Nobel prize-winning Swiss physicist Charles Édouard Guillaume had discovered in 1896 and named invar. Industrialised by Imphy Alloys of France, invar has a near-zero coefficient of thermal expansion.

The Worms Group put Pierre Jean in charge of a research team to look at invar in more detail and he was assisted by Pierre Legendre of Imphy. By October 1965 the researchers' confidence in the material was sufficient



Audy Gilles (left) and Pierre Jean, the men who brought the Gaz Transport membrane tank containment system to life

for the Worms Group to establish Gaz Transport as a new subsidiary.

Six engineers joined president and founder Audy Gilles as the initial team members of Gaz Transport. Pierre Jean headed the group, which included naval architect Roger Lootvoet and Jacques Lenormand. Jacques Guilhem, who had been the engineer in charge of the *Jules Verne* project, also joined the team together with two other *Jules Verne* technicians, Michael Bourgeois and Jean-Pierre Morandi.

Work on the Moss LNG spherical tank containment system design started at Moss Værft in Norway in February 1969. Mikal Grønner, the president and CEO of Moss Rosenberg Værft (MRV), and his design team set off with a simple three-pronged strategy. The design had to provide a high standard of safety; the construction would have to be based on traditional shipbuilding methods; and the initial and operating costs of a spherical tank ship must be kept low.

The other members of the team were Hans Jorgen Frank, who joined MRV from the Lorentzen Group, Ragnar Bohgaes, the technical director of Moss Værft, and Olav Solberg, who was head of the steel structure department at Kværner Brug. The Kværner engineering group was the parent of MRV.

In early 1970 DNV was commissioned to help with the project and a team was assembled under the guidance of manager Rolf Kvamsdal. The society's Per Tenge, Gunnar Wold and Odd Solli were directed to weigh up the choice of materials for the spherical tanks while Helge Ramstad examined stress levels and Odd Solumoen investigated insulation matters.

DNV president Egil Abrahamson played an active role in this study, providing guidance on dealing with national and other regulatory bodies. Early on in the study James Howard, a former US Coast Guard officer, joined the Kværner Group and his background proved useful when dealing with the US maritime authorities. Later Tormod Grove and Hans Richard Hansen contributed extensively to the Moss spherical tank project with input on stress and fatigue analysis. In January 1971 Rolf Kvamsdal joined MRV as head of the gas technology department and quickly became the well-known frontman and publicist for Moss spheres.

After *Methane Princess*, *Methane Progress* and *Jules Verne* had established the initial Algeria-to-Europe LNG trade lanes, subsequent projects



William Wood Prince is acknowledged as the father of LNG

generated their own contributions to the pioneer pool. Esso's DM Latimer played a key role in developing both the shipping and terminal elements for his company's Libya venture while Alexander Delli Paoli was section head of Esso International's tanker department and the man responsible for the design and construction of the four 41,000m³ vessels built for the project.

Ed Torney, another naval architect from the JJ Henry stable, acted as design and construction advisor to Esso. He later joined Energy Transportation Corp, the company which operated the eight spherical tank ships on the Indonesia-Japan route on behalf of Burmah Oil.

The Alaska-Japan trade began in October 1970 and Phillips Petroleum's vice-president LeRoy Culbertson and John Horn in the natural gas sales department were leading figures in getting the venture off the ground. RJ Wheeler, the company's director of marine operations, headed the team responsible for the running of the two vessels that served the trade, *Polar Alaska* and *Arctic Tokyo*.

There were many other LNG shipping and terminal pioneers who did not grab as much limelight as those mentioned above. As SIGTTO and GIIGNL point out in their introductory remarks to this magazine, our industry owes a great deal of gratitude to all the pioneers that helped establish the solid foundation stones that are in place. This group encompasses not just those who made the headlines but also those shipyard workers, welding experts, steel and aluminium manufacturers, insulation specialists, electrical engineers and cryogenic equipment suppliers who have played key but mostly unsung roles in logging 50 years of safe LNG operations. **SH**

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European yards centre stage in LNG industry's opening act

Although LNGC construction today is concentrated in the yards of Korea, Japan and China, they were not amongst the sector's pioneering shipbuilders



The Genoa Sestri-built LNG *Palmaria*, née *Esso Brega*, shared a long service life record with *Jules Verne*

There was a great number of shipbuilders involved in the construction of the early LNG carriers. Some yards built only a single, albeit significant, vessel while others were involved with one or more series of ships, honing their skills with each delivery. As much of the LNG industry's groundbreaking work was carried out in the UK, France and the US, and all three countries had both a strong shipbuilding tradition and growing demand for gas, it is not surprising that this trio of nations is responsible for many of the pioneering LNG carrier designs.

Politics also played a part. For example, *Methane Princess*, *Methane Progress* and *Jules Verne*, the first three LNGCs in commercial service, were required to be built in a home shipyard.

Vickers Armstrong (Shipbuilders) of Barrow-in-Furness in the northwest of England delivered the 27,400m³ *Methane Princess* in June 1964. As the lead contractor on the project, the company also prepared the working drawings and placed material orders for the sistership *Methane Progress*, which was built at Harland and Wolff

(H&W) of Belfast in Northern Ireland. However, the contract allowed the latter yard to follow some of its own building practices when constructing the conventional parts of *Methane Progress*.

Both ships featured nine aluminium alloy, prismatic cargo tanks of the Conch design. All drawings required approval from five separate organisations, namely Lloyd's Register and American Bureau of Shipping as the dual classification societies, Conch, British Gas and Shell, which worked with J J Henry of New York on the vessels' design.

Both ships were built on time and close to budget, although the first purpose-built LNGC for commercial service, *Methane Princess*, was to be the only gas ship built by Vickers. The yard, now BAE Systems, is still constructing sophisticated vessels, including nuclear-powered submarines and other complex naval ships.

H&W completed *Methane Progress* in July 1964. During work on the vessel the Belfast shipbuilder gained some experience with LNG membrane technology by building a prototype tank based on a Conch Methane Services idea. The membrane consisted of two sizes of

rotating stainless steel trays supported by a balsa and plywood insulation system. The prototype was fitted inside a mild steel tank and installed on board the collier *Findon*. Towards the end of 1974 the tank was tested in service with cargoes of LNG, ethylene and liquid nitrogen. The test results were disappointing and the research work stopped.

In 1982 H&W completed and tested to destruction another prototype tank designed for the storage of gas liquids under pressure or at low temperature. This test tank was a one-third scale model of a multi-lobe tank design ordered by Motherwell Bridge Engineering and Ocean Phoenix Gas Transport of the Netherlands. The same year the yard delivered two 59,000m³, fully refrigerated LPG carriers, *Isomeria* and *Isocardia*, for Shell. The pair were H&W's only other involvement with gas carriers.

In June 1962 Gaz Marine placed the contract for the 25,500m³ *Jules Verne* at Ateliers et Chantiers de La Seine Maritime (ACSM) in Le Trait, France. Completed in March 1965, the ship had seven independent, vertically mounted, cylindrical cargo tanks of nine per cent nickel steel. Two months later the ship discharged France's first LNG cargo, a shipment from Algeria, at the newly commissioned Gaz de France import terminal at Le Havre.

Describing the *Jules Verne*'s cargo tanks as cylinders does not do justice to their ingenious shape. The lower bottom of each tank was an inverted cone with a rounded peak; the bottom at side was elliptical-toroid; and the top was ellipsoidal. Only the sides were cylindrical.

The design was selected from one of three different tanks which had been fitted on the 640m³ converted experimental vessel *Beauvais*. The conversion had been completed in February 1962 by Chantiers de l'Atlantique at St Nazaire. *Jules Verne* was broken up in 2008 as *Cinderella* after a record-breaking 43 years in service.

Another experimental ship, the 630m³

Pythagore, was completed by Ateliers et Chantiers du Havre (ACH) for Gazocéan in May 1964. The vessel was provided with two stainless steel membrane cargo tanks and this technology was to be the foundation of the Technigaz membrane containment system. However, the matter was not settled until prolonged legal wrangling between Conch and Gazocéan over a number of patents was resolved. *Pythagore* carried two LNG cargoes and was then switched to trading in ethylene and LPG.

The ACH yard also delivered the 4,000m³ *Euclides*, the first LNG carrier built with spherical cargo tanks, to Antarctic Gas, a Gazocéan subsidiary, in February 1971. Designed by Technigaz, the ship had four nine per cent nickel steel cargo tanks. The ship's maiden voyage was a stormy Atlantic crossing with a cargo of Algerian LNG for discharge at the Everett terminal in Boston, Massachusetts.

Kockums Mekaniska Verkstads in the Swedish port of Malmö constructed the first LNGC to the Gaz Transport membrane tank containment system design, with its distinctive invar primary and secondary barriers. The vessel, the 71,500m³ *Polar Alaska*, was completed in August 1969 while sistership *Arctic Tokyo* followed in December of the same year. Both ships were employed carrying LNG on the first Pacific Ocean trade, from Kenai in Alaska to the Negishi terminal in Japan.

Kockums had already accumulated expertise with gas carrier construction,

having completed the first fully refrigerated LPG carrier to be built in Europe, the 25,100m³ *Paul Endacott*, in May 1964. *Arctic Tokyo* was built alongside another LPG carrier, the 26,500m³ *Phillips Arkansas*, in the yard's mammoth new building dock. The facility included a 140m tall gantry crane with a lifting capacity of 1,500 tonnes.

Italcantieri's Genoa Sestri yard was the next to join the LNG shipbuilders' club. Genoa Sestri completed a remarkable trio of 41,000m³ ships for Esso International. These were *Esso Brega*, delivered in October 1969, *Esso Portovenere* in March 1970 and *Esso Liguria* in July 1970. A fourth, similar vessel, *Laieta*, was delivered to Esso in April 1970 from the Astano yard in El Ferrol. This was the first LNG carrier to be built in Spain.

Esso had developed its own independent cargo tank design for the four ships and commissioned the quartet to transport LNG from the new export terminal it had built in Marsa el Brega in Libya. Back in 1965 the energy major had signed a gas sale and purchase agreement covering the delivery of Libyan LNG to new receiving terminals at Barcelona in Spain and Panigaglia near La Spezia in Italy.

The four prismatic cargo tanks on each Esso ship were constructed with aluminium alloy and built by Chicago Bridge & Iron (CB&I). To avoid a Conch patent dispute, the tank vertical positioning keys were located at the centreline of the ship at the ends of the cargo tanks and at the mid-length at the sides. Sharing a joint lifetime service record with *Jules Verne*, *Esso Brega* was 43 when the ship was broken up in 2012 as *LNG Palmaria*.

The Heinrich Brand yard in Oldenburg, Germany, got in on the LNG carrier construction act in June 1971 when it delivered the 2,720m³ *Melrose* to George Gibson of Leith in Scotland. This was the first of five ships from the shipbuilder for Gibson and Bernhard Schulte that were capable of carrying LNG cargoes. Although the ships never traded in LNG, they were the forerunner of today's multipurpose LNG/ethylene carriers. At the time they were a notable achievement for both the shipyard and the vessels' gas plant designer Liquid Gas Anlagen (LGA) of Rolandseck near Bonn.

Chantiers de l'Atlantique at St Nazaire achieved a major breakthrough with the completion of the 50,000m³ *Descartes* for Gazocéan in September 1971. Able to transport both LNG and LPG, this was the first commercial size ship to be fitted with

the Technigaz stainless steel membrane containment system.

The St Nazaire yard, now STX France, was not new to LNG technology, having supplied an aluminium tank surrounded by loose perlite insulation for the experimental ship *Beauvais*. Following *Descartes* the shipbuilder won a contract to construct four 75,000m³ LNGCs for Shell for the Brunei-Japan trade. These Technigaz ships were delivered over the 1972-74 period.

Another French yard, Constructions Navales et Industrielles de la Méditerranée (CNIM) in La Seyne on the country's Mediterranean coast, delivered its first LNG carrier, the 40,100m³ *Hassi R'Mel*, in December 1971 to Compagnie Algérienne de Navigation (CNAN). As shareholders in Gaz Transport, the shipyard naturally chose the No 82 membrane containment system for the ship's six cargo tanks.

CNIM had already acquired some valuable experience with membrane tank construction during the Gaz Transport system's development phase. In December 1968 it had completed the 28,866m³ prototype LPG carrier *Hypolite-Worms*, the tanks of which featured a single invar primary barrier.

Two months after CNIM completed *Hassi R'Mel* Chantiers Navals de la Ciotat, a rival of the neighbouring CNIM yard, handed over its first LNG carrier, the 40,000m³ *Tellier*, to Messigaz. This five-tank ship had the Technigaz Mark I membrane containment system.

The first Moss spherical tank LNG carrier, the 88,000m³ *Norman Lady*, entered into service in November 1973 on behalf of London-based owners Buries Markes and Höegh of Oslo. This distinctive ship was built at Moss Rosenberg Værft in the Norwegian port of Stavanger. One month later the 29,000m³ *Venator*, also with spherical tanks, was delivered by the smaller yard Moss Værft in Moss, Norway, to Smedvigs Tankrederi of Stavanger.

By the mid-1970s the major rival LNG carrier cargo containment systems had been tested in service and the industry had proven the viability of each system. Today's Q-flex and Q-max giants and the small-scale multigas carriers owe much to the tenacity of the entrepreneurs, innovative designers and shipbuilders of yesteryear. Bearing in mind the oil crises and other troubles of the time, these pioneers, in their wildest dreams, could not have predicted today's LNGC fleet of over 400 ships and orderbook of 130-plus vessels. **SH**



Methane Princess at Vickers on launch day – 22 June 1963



Hassi R'Mel was one of 10 LNG carriers built to the Gaz Transport No 82 membrane tank design

Established LNGC containment systems fend off all comers

Despite the occasional announcements of proposed new LNGC containment systems, none has yet posed a serious threat to the established designs

Today's LNGC cargo containment systems are well established and proven in service. The developers of these systems had their ups and downs in the early days as they worked through steep learning curves to bring their technologies to maturity. The rivalry between them was intense and sometimes more time was spent on highlighting the weaknesses of competing systems rather than extolling the merits of the in-house product.

In truth there is something to be said for all the containment systems in use today. They would not have achieved the degree of acceptance they have if that was not the case. Each incorporates touches of technical brilliance, good engineering and innovative thinking throughout the supporting structures, materials and layouts that go to make up the system.

Early research and development work into how to carry a liquefied gas cargo at near atmospheric pressure and a temperature of -162°C produced three basic approaches to LNG containment. One solution was the use of independent, self-supporting cargo tanks based on traditional shipbuilding techniques. Such

tanks had internal webs and stiffeners and external insulation. Another offering was spherical tanks while perhaps the most radical was the use of a thin membrane supported by insulation and the hull structure.

Independent, self-supporting tanks were the first to get an airing. The converted, $5,000\text{m}^3$ prototype vessel *Methane Pioneer*, the first ship to carry a seagoing cargo of LNG, in 1959, was provided with five aluminium alloy grade 5356-0 tanks. The insulation comprised prefabricated panels of balsa wood faced with maple and oak plywood fixed to the vessel's hull. In 1962 the experimental ship *Beauvais*, fitted with three different types of independent cargo tank, was put through a series of tests off the coast of Brittany in France.

As a result of the *Methane Pioneer* and *Beauvais* trials, the first three commercial LNGCs were ordered. All had independent cargo tanks and all were constructed to transport Algerian LNG exports. The $27,400\text{m}^3$ *Methane Princess* and *Methane Progress* were built in the UK to carry cargoes to the UK while the $25,500\text{m}^3$ *Jules Verne* was built in France

to handle French imports.

Each of the British pair had nine aluminium alloy 5083-0 prismatic tanks of the Conch design. These were insulated using glass fibre and plywood-faced balsa panels. The French ship had seven vertically mounted, cylindrical 9 per cent nickel steel tanks. Each tank was supported on KlegetCell insulation with loose perlite arranged around the sides and top.

The next newbuilding series, ordered in 1966, also sported independent, self-supporting tanks. The four $41,000\text{m}^3$ vessels were built to carry Libyan exports to Italy and Spain on behalf of Esso. The vessels, each of which had four prismatic, aluminium alloy 5083-0 tanks, were built to the oil major's own design. The insulation comprised a layer of polyurethane foam (PUF), plywood sheets, a second layer of PUF, aluminium sheathing and aluminium batten strips. The insulation arrangement was mounted on the outer tank boundary while the plywood was secured to the cargo tank with studs, and the aluminium batten strips fixed to the plywood with screws.

During the early 1960s French

researchers had been promoting membrane technologies as technically and commercially sound solutions to the challenge of transporting liquefied gases by sea. Gaz Transport and Technigaz each developed such a membrane system and both were to go on and achieve great success with their respective technologies. Although the two companies merged in June 1994, in the early days they marketed their systems separately and competed fiercely for business.

In 1967 Gaz Transport signed a breakthrough commercial contract for the first application of its membrane tank containment system. The technology was chosen for *Polar Alaska* and *Arctic Tokyo*, a pair of 71,500m³ vessels built by Kockums of Sweden for the pioneering Alaska-Japan trade.

Of major importance to the development of the Gaz Transport membrane system was the 28,700m³ LPG carrier *Hypolite-Worms*. The Worms Group wanted to build a prototype ship to prove the viability of membrane technology to shipowners. The ship was ordered from Forges et Chantiers de la Méditerranée (FCM) in mid-1966, prior to the contracts for *Polar Alaska* and *Arctic Tokyo*, and was delivered in December 1968. In the same year FCM became Constructions Navales & Industrielles de la Méditerranée (CNIM).

On *Hypolite-Worms* a single, 0.5mm thick invar membrane was fitted as the primary barrier, supported on a layer of plywood boxes filled with perlite insulation. The ship's inner hull and cofferdams were constructed with low temperature steel to form the secondary barrier. A voyage from Ras Tanura to Tokyo Bay with a cargo of propane proved invar to be a suitable primary barrier material for the containment of liquefied gas cargoes.

Gaz Transport supplied its No 82 system for *Polar Alaska* and *Arctic Tokyo*. With this design both the primary and secondary barriers were constructed from invar, in this case 400mm wide strips 0.5mm thick. The strips had upturned edges and these were connected using automatic welding machines. The invar strips were set longitudinally in the holds of the two ships in a single length and secured at the ends.

The primary and secondary barrier thermal boxes had standard dimensions of 1,000 x 400 x 200mm and were filled with perlite insulation. The insulating boxes, each of which weighed about 40kg, were secured to the ship's inner hull by a system of metal and wood support beams.

A total of 10 ships were constructed with the Gaz Transport No 82 system, including the 40,000m³ *Hassi R'Mel* and the 125,000m³ *El Paso Paul Kayser*.

In the early 1960s Technigaz bought the rights to the membrane patent taken out by Bo Bengtsson of Det Norske Veritas (DNV) in Norway. In May 1964 the 630m³ experimental ship *Pythagore* was delivered to Gazocéan by Ateliers et Chantiers du Havre (ACH). This ship was fitted with two stainless steel membrane cargo tanks of the Technigaz Mark I type. The trials established the design as suitable for the carriage of LNG.

The first commercial ship to be ordered with the Technigaz stainless steel membrane was the 50,000m³ *Descartes*, completed in September 1971. The vessel was ordered by Gazocéan speculatively in order to prove the viability of the Technigaz Mark I membrane system on a commercial-scale vessel. The newbuilding contract went to Chantiers de l'Atlantique at St Nazaire.

The primary barrier membrane of the Mark I system comprised 1.2mm thick sheets of 304L stainless steel. The pieces were corrugated in two directions to allow for thermal contraction and expansion. The primary barrier was supported by balsa wood blocks. The secondary barrier consisted of a layer of sugar maple plywood supported on three layers of balsa wood.

The 4,000m³ *Euclides* was the first LNG carrier built with spherical cargo tanks and the first without a secondary barrier. The system was also a Technigaz design and the vessel, like *Pythagore*, was built by ACH. The ship had four 9 per cent nickel steel cargo tanks cunningly hung from the main deck and was delivered to Gazocéan in February 1971.

The Moss LNG spherical tank design was to dominate the LNGC market during the 1970s and 1980s. Work on that concept started at Moss Værft in Norway in February 1969. Norwegian shipowner Leif Höegh was interested in exploring opportunities in LNG transport and had presented the Moss yard with an outline specification for a membrane LNGC for its opinion. Moss studied that and also some spherical tank options. At that point Moss decided that spherical tanks offered the optimum solution and that it would develop its own design for such tanks.

One of the aims of the Moss team examining the alternatives then in service was to come up with an approach that obviated the need for an expensive secondary barrier and was suitable for use on large vessels. They were able to

achieve this by looking at a pressure vessel type of tank to see if the applicable stress analysis and non-destructive material and welding tests could be used as a basis for an LNG cargo tank design.

Moss was fortunate that DNV and other researchers in Norway were at the forefront of finite element and fracture mechanics stress analysis. These parties between them were able to produce what came to be known as the 'leak before failure' concept for spherical cargo tanks supported by an equatorial ring. This simple, stress-determinate structural design does not require the traditional secondary barrier found on other gas carriers. Instead there is a leak protection system consisting of a drip tray under the tank and splash shields up to a suitable height around the tank.

The first ship fitted with Moss spherical tanks was the 88,000m³ *Norman Lady*, delivered by the affiliate yard of Moss Rosenberg Værft in Stavanger to a Lief Höegh/Buriers Markes joint venture in November 1973. The ship's five 9 per cent nickel steel tanks had a polystyrene spiral-wound insulation system developed by Teknisk Isolering.

Two months later the 29,000m³ Moss spherical tank *Venator* was delivered to Peder Smedvig from the smaller Moss Værft. The vessel's four aluminium alloy tanks were insulated using a panel system developed by Kaefær.

The membrane and Moss spherical tank concepts have remained generally unchallenged in the intervening years. While invar strips and plywood boxes have increased in size, secondary barriers have been tweaked and tank dimensions and diameters have been boosted, no serious contender has emerged to offer competition to these pioneering French and Norwegian designs. **SH**



Methane Progress was fitted with nine self-supporting, prismatic tanks made of aluminium



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Long shelf life for original LNGC kit

The durability of the cargo-handling equipment on the early LNG carriers highlights the sound engineering principles on which the suppliers based their designs

In discussions on the various early LNG carrier designs, the emphasis has always been on the relative merits of the rival cargo containment systems. Engineering components like cargo pumps, compressors, valves, gauges and control systems, so vital to the safe and effective operation of the vessels, rarely get a mention.

Many of the essential pieces of cargo-handling equipment developed for the early LNG carriers enjoyed universal applicability, irrespective of the ship's chosen containment system. And many of these pioneering equipment items are still around today, albeit in scaled-up versions. Their longevity bears testimony to the sound engineering principles and innovative technology on which the design of the original equipment was based.

One good example is the submerged electric motor pump (SEMP). Without these sophisticated cargo pumps, with the ability of their motors to operate within the liquid cargo, the progress from original experimental LNG vessels to the modern ships of the 266,000m³ Q-max size would not have been possible.

The original JC Carter cryogenic centrifugal pump was developed in 1947 in support of the US government's early rocket programmes. The pumps were used to feed liquefied gas fuel to the rocket engines. James Coolidge Carter conceived the idea for a SEMP for liquefied gas service at his factory in Costa Mesa, California in 1958.

SEMPs have a major safety advantage over their external motor counterparts in that there is no need for a shaft to penetrate the tank, thus eliminating mechanical seals. Another advantage of integrating the pump and motor into a single unit with a common shaft is that coupling and alignment issues are removed. As hydrocarbons are dielectric fluids, electrical cables and the motor itself can be safely surrounded by LNG.

Deepwell pumps had been fitted on *Methane Pioneer* for its historic trial voyages in 1959 but such units proved not to be ideal in LNG service as the temperature differential between the tank and the external atmosphere had a tendency to cause the shaft to bind.

The first shipboard JC Carter SEMPs were installed in one of the three cargo tanks on the experimental 640m³ LNG vessel *Beauvais*, the conversion of which was completed in February 1962. The tests proved to be satisfactory and a shipset of nine JC Carter SEMPs was ordered for both *Methane Princess* and *Methane Progress*. Each cargo tank on the vessels was fitted with a single pump with a capacity of 205 m³/hour. A secondary gas lift pumping system was

fitted on the deck. Mr Carter himself was amongst the distinguished guests present at Canvey Island in October 1964 to welcome the arrival of *Methane Princess* from Algeria with the first commercial LNG cargo.

Early on in the evolution of LNGC design it was decided that two cargo pumps per tank offered the optimum arrangement for timely and efficient cargo discharges. JC Carter was to become the market leader for SEMPs for LNG carriers over the next two decades.

Honeywell was another US supplier of equipment to *Methane Princess* and *Methane Progress*. A Honeywell 320 point data logger was installed in each vessel's main cargo control room for recording temperatures from the cargo tank surfaces, the insulation and the hull structure. The data recorded was transferred to a strip printout sheet for onboard use and a punched tape for computer analysis ashore.

Foster Wheeler provided two of its ESD II main boilers for each of the steam turbine-driven *Methane Princess* and *Methane Progress*. The units were the first to utilise cargo boil-off gas (BOG) on an LNG carrier, and the combustion system was designed to burn fuel oil, methane BOG or a combination of both. Foster



More often than not, modern equipment is simply a scaled-up version of the technologies first proven on the early LNG carriers

Wheeler was responsible for the boiler design and the engineering of the firing equipment, automatic controls and the boiler instrument panel.

The Scottish engineering firm Munro & Miller of Edinburgh was another supplier. Five years earlier the company had provided 150mm and 200mm diameter expansion joints for the cargo piping systems on *Methane Pioneer*. The success of that vessel's trial shipment programme prompted Conch Methane Services to order a total of 190 Munro & Miller expansion joints for *Methane Princess* and *Methane Progress*. The equipment accommodated the thermal expansion and contraction of the vessels' fixed piping systems.

The company's success in the LNGC field continued when it was contracted to supply 555 expansion joints of between 50 and 400mm in diameter for the cargo piping systems on the four 41,000m³ *Esso Brega*-series ships built in Italy and Spain later in the 1960s.

The most common liquid level float gauge on the early LNG carriers was from Whessoe Systems and Controls of Darlington in the north of England. The Whessoe float gauges that had been widely used on pressurised LPG carriers required some changes to component materials to ensure suitability for the new LNG application. LNG carriers must also have in place a secondary means of top level measurement and on the early vessels this was achieved through the provision of a toughened glass sight gauge in the cargo tank dome with a measuring scale visible below inside the tank.

The distinctive shape of the Luceat pilot-operated safety relief valves (SRVs) arranged in pairs on LNG carrier cargo tank domes was first seen on *Jules Verne*. The pioneering French ship was fitted with 14 such SRVs, two per cargo tank and each 6 inches in diameter. The relatively low maximum design pressure employed for fully refrigerated LNG carrier cargo tanks requires accurate and delicate pressure control. With the Luceat valve the tank pressure was determined by a pilot diaphragm with a large surface area to amplify any small variation in the tank pressure. The valve was of rugged construction, the delicate pilot diaphragm being fully integrated into the valve housing head. Most of the early LNG carriers built in Europe were fitted with Luceat pilot-operated SRVs.

French engineering components were encouraged and commonplace on *Jules Verne*. The vessel was fitted



Lifting a cargo pump clear of the tank for servicing

with two 450 m³/hour stainless steel Guinard SEMP's in each of its seven cargo tanks. Having been successfully tested on *Beauvais*, Hibon Pompes Roots blowers were installed on *Jules Verne* to supply boil-off vapour to the boilers and for gas-freeing cargo tanks. Hibon supplied a wide range of Roots blowers to many of the early European-built LNG carriers with the French membrane cargo containment systems.

Another two companies whose names were to become familiar in LNG circles were associated with the construction of the independent, prismatic-shape cargo tanks for the four ships in the *Esso Brega* series. Chicago Bridge & Iron (CB&I) built the four double-walled cargo tanks required for each ship in Italy, using aluminium supplied by Kaiser. Air Liquide contributed a 22,000-litre nitrogen tank for each of the quartet, for purging and inerting the cargo tanks' inner barrier spaces, hold void spaces and cargo compressors.

Two centrifugal compressors manufactured by Paul Airco Cryogenic of California were fitted in a deckhouse room within the cargo area on each of the four *Esso Brega* series ships. Driven by a coupled steam turbine, the compressors were used to deliver cargo BOG to the main boilers. The Airco package for each vessel included two cargo heaters, a control panel and associated equipment. MSA of Pittsburgh supplied a fixed gas detection system in the cargo control room on each of the *Esso* ships.

The breakthrough order for Gaz Transport, when it was contracted to supply its membrane containment

system for the 71,500m³ *Polar Alaska* and *Arctic Tokyo* building at Kockums in Sweden, brought the manufacturers of non-traditional shipbuilding materials into the LNG arena for the first time. The key components of the ships' Gaz Transport system were the invar primary and secondary barrier material and the plywood boxes filled with perlite used as insulation.

The 36 per cent nickel steel alloy invar had been developed in the 1920s by the Imphy Division of Société des Forges et Ateliers du Creusot (SFAC) as a material with a very low coefficient of thermal expansion. The only manufacturer of invar, the Imphy steelworks had to step up production to deliver the required sheets for *Polar Alaska* and *Arctic Tokyo*.

Kockums contracted the Finnish company Kaukas to supply the containment system's perlite-filled plywood boxes. The loose perlite was not the easiest material to handle and protective masks and gloves were needed. The factory workers called this irritating material French snow. Kaukas was to become a key supplier of plywood boxes to Gaztransport and Technigaz (GTT) in later years.

Although LNG carrier construction has now switched from Europe and the US to Asia, many of the original component manufacturers are still supplying their specialist equipment to the sector. While some may be operating under different names, they continue to promote the same proven technologies that have stood the industry in good stead over many years, sometimes as many as 50! **SH**

25

YEARS OF LNG EXPORT

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Today's LPG and ethylene carriers stem from many starting points



Now scrapped, the 30,000m³ *Donau* was the largest semi-ref gas carrier ever built

The genesis of today's LPG and ethylene carriers was peopled by as many pioneers as the LNG carrier sector, and often their paths would intersect to mutual benefit

Because of the simplicity of the design and the range of worldwide trading opportunities, more fully pressurised (FP) LPG carriers have been built than any other type of gas carrier. The FP fleet is engaged in the distribution of liquefied gases to virtually every country with a coastline. FP ships are amongst the smallest of the gas carriers and tend to serve regional trades.

The design parameters for pressurised cargo tanks remain as they were in 1934, when the first riveted types were installed on board the pioneering Shell tanker *Agnita*. Because the tanks are essentially pressure vessels for carrying cargoes under pressure at or near ambient temperature, mild steel is used as the tank material and no tank/piping

insulation or reliquefaction plant is required. Tanks are designed typically based on a minimum cargo temperature of -5°C and maximum design pressures between 17 and 18 barg (1,800 and 1,900 kPa).

Trade routes in the 1950s and 1960s – the real formative years of LPG transport – fell into two categories and influenced ship design. First the oil majors, anxious to make use of the LPG produced by their oil refineries, looked at ways of moving all the products of the refining process to market. This resulted in the development of combined oil/LPG carriers and oil tankers with additional deck pressure vessels for LPG. The second basic ship type was the small dedicated LPG carrier specifically built to supply remote coastal and island communities

with gas for use as a fuel.

A key early ship in the annals of LPG transport history was the 6,050m³ *Natalie O Warren*. This vessel, a former CA-I type cargo ship named *Cape Diamond*, was converted at the Bethlehem Steel yard at Beaumont, Texas in 1947 for Warren Petroleum, a subsidiary of Gulf Oil. *Natalie O Warren* was provided with 68 vertical, cylindrical cargo tanks. Elsewhere in the US in 1947 and 1948 Esso modified its oil tankers *Esso Sao Paulo*, *Esso El Salvador* and *Esso Brazil* by installing pressurised tanks for LPG in part of the oil cargo spaces below the main deck.

A number of European companies also entered into LPG transport by sea in the years immediately after World War II. Norsk Hydro took delivery of the 1,454m³ anhydrous ammonia carrier *Hydro* in 1950. This conversion, by the Marinens shipyard in Norway, had 20 cylindrical cargo tanks and traded between Hydro's plants.

In Denmark the Tholstrup family LPG business had started in 1941 based on the import of LPG from Poland and

Germany using railway tank wagons. In 1951 Tholstrup contracted the Svendborg shipyard to convert the small coaster *Morild* to the 129m³ *Kosangas* by installing a single horizontal cargo tank.

Italy introduced LPG distribution in the Mediterranean. In 1953, to enable the carriage of LPG from the mainland to Sicily and Sardinia, a small coaster was converted to the 540m³ *Flavia Bonfiraro*. A year later another conversion, the 315m³ *Cornelia*, entered service; she was provided with onboard bottle-filling equipment as there was no shore storage.

In 1954 the 817m³ *Cap Carbon*, built by the Dutch shipyard Foxhol and fitted with 14 vertical cylindrical tanks, opened a new trading route from a facility near Marseilles in southern France to Arzew in Algeria.

In 1955 two European oil majors took delivery of their first purpose-built LPG vessels. The French yard La Ciotat built the 1,390m³ *Butagas*, with 36 cylindrical cargo tanks, for Maritime Shell while in Germany the Ottensener yard constructed *Nevigis* and *Langenburg*, a pair of 2,580m³ sisterships, each with nine cargo tanks, for British Petroleum.

The Dutch Bijkers yard made two contributions to the early fleet of LPG carriers with the 2,006m³ *Marion P Billups* in 1956 and the 3,178m³ *Fred H Billups* in 1960. Both ships were for Marine Caribbean Lines, a subsidiary of New York-based Marine Transport Lines, and were fitted with 19 vertical cylindrical tanks.

The conversion of the cargo ship *Haut-Brion* to the 1,012m³ LPG carrier *Loex* by the INMA La Spezia yard in Italy on behalf of Gazocéan in 1958 represented a significant design change in terms of cargo tank orientation. The nine cylindrical pressure vessel cargo tanks on this ship were horizontally mounted.

Japan was in the vanguard in introducing LPG transport to Asia. In 1960 *L P Maru No 1*, with 13 vertical cylindrical tanks, was delivered to Nippon Ekika Gas Yusō by the Harima shipyard in Aioi. This 990m³ ship also had a horizontally mounted tank on the main deck forward which was used to discharge each of the other tanks using two compressors and an electric cargo pump.

The combined oil/LPG carrier *Esso Puerto Rico*, built in 1958 by Cantieri Riuniti dell'Adriatico in Italy, was able to carry 12,788m³ of LPG and was the largest ship ever built with fully pressurised LPG tanks. The ship,

configured with the typical 'three island' oil tanker profile of the time, had a forecastle, a bridge deckhouse over the cargo tanks and a poop. *Esso Puerto Rico* could carry 33,600m³ of oil in the lower wing tanks, while 40 of the ship's 58 pressure vessel tanks were positioned vertically in the centre tanks and 18 horizontally in the upper wing tanks.

How do modern FP LPGCs differ from the pioneering vessels of this type? The main difference is that now two or three horizontally mounted tanks are the preferred arrangement rather than the multiple numbers of vertical tanks. Also tank thicknesses have increased, enabling considerably larger individual tank capacities as a result. Another significant change is that most modern carriers have deepwell pumps to discharge the cargo rather than using compressors and booster pumps.

Looking to the future there is every indication that in coming years there will still remain more fully pressurised LPG carriers in service than any other type of gas carrier due to not only their versatility and simplicity of design but also the nature of market demand.

In terms of cargo-handling characteristics the semi-pressurised/fully refrigerated (semi-ref) LPG carrier is a more technically challenging gas ship to operate than the simple FP LPGC.

From the mid-1950s to the mid-1960s a great deal of research was carried out in Europe on onboard refrigeration in order to enable the carriage of larger volumes of LPG in lighter weight tanks. The experiment that was to lead to the successful refrigeration of LPG carrier cargoes was carried out in France in 1958 when a 40m³ pressurised cargo tank on board the fully pressured 1,390m³ *Butagas*, the first ship to be built at La Ciotat, was specially insulated. Then, through the use of a gas

compressor, the cargo in this tank was cooled. The tank in question was one of 36 vertically mounted, pressurised cylindrical tanks on board the ship.

As a follow-up an order was placed at La Ciotat by Gazocéan for the 920m³ *Descartes*. All the tanks on the ship were modelled on the *Butagas* experimental tank. *Descartes* was to be the first semi-ref LPG carrier.

In the years immediately following the French breakthrough other European shipyards converted or built relatively small LPG carriers with a cargo refrigeration capability, each one experimental in its own way. Tank pressures varied in the range 5–9 barg (600–1,000 kPa) and, depending on the products carried, different minimum design temperatures were specified for these early refrigerated ships, including 0°C, –10°C, –25°C, –30°C and –34°C.

A major decision was made by the classification societies in 1966 when they specified that, subject to strict requirements for the gas-handling and storage arrangements, a semi-pressurised LPG carrier could carry fully refrigerated cargoes without a secondary containment system barrier.

This ruling cleared the way for a busy few years, beginning in 1967 when the first semi-ref LPG carriers were delivered. The tanks on these ships were designed for the carriage of liquefied propane at its atmospheric-pressure boiling point of –48°C.

A considerable change of direction occurred in 1976. The publication of the then IMCO Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk required a rethink on design as ships with large, above-deck tanks could not satisfy the damage stability requirements of the Code. Transversely mounted, below-deck, cylindrical tanks and



The fully pressurised LPGC remains the workhorse of the gas carrier fleet, extending the supply chain into the remotest parts

longitudinally mounted, below-deck, bilobe tanks were two of the solutions used to improve ship stability.

Some noteworthy series designs were completed in Europe. Moss Værft delivered the 12,060m³ *Inge Maersk* to A P Møller in 1972 as the first of nine-ship series. The Jos L Meyer shipyard was rebuilt to enable it to win an order for six 12,000m³ semi-ref LPG carriers from Latvian Shipping. The first, *Yurmala*, was delivered in 1975 and all were fitted with three bilobe cargo tanks. In 1981 the Danish yard of Odense at Lindo completed the 15,070m³ *Sally Maersk* as the first of six semi-ref LPG carriers for its A P Møller parent company.

The first South Korean yard to enter this niche market was Hyundai Heavy Industries (HHI) when its Ulsan yard delivered the 4,415m³ *Greta Kosan* in 1990, one of a pair for Kosan Tankers of Denmark. China took its first step down the semi-ref path in 1996 when the Shanghai Edward yard built the 3,200m³ *Coral Obelia* for Anthony Veder.

“The apple does not fall far from the tree,” is an old adage that springs to mind when considering the small-scale LNG/ethylene/LPG carriers which are currently joining the LNG fleet in increasing numbers. This multi-gas carrier concept was exactly the approach taken in the early 1960s when designers were competing to find the best way to transport LNG by sea safely and economically.

The initial ethylene trade routes were established around the coasts of Europe, Mexico and Japan. In addition to the cargoes carried by a semi-ref LPG carrier, a typical liquefied ethylene gas carrier (LEGC) could also trade with ethane, ethene and ethylene, ensuring the longest cargo list of all the gas carriers.

Ethylene ships have incorporated a grand variety of cargo tank shapes over the years, including spherical,

prismatic and membrane versions and longitudinally and transversely mounted cylindrical and bilobe types. Cargo tank materials compatible with the -104°C boiling point carriage temperature of ethylene have included aluminium alloys and 5, 9 and 36 per cent nickel steels.

In May 1964 *Pythagore*, a 630m³ experimental LNG/ethylene/LPG carrier, was delivered to Gazocéan by Ateliers et Chantiers du Havre in France. The first ethylene carrier built in Japan was the appropriately named *Ethylene Maru No 1*, which was delivered to Ishikawajima Ship and Chemical Company in Tokyo in 1965.

Also in the mid-1960s the Scottish shipowner George Gibson received a contract to ship ethylene for Imperial Chemical Industries (ICI) from Teesside in the UK to Rozenburg, near Rotterdam. This deal resulted in the delivery, in July 1966, of the 833m³ *Teviot* and, later in the same year, the 824m³ *Traquair* from the Burntisland shipyard in Scotland. This pair of fully refrigerated ships each had a single prismatic aluminium-magnesium alloy cargo tank extending in a sloped fashion above the main deck.

In September 1966, on the other side of the North Sea at Bremen, AG Weser delivered the 824m³ *Lincoln Ellsworth* to Oslo shipowner Einar Bakkevig. Like *Teviot*, *Lincoln Ellsworth* was fitted with a single, fully refrigerated cargo tank.

During the 1967-70 period Japanese shipyards flexed their muscles with eight LEGC deliveries. The Sumitomo yards built the experimental 785m³ *Ethylene Daystar* in 1968 and the 1,188m³ *Ethylene Dayspring* in 1969 for Daiichi. Each ship had two aluminium membrane cargo tanks developed by Bridgestone, utilising 3mm thick plate, and the cargo tank area was protected by a double hull.

European shipbuilders introduced more LEGC variations at the start of the 1970s. The Hebburn shipyard of Swan Hunter in the UK delivered the fully refrigerated 3,344m³ *Emiliano Zapata* to Petroleos Mexicanos in 1970. Another Technigaz prototype for Gazocéan, the 4,073m³ LNG/ethylene/LPG carrier *Euclides*, built at Le Havre in 1971, was the first LNG carrier with spherical cargo tanks and the first without a secondary barrier. German shipbuilder Heinrich Brand in Oldenburg delivered the 2,741m³ *Melrose* with aluminium bilobe cargo tanks in 1971. The ship was the first in a series of five LNG/ethylene/LPG carriers for George Gibson and Bernhard Schulte from Brand but none of the quintet ever carried LNG.

Moss Værft in Norway introduced what was to be the first in a long line of successful LEGC designs in 1971, through the delivery of the 4,100m³ *Roald Amundsen* for Einar Bakkevig. To round off 1971, a remarkably varied 12 months for LEGC newbuildings, the Yokohama yard of Mitsubishi delivered the 1,120m³ *Shinryo Ethylene Maru*, a ship with two Technigaz membrane tanks, to Shinwa Chemicals.

In 1972 Italy completed its first ethylene carrier, the 1,100m³ *Capo Verde*. In 1974 Hitachi's Innoshima yard delivered the 1,106m³ *Sankyo Ethylene Maru*, a unique experimental LNG carrier embodying two different cargo tank systems. The forward aluminium spherical tank was based on a Chicago Bridge & Iron design, and the aft 9 per cent nickel steel prismatic tank had a part-Exxon pedigree.

The Spanish built a prototype LNG/ethylene/LPG carrier, the 4,936m³ *Sant Jordi*, to a design by Sener at the Tomas Ruiz de Velasco yard in Bilbao in 1976. Constructed with four spherical, 9 per cent nickel steel cargo tanks, the ship

An early FRLPGC, the 1972-built *Lincolnshire* enjoyed a full 30-year working life



was used in the transport of ethylene and LPG as no employment could be found for it in the LNG trades.

By the mid-1970s the experimenting in LEGC construction had stopped and an ever-increasing number of shipyards, particularly in Germany and Italy, successfully built semi-ref ethylene carriers with independent cargo tanks of similar design. The capacity of these ships has risen steadily, culminating in the 22,000m³ *Navigator Mars* and her four sisters delivered by the Jiangnan yard in China, beginning in the late 1990s.

The series production lines and full orderbooks for fully refrigerated LPG carriers (FRLPGCs) in China, Korea and Japan are in stark contrast to the one-off, pioneering designs of such ships developed in Europe and Japan four to five decades ago.

What progress, in terms of ship design, has been made in the intervening years? All FRLPGC carriers completed in the last 25 years, be they sized at 22,500, 35,000, 60,000, 78,000 or 84,000m³, are built to virtually the same design concept. Looking at a cross-section of a modern FRLPGC in way of the independent prismatic cargo tanks will reveal a double bottom and upper and lower side water ballast tanks. The IMO Type A cargo tank is constructed with low temperature steel suitable for a minimum temperature of -48°C and a maximum pressure of about 0.25 bar (25 kPa). Insulation is fitted externally on the cargo tank.

In order to provide a secondary barrier within the ship's overall cargo containment system, the transverse bulkheads between the cargo tanks, the inner bottom, the side ballast tank boundaries, the side hull and the main deck at centre are constructed with the same low temperature steel as the cargo tank. The cargo tanks are held in place with a system of chocks and supports to prevent movement when the ship is underway.

This basic approach to FRLPGC cargo containment has been around for a long time. The first LPG carrier utilising the side hull as the secondary barrier was the 29,540m³ *Antilla Cape*, built in 1968 at AG Weser yard in Germany.

French engineers had earlier made the breakthrough in refrigeration technology needed to enable the carriage of LPG in ships in a fully refrigerated state. In 1961 the product tanker *Iridina* was converted at the La Ciotat yard and the resultant ship was able to carry up to 10,800m³ of refrigerated butadiene or



In its ability to switch from the carriage of LNG to join Coral Lophelia in the ethylene trades, Coral Methane is one of the latest in a line of multigas vessels

butane at near atmospheric pressure.

The first purpose-built FRLPGC was the 28,837m³ *Bridgestone Maru*, delivered from the Yokohama yard of Mitsubishi Heavy Industries (MHI) in 1962. The shipowner and yard adopted a conservative approach for most aspects of the ship's design.

Cargo tanks with above deck trunks were a distinctive, early feature of European designs. Kockums in Sweden delivered the 25,100m³ *Paul Endacott* in 1964 based on a design by Marine Service GmbH of Hamburg, while Norway's Moss Værft completed its first FRLPG, the 11,070m³ *Havgas*, in 1965. Hawthorn Leslie in the UK delivered the 11,750m³ *Clerk-Maxwell* to Nile Steamship in 1966 and Spanish builders Euskalduna delivered the 11,200m³ *Alexander Hamilton* to A L Burbank in 1968. Also in 1968 the Kiel yard of HDW completed the 18,300m³ *Roland*, another FRLPGC constructed to the trunk deck design.

Elsewhere certain designers were beginning to question whether the trunk deck feature was all that advantageous. The cargo tanks on trunk deck-type LPG carriers, with their many radius tank corners, were difficult to build. In order to cut costs the now 'standard design', with the side hull as the secondary barrier, was introduced and quickly gained in popularity.

French engineers had one or two ideas of their own. The La Ciotat yard decided that surrounding the cargo tanks with loose perlite insulation was a good design feature and delivered the 14,300m³ *Capella*, the first FRLPGC with this type of insulation, to a company affiliated with Gazocéan in 1967.

FRLPGC innovation was also taking place in Japan during the early days of LPG transport. In 1969 Bridgestone

Liquefied Gas co-operated with Kawasaki Heavy Industries in the design and construction of the 72,300m³ *Bridgestone Maru No 5*, the first ship built with the award-winning KASMET semi-membrane cargo tank system.

Six semi-membrane tanks for propane were arranged in pairs over the ship's parallel midbody while ship-shape, integral tanks for butane were arranged forward and aft of the propane tanks. *Bridgestone Maru No 5* had a double bottom and double side hull. The ship's semi-membrane tanks were cube-shaped, with all the edges rounded, and anchored at the top under the cargo dome. Eight FRLPGCs were built with KASMET semi-membrane tanks.

During the 1970s Norwegian, Finnish, French and Polish shipyards constructed 24,000, 52,000 and 75,000m³ FRLPGCs to designs developed by Kvaerner Moss. At about the same time in Japan Mitsubishi and Shell pioneered an internal insulation system. This was installed on three ships built at MHI's Yokohama yard, beginning with the 77,400m³ *Pioneer Louise* in 1976, but the concept did not prove successful.

MHI transferred the construction of FRLPGCs to its Nagasaki yard in the early 1980s. In 1989 the yard delivered *Nichiyuh Maru*, the first ship built to Mitsubishi's standard 78,000m³ V-Series, to Yuyo Steamship.

Over the past 45 years fully refrigerated LPG carriers have been built at a myriad of shipyards in Europe and Asia. Today, however, such vessels are only built in Asia at eight yards - two in Japan (MHI and KSC), two in Korea (HHI and DSME), three in China (Jiangsu, China Shipbuilding and Jiangnan) and one in the Philippines (Hanjin). *SH*



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US shale revolution sweeps up LPG carrier fleet

The surging output of US shale oil and gas is proving to be a game changer for not only LNG ships but also all types and sizes of LPG and chemical gas carriers

Shipowners poised to benefit from the US shale gas revolution are not limited to those in the LNG sector. Because shale gas, and shale oil, are rich in natural gas liquids (NGLs) and because the volumes being produced are rising rapidly, US exports of the principal NGL fractions propane and ethane are set to climb.

These products are also providing US petrochemical manufacturers with cheap feedstocks and boosting their competitiveness in the world marketplace. There are currently 11 major projects underway in the US to either expand existing chemical plants or build new ones to run on ethane feedstock. These developments, in turn, will support resurgent US chemical exports, including of chemical gases such as ethylene.

As a result, the US shale boom is going to reverberate throughout all the gas shipping sectors, not just LNG. In fact LPG carriers are already accruing benefits. Whereas the first US exports of LNG derived from shale gas are not due to begin flowing until late 2015, LPG loadings for overseas customers are already on the rise.

After a decade in which LPG imports

outweighed exports, the US became a net exporter of LPG once again in 2011 and seaborne shipments are forecast to grow strongly in the years ahead. The US exported 9 million tonnes (mt) of LPG in 2013, about 75 per cent ahead of the level recorded in 2011.

Propane accounts for 90 per cent of this traffic and butane 10 per cent. With propane in Houston now costing about 60 per cent of that in Japan and the US market for propane currently oversupplied, it is not difficult to appreciate the overseas interest in US product. US exports are driving the demand for new very large gas carriers (VLGCs) and supporting the healthy freight rates commanded by the ships in the existing fleet.

Falling in the 75-85,000m³ size range, VLGCs are the largest LPG carriers afloat and the gas shipping industry's workhorses when it comes to transporting large volumes of propane and butane over long distances. The 156-vessel VLGC fleet transports LPG as fully refrigerated cargoes. The current VLGC orderbook stands at a massive 82 such vessels.

Approximately 90 per cent of the US LPG export cargoes are shipped from

Gulf Coast terminals. Existing Gulf LPG terminals are being expanded and new facilities are under construction to cope with the growing export volumes. The terminal expansion projects will help US LPG exports reach an estimated 13.5mt in 2014 and rise to a possible 21mt in 2017.

At the moment, most of the US exports are shipped to customers in Latin America and Europe. However, given the relatively low price of US LPG and rising local demand, it is hardly surprising that Asian buyers are becoming increasingly interested in the VLGC cargoes loading on the Gulf Coast.

The opening of the enlarged Panama Canal in 2015 will help trim the shipping costs associated with these long-distance deliveries. In terms of Panama Canal transits VLGCs are currently a borderline case. Only the smallest ships in the class, or about 20 per cent of the fleet, are able to utilise the Canal as it stands. The enlarged waterway will be able to accommodate the entire VLGC fleet.

Chinese plastics producers are lining up to become major buyers of US LPG. There is a major shortage of

propylene in China due to the growing demand for its use in the manufacture of high-quality plastics for consumer goods. The construction of propylene dehydrogenation (PDH) plants in China that will use US propane as feedstock has been identified as the optimum solution. Chinese firms have plans for nine such plants and it is estimated that the country will need 6 mta of propane feedstock from US suppliers by 2017. When all the plants are completed in 2016, China will account for 40 per cent of global PDH capacity.

Although the Middle East region remains the leading exporter of LPG by a considerable margin, increasing volumes of its gas output are being used as feedstock for its own expanding petrochemical production. The timely rise in US LPG exports is helping to compensate for declining Middle East shipments and to offset any potential market disruption. It is also generating more tonne-miles in delivering cargoes to customers, thus keeping VLGCs busy and shipowners happy.

Healthy VLGC freight earnings are expected to be sustained for the next two years, at the very least, due to close alignment between the newbuilding delivery schedule and the steady rise in the industry's tonne-mile demand. Assuming an average vessel lifespan of 28 years, there will also be a number of older vessels taken out of service for recycling over the next three years.

Another type of gas carrier fleet for which demand is expected to remain strong is the semi-pressurised/fully refrigerated (semi-ref) gas ship. Their high technical specification provides them with the ability to carry a wide range of cargoes and to switch between grades according to market fluctuations.

Until recently, those semi-ref ships able to carry ethylene at its boiling point of -104°C represented the apogee of what was possible with semi-ref vessels. There are approximately 140 such gas carriers in service. In recent years, however, 'multigas' ships able to carry LNG as well as ethylene and LPG have been introduced. The flexibility of their cargo-handling systems enables them to move between coastal LNG distribution and international ethylene trading duties according to market demand.

The future of the multigas ships appears assured, due not least to the current expansion of the global LNG industry and, in tandem, the small-scale end of the LNG supply chain. The regional distribution of LNG is poised



The Enterprise LPG export terminal in Houston has just completed one expansion project and is embarking on another

for rapid growth in the years ahead. One key driver is the increasing use of LNG as marine fuel and the need to supply local bunkering stations. Another is the desire of customers in remote locations to replace their expensive oil fuels with more competitively priced, clean-burning natural gas.

LPG carriers that fall in the 12,000-23,000m³ size range are identified as the handysize fleet. There are currently 135 such vessels in service and 35 on order. Although this fleet does include some fully refrigerated ships, the vast majority are semi-ref vessels. Furthermore most of the handysize gas carriers in the semi-ref segment are ethylene-capable. Some of the newbuildings will be dedicated to the carriage of ethane itself. Ethane carriers are the focus of the following article in this publication.

Ethylene is a basic petrochemical building block and the volume transported by sea represents only 5 per cent of global production. It is nevertheless an important cargo for gas carriers and even a small rise in ethylene output worldwide, as is happening on a continuous basis at the moment, can have a significant impact on the demand for semi-ref ships.

Another factor affecting the requirement for longhaul ethylene shipments is regional production imbalances. As an example, until recently China produced only 50 per cent of its ethylene requirement domestically. Although the construction of new chemical plants is helping the

country become more self-sufficient, China's buoyant economy continues to grow at such a rate that it is likely to remain a significant importer of ethylene for some time.

The small-ship segment of the LPG carrier fleet comprises 350 fully pressurised ships and 220 semi-ref vessels. Small gas ships have not enjoyed such a buoyant freight market as VLGCs and handysize ethylene carriers in recent years, due primarily to the effects of the global economic recession, but the trades have still been lucrative. The relatively restrained orderbook of only 30 small gas carriers also bodes well for a continuation of the good balance between ship supply and demand.

The small-ship segment also expects strengthening demand for its vessels in the years ahead due to the trickle-down effects of the US shale gas boom. A significant percentage of the new shipments of LPG and chemical gases moving in larger vessels on international routes will require onward distribution to local and regional customers when they arrive at their main discharge port.

Today investments in LPG carriers of all types make more sense than they have done for many years. Bold ship and terminal newbuilding decisions are being encouraged by healthy revenue streams, strong demand and the promise of rising freight volumes for several years to come. Supporting all these developments is the bandwagon that is the US shale revolution. **MC**



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Enter the ethane gas carrier

Ethane carriers are a new type of gas ship, configured to deliver the burgeoning output of this US shale byproduct to meet the feedstock needs of chemical producers worldwide

The scene is set for the emergence of ethane as a notable liquefied gas carrier cargo on deepsea routes.

The product is a key component of the natural gas liquids (NGLs) in which the new US shale oil and gas volumes coming onto the market are rich. It is also a major petrochemical industry feedstock offering many advantages over the alternatives.

As a reflection of this new dawn for a liquefied gas that has figured only marginally in the annals of gas shipping to date, orders have been placed for several comparatively large ethane carriers in recent months. The contracts are backed by long-term charters with European chemical manufacturers seeking to gain advantage from imports of competitively priced US ethane feedstock.

Ethane is at the 'light' end of the NGL mix and the most prolific of its five components. The other constituents are propane, normal butane, isobutane and natural gasoline. In most NGL flows ethane accounts for almost 50 per cent of the total volume. Gas fractionators are used to process NGLs

into their pure, component parts.

Ethane has traditionally not traded in global markets and is used primarily in facilities adjacent to where it is processed. This is because it is relatively difficult to liquefy and transport in bulk. Ethane has a vapour pressure of 3.85 MPa at 21.1°C and a boiling point of -88.5°C. It has a specific gravity of 0.54, as opposed to 0.45 for LNG. These properties mean that ethane must be either refrigerated to a very low temperature, compressed to a high pressure or have both temperature and pressure controlled to keep it in a liquid state and enable its transport by sea in bulk.

In gas carrier terms ethane can be carried fully refrigerated in liquefied ethylene gas carriers (LEGCs), because ethylene has a boiling point of -104°C, or at -45°C and a pressure of 5 bar (500 kPa). Some ethane, processed from North Sea gas, is moved around locally in the North and Baltic Seas region in small semi-pressurised/fully refrigerated (semi-ref) gas carriers provided with extra compressor power.

The biggest production centre is at Kårstø in Norway, where some 900,000 tonnes per annum of ethane are separated out from the North Sea dry gas arriving at the terminal by pipeline. Aside from these European shipments, which have been underway for a couple of decades, the movement of ethane has been limited to transmission through pipelines in gaseous form.

The new ethane carriers that have been ordered recently are being built with US ethane exports in mind. The newbuilds comprise a series of six 27,500m³ vessels and four of 35,000m³. These new ethane carriers are being built as semi-ref vessels with IMO Type C, bilobe, pressure vessel cargo tanks. All are bigger than the largest LEGC yet built.

The 27,500m³ ships are under construction at the Sinopacific Offshore & Engineering (SOE) yard in China for Copenhagen-based Evergas. Termed the Dragon series by the shipowner, they will also be able to transport LNG, LPG and petrochemical gases, including

In 2000-01 Jiangnan delivered to Navigator Gas a series of 22,000m³ ethylene carriers that remain the world's largest vessels of this type



ethylene, and are being provided with Wärtsilä cargo-handling and dual-fuel propulsion systems.

The propulsion system on each ship comprises two Wärtsilä 50DF dual-fuel main engines, two Wärtsilä 20DF auxiliary gensets, a gearbox and a controllable pitch propeller. The cargo-handling package features a reliquefaction plant for ethane and LPG cargoes and an integrated LNG fuel supply system. The ships are reported to be priced at US\$64 million each.

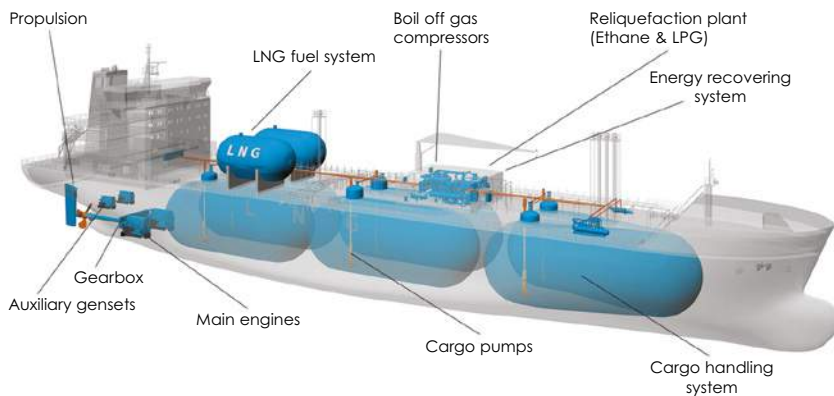
All six Evergas ships have been taken on 15-year charters by the chemical major Ineos for the transport of US ethane to Europe for use as feedstock. Most of the cargoes will be loaded at Marcus Hook in Pennsylvania and carried across the Atlantic to the gas company's ethylene crackers in Rafnes, Norway and Grangemeouth, Scotland.

The Marcus Hook ethane will be processed from the huge Marcellus shale gas play in the northeastern US. The new Marcus Hook loading terminal near Philadelphia will be operated by Sunoco Logistics. Ineos has also secured capacity at the ethane export facility that Enterprise Products plans to build on the Texas Gulf Coast to capitalise on that region's important shale gas deposits. Due for completion in mid-2016, this will be a large facility capable of producing 240,000 barrels per day of ethane. That is more than enough feedstock to run two worldscale ethylene crackers.

The Evergas sextet, which are due for delivery in 2015, represent the final component in what Ineos calls Mariner East, the first-ever US ethane export project. New ethane receiving terminals are being built at Rafnes and Grangemouth, for completion in mid-2015 and 2016, respectively.

Ordered by Navigator Gas at the Jiangnan yard in China, the four 35,000m³ vessels are designed as ethane/ethylene/LPG carriers and each will be powered by a low-speed MAN ME-GI dual-fuel engine. Each ship is priced at US\$78.4 million and the first in the series is due for delivery in April 2016. TGE Marine Gas Engineering has been contracted to design and supply the cargo handling and high-pressure fuel gas systems, including the cargo and LNG fuel tanks.

Each vessel will have three bilobe tanks, the two largest of which will have capacities in excess of 12,000m³. TGE



All the ethane carriers on order will have dual-fuel propulsion systems while the Evergas ships will also be able to lift LNG cargoes

Marine points out that the Navigator Gas ships will be the world's largest Type C tank-based gas carriers and that it is developing conceptual designs for even larger ethane carriers.

In August 2014 Navigator Gas signed a 10-year charter for the first of its 35,000m³ vessels with the chemical company Borealis. Under the agreement, which is scheduled to commence in late 2016, the ship will transport ethane from the Marcus Hook terminal to Borealis' cracker at Stenungsund in Sweden.

Another attraction of exports from Marcus Hook is the fact that there is no sizeable petrochemical industry in the northeastern US able to absorb the volumes of ethane that Marcellus is starting to produce. Transatlantic shipments will assist in revitalising parts of Europe's ageing petrochemical industry. It is estimated that, even including shipping costs, the Marcellus ethane arriving in Europe will be 50 per cent cheaper than local product processed from North Sea gas.

Interestingly, all the new deep-sea ethane carriers contracted to date have been specified with dual-fuel propulsion systems that include an LNG-burning capability. Shale gas production in the US is spurring the construction of numerous natural gas liquefaction plants while the LNG bunkering concept is spreading in Europe. It appears likely that there will be adequate sources of LNG bunker fuel for the ships serving on transatlantic routes.

Another option is to use boil-off gas from ethane cargoes as a propulsion system fuel. MAN is developing its ME-GI dual-fuel engine range to run on a variety of fuels, and ethane is one under consideration. Ethane would require the introduction

of the gas to an ME-GI engine at an even higher pressure than is the case with methane, so the current LNG engine would have to be modified with respect to fuel valves, control block, piping and material.

For the future the industry is considering ethane carriers larger than those ordered to date, most notably fully refrigerated very large ethane carriers (VLECs) of up to 90,000m³ in capacity. Class societies have been investigating designs for such vessels, including suitable containment systems. All the LNG systems, or variations thereof, are deemed to be viable. Due to the nature of the cargo a VLEC will have to be a much more robust and sophisticated vessel than an LPG-carrying very large gas carrier (VLGC) of similar size.

Compared to the recently ordered ships, VLECs will realise further transport economy-of-scale benefits, especially on long-haul routes to India and to China via a widened Panama Canal. However, appropriate infrastructure would need to be in place at each end of the supply chain.

Reliance Industries is an Indian chemical producer interested in the benefits that VLECs and imports of US ethane might realise for their operations and recently ordered six 84,000m³ membrane tank VLECs at Samsung in Korea. The ethane will be used as feedstock at the new ethylene cracker it is building at its Jamnagar refining and petrochemical complex on the northwestern coast of India.

Ethane holds the potential to develop further as a deepsea gas carrier cargo in the years ahead as shale oil and gas plays in other parts of the world are developed. However, for the moment, all eyes are on the US and the ethane carrier newbuildings that will take to the seas over the next two years. **MC**



Douglas on the Isle of Man was the venue for a SIGTTO board meeting in June 2012

SIGTTO – the face of the LNG shipping and terminal industry

SIGTTO's impartiality, integrity and commitment are cornerstones underpinning the exemplary safety record established by LNG carrier and terminal operators

There was no body dedicated to liquefied gas during the formative years of the industry. Although the International Group of LNG Importers (GIIGNL) was established in 1971, this still left a gap, most notably as regards gas carriers and their interface with terminals.

During the 1977–78 period a number of operators of LNG vessels in mutual correspondence had expressed interest in the establishment of some form of association in which LNG carrier operators internationally could assist each other in tackling safety and reliability issues and maintaining high operational standards across their expanding industry.

Stemming from this interest a series of meetings was convened in order to discuss the need for and possible formation of such an association. The first meeting took place at the Princess Hotel in Hamilton, Bermuda on 11–12 December 1978. The meeting had been called at the request of El Paso LNG

Company following suggestions made by Compagnie Nationale Algérienne de Navigation (CNAN) and others that such an organisation could prove useful. At the time, the intention was to call the new group the Society for International Methane Tanker Operators (SIMTO).

Although the initial interest was centred on LNG carrier operations, these meetings included representatives from across the liquefied gas transportation field. It was quickly recognised that any such association would be the more valuable if it encompassed all forms of liquefied gas carrier operations (LPG and chemical gases as well as LNG) and if it also included the operation of terminals loading or receiving these cargoes.

In recognising this it was appreciated that safety and reliability issues were broadly similar throughout the various forms of liquefied gas marine transportation. Also, there would be great value in providing a channel of direct liaison

between ship and terminal operators in the matters of safety and reliability at the ship/shore interface.

It was understood that in developing and maintaining appropriate safety standards and in gaining public acceptance of these standards, the various components of the industry – LNG and LPG ships and terminals – were mutually supportive. The Society of International Gas Tanker and Terminal Operators (SIGTTO) was therefore decided upon as the most appropriate name for the new industry body.

In these formative discussions the participants had the very ready help of senior executives from the International Chamber of Shipping (ICS) and the Oil Companies International Marine Forum (OCIMF). Both bodies had already included consideration of the liquefied gas shipping industry within their activities and both already had consultative status with IMCO (now IMO).

A most pertinent question clearly was whether the perceived

aims and activities of the proposed new organisation could not be more appropriately achieved by ICS and OCIMF, either singly or in combination. It was concluded, however, that an association dedicated exclusively to the liquefied gas marine transportation industry and providing under one umbrella a comprehensive forum for operators both on ship and shore would be the most appropriate means of achieving the desired objectives.

As a result of these formative meetings, the Society of International Gas Tankers and Terminal Operators Ltd came into existence as a Bermuda-exempted company with limited liability and with availability of membership and shareholding in the company to those owning or operating a liquefied gas carrier or a liquefied gas marine terminal. The first board meeting was held in Bermuda on 5 October 1979. The founder members were:

- El Paso LNG Company
- Energy Transportation Corp
- Malaysian International Shipping Corp
- BP Tanker Company Ltd
- Moore, McCormack Bulk Transport Ltd
- P&O Bulk Shipping Ltd
- Gotaas Larsen Inc
- Marine Transport Lines
- Exxon.

A further board meeting with more members present was held in Houston

on 12 November 1979. At this board meeting Maurice Holdsworth was appointed as the first general manager of the Society and Barry Hunsaker of El Paso Natural Gas as the founding president. At this time there were 52 LNG carriers in service.

The first technical advisor was Dick Oldham, who joined SIGTTO in July 1980. He recalls his appointment well: "Maurice Holdsworth and the nine founder members had set up in an office near Marble Arch in London. I had been a newbuilding superintendent, having been involved with the G-class LNG carriers and the two I-class LPG carriers for Shell, and was used to being fairly autonomous. The attraction of joining an unknown and embryonic SIGTTO was pretty small. However, Maurice persuaded me and I became SIGTTO's first technical adviser in July 1980. The offices in Staple Hall were much better than Marble Arch and my job was made much easier as a result of the support given by our excellent members."

The first technical issues the society dealt with were as follows:

- Contingency planning
- Ship/shore linked emergency shutdown
- Safe havens
- Cargo strainers
- Training.

It is interesting to note that the SIGTTO General Purposes Committee in 2014 is still discussing most of the above to some degree or another!

SIGTTO GENERAL MANAGERS

Oct 1979 – May 1985	Maurice Holdsworth (Shell)
May 1985 – Jun 1991	Robin Gray (British Shipbuilders)
Jun 1991 – Jul 1995	Bruce Keer (BP)
Jul 1995 – Jul 1998	Alain Vaudolon (Petronas Tankers)
Jul 1998 – Feb 2003	John Gyles (Shell)
Feb 2003 – May 2007	James MacHardy (BP)
May 2007 – Nov 2012	William Wayne (Shell)
Nov 2012 – present	Andrew Clifton (BP)

By the end of the first year the membership had grown to 30 companies, including several terminal operators. One of the immediate priorities was to achieve consultative status at IMO. This was achieved in 1982 when the membership had grown to 50 companies. By this time the Society had an active GPC and a well-established Panel Meeting programme.

In the following years SIGTTO steadily grew in membership and progressed to a point where it was acknowledged as the authoritative voice of the liquefied gas shipping and terminals industries. This position rests on the reputation that the Society quickly established for its impartiality and integrity in addressing operational and safety issues. A number of publications were



A recent gathering of SIGTTO general managers and technical advisers, past and present

released to the industry as a result of issues addressed by the GPC and working groups.

Robin Gray became the second SIGTTO general manager in May 1985, by which time the Society had over 60 members. Bruce Kier became general manager in June 1991 and in April 1993 the Society moved into its present offices at St Helen's Place in London. The next day the infamous Bishopsgate car bomb explosion occurred nearby. It was a Saturday morning and, although no one from the Secretariat was in the office at the time, the damage to the immediate area was substantial. Access to the office was not permitted for several weeks afterwards.

In 1994 membership passed the 100 mark. Alain Vaudolon served as general manager from July 1995 to July 1998, when John Gyles succeeded him. That year the number of LNG ships in service had just passed 100. By the time James MacHardy was appointed general manager in February 2003 the industry was entering a phase of rapid expansion. Many new players were entering the marketplace and new projects, terminals and ships were being commissioned.

The seventh general manager, Bill Wayne, was appointed in May 2007 and he led the Society through

a period of great change in the liquefied gas shipping and terminals industry. Floating liquefaction and regasification vessels were being ordered and put into service while ship size and numbers were increasing and new technologies, including innovative propulsion systems, were being introduced.

In a major project SIGTTO facilitated the revision of *The International Code for the Construction and Equipment of Ships Carrying Liquefied gases in Bulk (IGC Code)* on behalf of IMO. In 2008 the Society formed nine working groups under the auspices of a steering group to undertake this work. Carried out over a two-year period, the revision of the document involved nearly 140 experts representing over 40 entities and 20 countries.

SIGTTO ensured that the draft revised IGC Code was delivered to IMO according to the agreed timetable. The draft was approved at the 92nd Session of IMO's Maritime Safety Committee (MSC 92) in June 2013 and it was adopted at MSC 93 in May 2014. The revised IGC Code will come into force in 2016.

In November 2012 Andrew Clifton, the present general manager, took over the reins, becoming SIGTTO's first general manager who was formerly a technical advisor. In 2013 SIGTTO established the Society for Gas as a Marine Fuel (SGMF) as a separate industry body to oversee the use of LNG as a marine fuel.

SIGTTO's General Purposes Committee and its Secretariat provide the vehicle through which the knowledge and information gathering within the organisation can best be promulgated to the members and

the regulatory bodies that influence the industry. SIGTTO has published over 50 books, recommendations and guidelines. On average, two such documents per year have been produced or updated.

The Society is as strong now as it has ever been. The membership controls around 97 per cent of the world's LNG vessels and terminals and encompasses around one-half of the LPG market. SIGTTO now has more members than ever before and remains the industry leader for best practice and technical support for liquefied gas shipping and terminals.

In 50 years of commercial shipping operation LNG carriers have carried over 77,000 cargoes. During this period there has been no loss of cargo tank containment and no onboard fatalities directly attributable to the cargo. This is a very impressive, in fact unprecedented, safety record for the carriage of liquid hydrocarbons in bulk by sea. SIGTTO has played a key part in achieving this safety record.

The philosophy of the Society is best described in the words of its founding president, Barry Hunsaker of El Paso Natural Gas, some 35 years ago: "We will best achieve our goals by sharing with each other our non-proprietary technical and safety information and operating experiences through open and frank discussion. Only in this way will each of us benefit from the experience and knowledge gained by all of us and thus maximise the safety of our operations. Remember, the industry will be judged by the record of its least safe operator. Let's help ourselves by helping that operator." **AC**

SIGTTO TECHNICAL ADVISERS (BY DATE APPOINTED)

Jul 1980	Dick Oldham
1984	Robin Buncombe (Shell)
Sep 1986	Roy Izatt (Shell)
Sep 1988	Doug Brown (BP)
Sep 1991	Richard Chadburn (Shell)
Jul 1993	Ken Spowles (Shell)
Jun 1994	John Cummings (Shell)
Jan 1997	Roger Roue (directly employed by SIGTTO)
Dec 1997	Marc Hopkins (BP)
Dec 2000	Gary Dockerty (Shell)
Apr 2002	Chris Snape (Shell)
Apr 2003	Andrew Clifton (Golar)
Dec 2005	Paul Steele (BP)
Dec 2007	Andy Murray (Chevron)
Sep 2008	Teo Popa (Golar)
Dec 2010	Craig Jackson (Teekay)
Jan 2011	Cherian Oommen (Maersk)
Nov 2012	Rick Boudiette (Chevron)
Jul 2014	Thierry Descamps (ConocoPhillips)



SIGTTO's second Asia Pacific Regional Forum, in Shanghai in February 2006

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Pictured at right:
Methane Pioneer at Lake Charles, Louisiana
Above:
Methane Kari Elin at Elba Island, Georgia



Rich history of cooperation amongst LNG importers

In this year of industry anniversaries the venerable International Group of LNG Importers (GIIGNL) can lay claim to being 43 years of age

As this SIGTTO/GIIGNL commemorative publication highlights, the LNG industry was launched in the 1960s when several export projects were developed, namely in Algeria, Libya and Alaska.

By the end of the decade Japan had received its first shipments and embarked down a path that would soon establish the country as the world's No 1 LNG importer. In the Atlantic Basin the US made preparations to receive Algerian volumes while Italy and Spain pushed ahead with plans to join France and the UK as European LNG importers.

The technologies needed to create a safe and effective LNG supply chain were novel and complex for the time. The industry was opening up new realms of engineering as it introduced natural gas liquefaction, LNG storage and LNG regasification on a large scale, as well as LNG carrier containment systems and concepts such as cold recovery.

LNG importers faced formidable technical and economic challenges when purchasing, shipping and handling LNG in the volumes required to justify the commercial viability of the project and to satisfy the needs of their customers. All these activities needed to be developed and implemented in the context of their respective national energy policies and regulatory frameworks.

A few companies, including Gaz de France, took the initiative to try to bring together from across the globe the top executives of those gas companies involved in LNG imports and facing common challenges. The idea of creating an industry association of LNG importing companies received very favourable feedback from the interests concerned.

Thus were laid the foundations of a new association consisting of 19 founding members. The International Group of Liquefied Natural Gas Importers (GIIGNL) was born just as the nascent LNG industry was taking its first tentative steps.

The association had, at least in its early stages, the character of a club without a rigid legal structure and statutory framework. The members exchanged information and developed studies covering the scientific, technical and economic aspects of issues such as purchasing, processing, transportation, storage, handling, regasification and the various uses of natural gas.

GIIGNL's work was undertaken with the aims of promoting the development of the industry and pursuing objectives of common interest, including the development of safety and industry best practice guidelines. Delegates from the US member companies in particular, anxious not to breach any anti-trust laws, appreciated the association's set-up and working methods.

The first meeting of the Group was held in Paris in December 1971 under the leadership of Gaz de France. Mr Le Guellec, honorary president of Gaz de France, accepted the presidency of GIIGNL while Hiroshi Anzai of Tokyo Gas and Howard Boyd of El Paso were appointed vice-presidents.

The association functioned well throughout the 1970s and 1980s. In tandem with the relatively slow expansion of the global LNG industry in those formative years, GIIGNL's membership grew only slowly and did not rise above 25. The resignations of some US members whose projects had

been discontinued were offset by new members joining from Asia.

On the occasion of this SIGTTO/GIIGNL commemorative publication, we had the opportunity to interview Robert Venet, GIIGNL director from April 1981 to April 1989, a key period in the association's history.

Q: Mr Venet, what was the state of the LNG industry in the 1980s and what were the interests of the world's major LNG importers at that time?

Robert Venet: "The late 1970s were a very turbulent period for the LNG industry because many of the leading buyers of gas, especially in the US, had become rather disillusioned by the high prices being demanded by the Algerian LNG producers.

"In Europe some new players, like the Italian companies, wanted to enter the LNG scene by acquiring some supplies. However, eventually most opted instead for cheaper pipeline supplies, especially from Russia.

"The LNG boom happened in Asia, and specifically in Japan, when supplies from Indonesia began to flow."

Q: Can you describe the function of GIIGNL at that time? What were the organisation's activities?

Robert Venet: "The International Group of LNG Importers was essentially an association which offered a meeting place for the top executives of our LNG importing member companies. At that time Howard Boyd, who was a leading personality in the US gas industry and had chaired El Paso, was GIIGNL president, while Pierre Alby from Gaz de France, Denis Rooke from British Gas and Hiroshi Anzai from Tokyo Gas were vice-presidents. All were distinguished captains of the gas industry in the 1980s and chief executives of leading gas companies.

"The activities of the association were mainly centred on two annual meetings. These gatherings allowed member representatives to meet, exchange views

Everett, a long-time member of GIIGNL and the first US import terminal, opened for business in November 1971, the month before the Group's first meeting





GIIGNL General Assembly in the Indian port of Kochi in 2010

and commission joint studies on topics of specific interest. These projects were carried out by the members themselves, of which one would act as coordinator.

“I remember one particular groundbreaking study on the certification of LNG carriers. Indeed at the time, the rules governing the design and construction of such vessels were in their infancy and work to establish an appropriate regulatory regime was being coordinated by the International Maritime Organization (IMO). GIIGNL, through the experience and expertise of its members, was able to provide valuable input to the investigations that underpin the regulations which were made mandatory for new ships in 1986.

“The study topics selected covered a very wide range of technical, operational, regulatory and commercial issues. It goes without saying that those sensitive commercial issues which might have impinged on competition law were strictly off-limits.”

Q: How was the association organised and managed?

Robert Venet: “GIIGNL worked on the basis of rules which had been laid down by the founding members at the First General Assembly in Paris in 1971 (these rules have since been transformed into statutes, the current version being updated in 2008). Day-to-day functioning of the association was managed by a permanent chief officer or general delegate in consultation with and under the guidance of the Group’s president.

“The statutes require that at least two meetings a year are held. These are a General Assembly of all members, in which all decisions of statutory importance are taken and plenary discussions are held, and an Executive Committee meeting attended by a selection of member companies representing the three regions in which the industry operates, namely Europe, the Americas and Asia. The Executive Committee receives an update on the activities of the association and prepares proposals to be voted on by the AGM.”

Q: Who conducted these meetings? ... and how did they evolve?

Robert Venet: “Many Japanese companies were represented at these meetings. When I joined the association in 1981, there were 13 Japanese companies among our 23 members. There were no other Asian members; the remainder comprised five European and five of the original eight American founding members.

“During the meetings the discussions were simultaneously translated into three languages – English, French and Japanese. Mitsubishi, with its very effective interpretation services, was in charge of the Japanese language translations.

“Gaz de France, British Gas and Tokyo Gas had assumed clear leadership roles in the meetings and the organisation in general. The first non-Japanese Asian members were Korea Gas in 1985 and CPC, headquartered in Taipei, in 1989.”

Q: Do you have any particular memories of your time at GIIGNL that stand out?

Robert Venet: “Given the level of participants at our meetings, not surprisingly the events did not lack in style. I remember the 1983 Steering Committee at Artigny country house in France. Steeped in history, this is a castle that Renaissance writer Rabelais used to visit. At our meeting Hiroshi Anzai was knighted as a member of the Confrérie des Tastevins, a brotherhood whose purpose is the development of burgundy wines.

“On another occasion, at the 1985 Steering Committee at Woodstock in the UK, Denis Rooke (by then Sir Denis) proposed to the delegates that we attend a parade of the guards at Blenheim Palace ... in the pouring rain. Sir Denis spoke perfect English but with such a pure Oxford accent that our French and Japanese interpreters had difficulty in understanding him. Away from the formal meeting proceedings, however, Sir Denis spoke much more ‘plainly’, with acid comments about, for example, the privatisation plans that UK prime minister Margaret Thatcher had for British Gas.

“While the American delegates

may have been somewhat more ‘conventional’ in their conversation, they were no less noticeable. At the Florence General Assembly in 1981, for example, several of the wealthier US companies had chartered a private Boeing 727 for their presidents to make the transatlantic flight.

“These same US delegates were somewhat amazed when, at the end of a meeting in Sapporo in 1984, our Japanese hosts proposed a lake excursion in a very American style Mississippi paddle boat steamer.

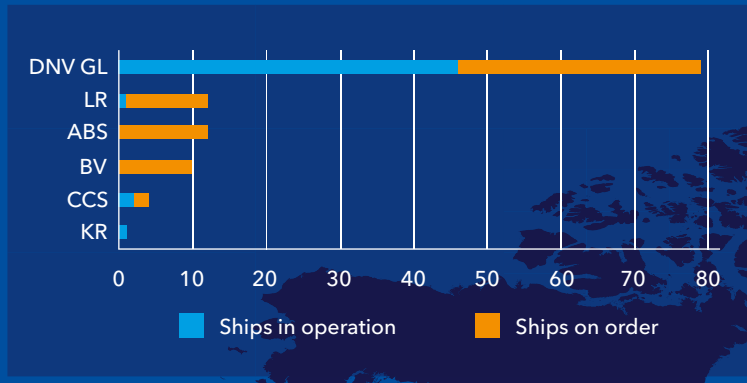
“These meetings were not always free of mishaps. During our 1989 Montreux Steering Committee in Switzerland the host company representative given responsibility for organising the closing dinner, no doubt in an effort to limit costs and impress his superiors, invited the delegates to an inn whose culinary standard could only be described as “average”. The chosen meal – a greasy raclette, which is melted cheese served with boiled potatoes and cold meats – was particularly average. The raclette did not agree with everyone’s digestive system, and the president of the host company did his best to put on a bright face and salvage the evening. All the while he was gritting his teeth and casting his eyes out over the congregation, looking for his minion who had booked the inn.”

Over the past 20 years GIIGNL’s membership has grown strongly. Today the Group has 74 member companies in 24 countries worldwide. The membership comprises nearly all the companies active in the import of LNG or in the operation of LNG import terminals. By region, 32 of the members are from Asia, 32 from Europe and 10 from the Americas, including North and Latin America.

It is a non-profit organisation and its resources only come from the membership fees. The association constitutes a forum for the exchange of experience among its members, with the goal of enhancing the safety, reliability and efficiency of LNG import activities. **J-YR**

2014 STATUS FOR LNG AS SHIP FUEL

DNV GL takes LNG ship fuel global



2013
Port of Antwerp contracts DNV GL to develop bunkering procedures, to ensure safe and efficient bunkering of LNG.



2011
Bit Viking is the first vessel to be converted to LNG fuel.



2018
Matson's 2 LNG fuelled container vessel will enter into operation.



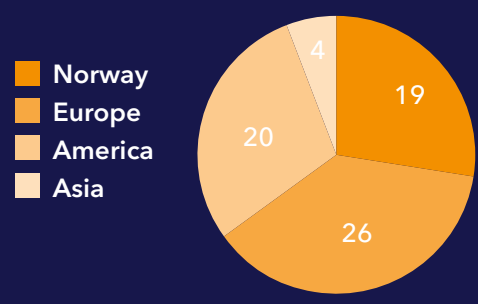
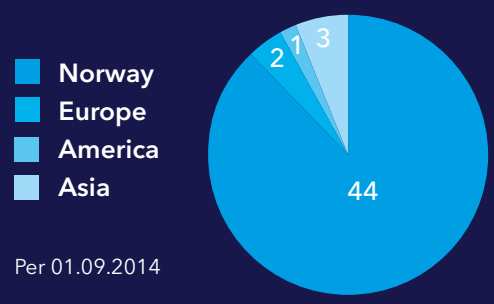
2017
Crowley's 2 ConRo vessels will join TOTE's container vessels on the U.S. - Puerto Rico trade.



2013
López Mena is the first LNG fuelled vessel deployed outside Norway, and set a world speed record with 58 knots.

50 LNG fuelled ships in operation

69 LNG fuelled ships on order



Per 01.09.2014



Important events

2000
The first LNG fuelled ship Glutra enters into operation.

2001
DNV publishes the first rules for gas fuelled ships.

2010
IMO Interim Guidelines for gas fuelled ships is developed based on DNV rules. Enabler for design and operation of LNG fuelled ships worldwide.

2011
DNV recognises the need for a standard for LNG bunkering and initiates an ISO working group. ISO TC 67 - Guidelines for systems and installations for supply of LNG as fuel to ships is finalized in 2014.

DNV·GL

www.dnvgl.com



2013
The world's first bunker vessel SeaGas enters into operation fuelling the RoPax Viking Grace.



2013
Fjordline takes delivery of Stavangerfjord, the world's first ship with pure gas engines not deployed in domestic trade.



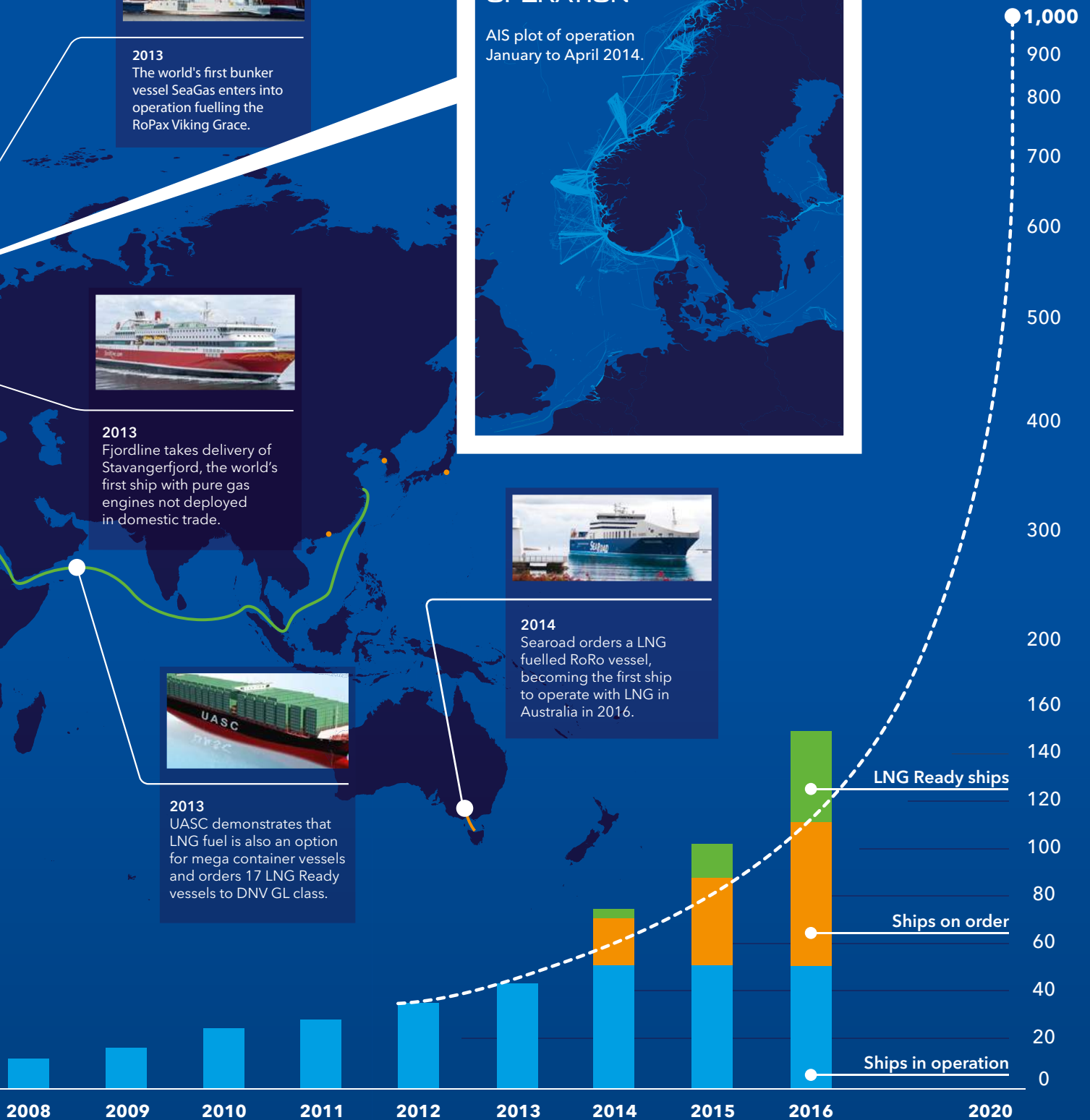
2013
UASC demonstrates that LNG fuel is also an option for mega container vessels and orders 17 LNG Ready vessels to DNV GL class.

LNG FUELLED SHIPS IN OPERATION

AIS plot of operation January to April 2014.



LNG fuelled ships



2013

DNV GL launches the LNG Ready concept, which is quickly picked up by the industry.

DNV GL launches Recommended Practice for LNG Bunkering, providing the industry with the first practical tool for developing bunkering procedures.

2014

NYK places order for a purpose built LNG bunker vessel (5100 m³), that will operate out of Zeebrugge from 2016. Several more orders for bunker vessels are imminent.

The IGF code is scheduled for completion and will reduce uncertainty for LNG fuel designs.

2015

The 0.10% sulphur limit for SECAs will enter into force and accelerate the uptake of LNG fuel.

2016

IMO NOx Tier III will take effect in the North American ECA, further increasing the rationale for choosing LNG for new ships that intend to have any extent of operation here.

2020

The global sulphur limit of 0.50% will enter into force, pending a fuel availability review in 2018, and will drive uptake of LNG fuel in the deep sea segments. Enforcement in EU is not subject to the availability review.

IGC Code revision reflects great changes afoot

Developing the international regime governing gas carrier design and equipment has required two monumental efforts – at its birth and during the current revision

In the early 1970s the Inter-governmental Maritime Consultative Organization (IMCO, the earlier name for IMO) was preparing an international code covering the construction and equipment of ships carrying chemicals in bulk. The nascent gas shipping community, aware of the need for a similar set of harmonised provisions for gas carriers, began to make representations to IMCO.

Up until that point shipowners and shipbuilders had relied on classification society rules to guide their design and construction work. The US Coast Guard (USCG) was a national maritime administration that also played a key role in laying down standards for gas ships. Before a gas carrier could enter a US port, it had to undergo a rigorous inspection by USCG staff and be issued with a Letter of Compliance. Like the class societies, the technical branch of the Coast Guard was struggling to keep pace with the rich variety of ship and containment system designs being introduced into the vibrant new gas carrier market.

IMCO, too, realised there was a need for a unified approach and in September 1971 the first meeting was held of a Ship Design Sub-committee ad hoc working group tasked with defining the general format and scope of the proposed gas code, including the type of ships to be covered. The working group, under the chairmanship of the USCG's Bob Lakey, continued its deliberations for four years, until 1975.

Progress was facilitated by the class

societies agreeing to work together, under the auspices of the International Association of Classification Societies (IACS), to help prepare universally agreed code chapters on cargo containment, cargo handling and materials of construction. The societies had done the early work in developing gas carrier design and construction criteria and in helping those bold shipowners launching pioneering projects. It was essential for IMCO and its efforts to develop a harmonised code to have the societies onside and speaking with a common voice.

The Organization's work was also supported by industry associations and technical bodies and their input was coordinated through the maritime administrations of certain IMCO member states. For example, the membership of a new USCG group that was to eventually become the Chemical Transportation Advisory Committee (CTAC) included a vast range of organisations, not least the American Gas Association (AGA) and the Society of Naval Architects and Marine Engineers (SNAME). The International Chamber of Shipping (ICS) and the UK Chamber of Shipping channelled their contributions to the IMCO deliberations via the UK Department of Trade.

Drafting work on the code was completed and a text agreed at an October 1974 meeting of the ad hoc working group. This set the scene for the adoption, at IMCO's Ninth Assembly in November 1975, of the *Code for the Construction and Equipment*

of Ships Carrying Liquefied Gases in Bulk, known as the GC Code. Governments were recommended to incorporate its provisions, which covered new ships built from 1976 onwards, into their national regulations as soon as possible.

To cover ships already in service another instrument, the *Code for Existing Ships Carrying Liquefied Gases in Bulk*, known as the Existing Ship Code, was introduced within a year of the first code. While mirroring the initial document in many respects, the new code recognised that there were areas where it would be neither easy nor cost-effective to bring existing ships into compliance with the provisions for new ships.

The international regime governing gas carrier construction and equipment has been updated over the years. The GC Code was a voluntary instrument but in 1983 the provisions for new ships were made mandatory with the adoption by IMO, the name for IMCO since 1982, of what was in effect a new code. The provisions of the *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*, popularly known as the International Gas Carrier Code, or IGC Code for short, govern vessels whose keel was laid on or after 30 June 1986.

Over the two decades following its adoption the IGC Code was amended several times. However, during the first decade of the new millennium the pace of change in gas carrier design and equipment accelerated. Shipboard reliquefaction and regasification of LNG



The revised IGC Code provides guidance for gas carriers periodically serving as regasification vessels (FSRUs)

were introduced, as were commercial ship-to-ship transfers of liquefied gases, new propulsion systems, new cargoes, sophisticated automation systems and a greater range of gas carrier sizes. It was clear that the next revision of the Code would require a much more extensive work programme than had previously been the case.

At its 83rd Session in October 2007 IMO's Maritime Safety Committee (MSC 83) agreed to include in the work programme of the Bulk Liquids and Gases (BLG) Sub-committee a new, high priority work item entitled *Revision of the IGC Code*. In keeping with the strategic approach IMO is now taking with the development of regulations, the revised Code was to be 'goal-based' in its approach.

At its 12th session in February 2008 BLG (BLG 12) agreed to a proposal by the UK that the industry itself conduct the revision, a departure from normal IMO procedure. In fact it was the first time that IMO had allowed industry to draft a document outside the Organization's direct control.

To initiate the revision of the Code a broad cross-section of industry representatives was brought together to establish a steering committee to oversee the work. The UK chaired the steering committee and SIGTTO provided secretarial support. The steering committee consisted of 19 senior industry representatives and oversaw the work of 10 working groups, each of which examined and revised different sections of the Code. Progress with the revision of the IGC Code was reported back to relevant IMO committees and sub-committees on a regular basis.

The working groups consisted of experts from classification societies, liquefied gas ship operators, shipyards specialising in the construction of liquefied gas ships and designers of ship systems and equipment. This participation translated into a wide range of industry coverage, as follows:

- Owner and operators controlling 51 per cent of the world's gas carrier capacity
- Classification societies with 98.5 per cent of the gas carrier fleet on their registers
- Shipyards responsible for 33 per cent of the world's LPGC construction capacity and 44.8 per cent of the world's LNGC capacity.

A total of 39 working group meetings were held in 14 countries during the 26-month period it took to complete the work of drafting the revised IGC Code. The steering committee met six times to review progress, offer guidance and



The Existing Ship Code recognises areas where it would be difficult to bring ships built before 1976 into compliance with the provisions for newer ships

direction, and agree on the final draft to be submitted to IMO.

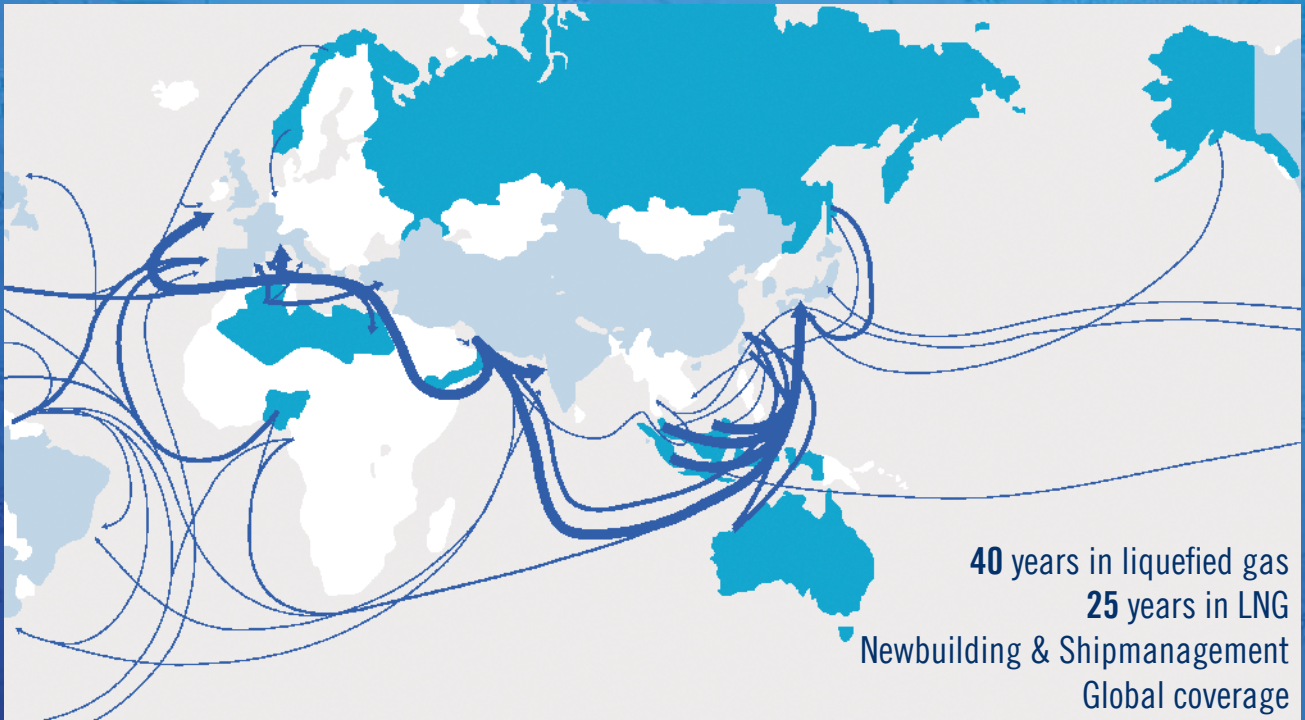
The draft revised Code was received by IMO in November 2010. It then went through various IMO committee and sub-committee reviews before being adopted at MSC 93 in May 2014. It will enter into force on 1 January 2016, with an application date of 1 July 2016. This gap between entry-into-force and application dates is to minimise the effect on existing shipbuilding contracts. In practical terms the revised IGC Code applies to ships with keels laid, or at a similar point of construction, on or after 1 July 2016. It is not to be retroactively applied to the existing fleet of gas carriers.

A number of important changes are included in this new revised edition of the IGC Code. These can be summarised as follows:

1. New IGC product data reporting introduced.
2. Concept of tripartite agreement introduced for carriage of cargoes that fall within the scope of the revised Code but are not specified in Chapter 19 of the Code.
3. Location of cargo tanks changed so that separation of cargo tanks from side shell is increased. Separation is now to be between 0.8m and 2.0m, as a function of the volume of the individual tanks.
4. Provides guidance for gas carriers periodically serving as floating LNG production (FLNG) vessels or floating storage and regasification units (FSRUs).
5. New sections addressing internal turret compartments and associated systems.
6. Provides guidance for limit state design for new containment system designs.
7. New, detailed emergency shutdown (ESD) system requirements.
8. Provides requirements for high-pressure fuel gas systems and for gas-fired internal combustion engines.
9. Requirements for thermal oxidation of vapours, which include boilers and gas combustion units (GCUs).
10. Provision for sequential lifting to reduce the amount of vented cargo, as well as a requirement for emergency isolation of pressure relief valves (PRVs).
11. Expands on requirements to prevent backflow in the inert gas system and adds a requirement to monitor the quantity of inert gas flowing into individual insulation spaces.
12. Alignment of electrical installation requirements with IEC 60092, *Electrical installations in ships*.
13. Alignment and reference to other applicable IMO codes and guidelines, such as the Fire Safety Systems (FSS) Code.
14. New sections on automation systems and systems integration.
15. Requirements for ventilation systems, vent systems and gas detection systems enhanced.
16. Incorporation of applicable IACS Unified Interpretations, the most significant of which covers justification for permitting filling limits greater than 98 per cent. A maximum filling limit of 99.5 per cent is specified.
17. Requires a Cargo Operations Manual.
18. Adds requirements for new cargoes. **MC/AC**



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SIGTTO and GIIGNL in partnership

The LNG import terminal ship/shore interface is where the interests of the SIGTTO and GIIGNL memberships come together and prompt wide-ranging cooperation

The nature of the objectives and the memberships of the Society of International Gas Tanker and Terminal Operators (SIGTTO) and the International Group of Liquefied Natural Gas Importers (GIIGNL) means that the two organisations share considerable areas of mutual interest. This alignment also means that SIGTTO and GIIGNL regularly work together on projects and initiatives of common interest to their memberships.

Both SIGTTO and GIIGNL were established in the 1970s as non-profit organisations. Both bodies have grown in tandem with the industry, and the rapid pace of change over the past decade has ensured that the areas of mutual interest and cooperation are greater than ever before.

SIGTTO was established in 1979 to promote liquefied gas shipping and terminal operations which are safe, environmentally responsible and reliable. GIIGNL, which held its first meeting in 1971, was formed to enhance the safety, reliability and efficiency of LNG import activities, and in the operation of LNG import terminals in particular. It is at the ship/shore interface, when an LNG carrier is at an import terminal delivering cargo, that the interests of the two associations overlap.

For several decades after the birth of the industry there was little variation at such ship/shore interfaces. Conventional-size LNG carriers would shuttle between dedicated terminals under long-term contracts. Ship and terminal staff involved with a particular project became very familiar with each other.

In more recent years, however, great changes have occurred in the industry and these changes have introduced new dimensions to operations at the ship/shore interface. Quite aside from the rapid rise in short-term and spot cargo movements, the LNGC fleet now contains mega gas carriers as large as 266,000m³ and coastal tankers as small as 1,100m³.

Import terminals are now gearing up to handle a much wider range of LNG carrier sizes as well as a new generation of LNG bunker vessels. Another type of import terminal becoming increasingly prevalent is the floating storage and regasification unit (FSRU), and such facilities often require the use of ship-to-ship transfers of LNG from visiting delivery tankers.

The good relationship that SIGTTO and GIIGNL have enjoyed over the years has strengthened in response to the expansion and diversification of the LNG industry. The two bodies meet on regular occasions and exchange views

on safety issues as well as information on their respective current projects.

Over the years topics which have been jointly covered by both SIGTTO and GIIGNL include:

- Gathering of LNG industry data
- Ship/shore compatibility
- LNG terminal and ship security
- LNG quality, weathering and quality adjustment
- Small-scale LNG
- Specificity of the LNG industry
- Guidance for the use of the Panama Canal.

A major joint project is the LNG terminal information web portal. This project was commenced in 2004 after a series of meetings. The initial objective was to establish a common location for LNG terminal compatibility information. This was later expanded to include LNG ship information. The portal is extensively used today and can be seen at <http://lngwebinfo.org>. The website is jointly funded by both organisations and both sets of members contribute towards inputting the information contained within it.

GIIGNL sits on SIGTTO's General Purposes Committee (GPC) and each organisation has nominated members to sit on those working groups established by its opposite number that are considering issues of mutual relevance.

Both SIGTTO and GIIGNL are part of the Protocol of International LNG bodies, which is an agreement between international gas organisations on cooperation and information sharing. This group last met in Geneva in April 2014.

This *LNG Shipping at 50* magazine is the latest example of cooperation between the two organisations. SIGTTO and GIIGNL are pleased to be joint sponsors of a publication they hope will be enjoyed by not only both their memberships but also the LNG industry at large. **AC/J-YR**

Terminal and ship compatibility is the subject of a joint SIGTTO/GIIGNL web portal project



Class underpins LNGC safety record

Although class society rules are empirical, in the early days of LNG carrier design there was no experience on which the required standards could be based

Back in the 1950s, when new LNG carrier design proposals were being considered, a face-to-face, roundtable discussion between designers, the shipbuilder and the classification society's technical staff was a common occurrence. In the early years class societies were in a fortunate position in that submissions of plans for approval were being made from various sources. They were able to discern whether any patterns of consistency in LNGC design were emerging.

Early class society work on rule development was augmented by the efforts of government agencies in some of the importing countries. The Italian Ministry of Merchant Marine, the Japanese Ministry of Transport and the US Coast Guard (USCG) had each drawn up their own operational requirements.

The USCG published tentative standards in August 1959 for the transport of liquefied flammable gases at atmospheric pressure. In 1965 the Coast Guard's exacting Letter of Compliance programme was initiated. The Japanese Ministry of Transport required fitness

certificates for gas ships trading in Japanese waters.

In 1970 the Italian Ministry of Merchant Marine published provisional rules for the carriage of liquefied gases in bulk in Italian waters. Ships were required to have a fitness certificate from the Italian maritime authority. Existing ships could generally comply with the Italian rules but a requirement that did catch some out was the need for lightning conductors or suitable lightning copper nails to be fitted at the vent masts tops.

Back in 1930 some small research projects had been undertaken in the US and the UK on uninsulated pressure vessel tanks used on ships for the carriage of butane and propane. Both the American Bureau of Shipping (ABS) and Lloyd's Register of Shipping (LRS) were involved in assessing these new ideas.

LRS followed up this work by classing the first purpose-built LPG carrier, *Agnita*. The vessel was delivered to Anglo-Saxon Petroleum, a Shell affiliate, in 1934 from the Hebburn yard of Tyneside shipbuilder Hawthorn Leslie.

During the 1950s ABS and LRS made



The register of ABS-classed gas carriers encompasses all the LNG carrier containment systems in service today

significant progress in understanding the techniques required to transport LNG by sea. These advances were made possible as a result of the pioneering LNG research work in the US and an extensive study by British Gas on the feasibility of transporting LNG from Venezuela to Britain.

On 26 January 1962, as the society's Notice No 2182 indicates, LRS added a new Section 70 to its *Chapter D Steel Ships* rulebook. Section 70 laid down provisional requirements for the carriage of liquefied petroleum and natural gases at or near atmospheric pressure.

In March of the same year a paper entitled *The Carriage of Liquefied Petroleum and Natural Gases* by principal surveyor J B Davies was presented to the Lloyd's Register Staff Association in London. The Association had been established to advance and disseminate within LRS knowledge of current shipbuilding and marine engineering problems and issues.

Appendix II of the Davies paper contained an example of calculating methane tank scantlings, complete with formulae for acceleration, and dynamic and static loading. Despite the stated restriction of this information to LRS members and technical staff, the paper was widely circulated and used, with biblical reverence, by naval architects to determine cargo tank scantlings.

In the period 1954-56, during the early phases of the development of the *Methane Pioneer* project, the USCG was assisted by an industrial advisory group. Established within the framework of the American Petroleum Institute (API), the group contributed to the drafting of preliminary regulations for cryogenic tank vessels. ABS participated in this activity and contributed to the formation of some of the basic principles of LNGC design.

At the time, ABS rules had requirements for refrigerated cargo installations for ships carrying refrigerated foodstuffs. However, these



The feedback of surveyors has been an essential element in the development of class society rulebooks for gas carriers

rules were not applicable for ships intended to carry LNG. To fill the gap, ABS introduced a new Section 24 in the 1970 edition of its rules specifically covering the construction and classification of steel vessels intended for the carriage of liquefied gases.

The French classification society Bureau Veritas (BV) has been closely associated with the development of gas carriers since the very beginning of this new technology. The society's early involvement began in 1953 with the classification of various pressurised LPG carriers built in Europe, mainly under the French and Danish flags.

In 1958 BV became the first class society to publish special recommendations for LPG carriers in its rules. These provisions were drawn up for vessels involved in the carriage of liquefied gases such as butane and propane at full pressure. BV followed this up with the publication of a guidance document entitled *Technical general conditions governing the sea transportation of liquefied natural gas* in 1962. To assist in the compilation of the guidance document, the Paris-based society had established, within its naval technical committee, a special commission made up of representatives from Gaz de France, shipowners, shipbuilders, steel manufacturers and other interested and duly qualified persons.

Det Norske Veritas (DNV, now DNV GL) has had gas carriers in its class since the late 1940s. *Hydro* and *Herøya*, a pair of 1,454m³ anhydrous ammonia carriers, were converted on behalf of Norsk Hydro in 1949 and 1950. The early DNV work on gas carriers was formalised in July 1960 when its research department published a document entitled *Preliminary recommendations for the design and construction of ships for the transport of liquefied gas*.

DNV's first comprehensive rules for gas carriers were published in 1962 in its *Rules for the construction and classification of steel ships* as 'Chapter XIV – Recommendations for the design and construction of ships for the transport of liquefied gas'.

In the early 1960s DNV's director of research Egil Abrahamsen was to the fore in presenting the extensive guidance on the classification of gas carriers compiled by his society. His paper *Special Ships for the Transport of Liquefied Gas, from the Classification Viewpoint* was heard in Oslo in 1960 while *Gas Transport and Ship Classification* was presented to API in 1963. Another paper, *The Carriage of*

Special Liquid Cargoes, was delivered to an audience in Sandefjord, Norway in 1964.

Nippon Kaiji Kyokai (ClassNK) developed its rules for refrigerated and pressure-type gas carriers in 1959. *Goshu Maru*, the first ship classed with NK to carry LPG, was delivered by Mitsui Engineering and Shipbuilding in October 1961. This ship was a combined crude oil and LPG carrier with five fully refrigerated prismatic LPG tanks providing a total capacity of 11,300m³. The ship design, in which 90 per cent of the available space for cargo was devoted to crude oil, was based on guidance plans from Esso and the ship was dual classed with ABS.

Registro Italiano Navale (RINA) published its rules for ships transporting liquefied gases in pressure vessels in 1966. The rules were based on the society's experience during the building of six fully pressurised LPG carriers built in Italy since 1956. During the construction of these small gas carriers

RINA had generally relied on its rules for oil tankers. The new 1966 rules specifically addressed gas carrier cargo tanks, piping and vent systems as well as other safety features.

Classification societies took on board the recommendations of the *IMCO Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* after it was published in 1976. Most class societies had taken an active part in developing the Code's recommendations. By the time this set of provisions became the IMO's *International Gas Carrier (IGC) Code*, class societies had incorporated the essence of the Code's recommendations into their rulebooks.

The success, progress and exemplary safety record of LNG carriers over the past 50 years owes much to class societies. The dedication, co-operation and foresight of their technicians, researchers and surveyors have been unparalleled. **SH**



Extensive research and testing programmes form a key part of class society involvement with LNG carriers

Training – the bedrock of safe LNGC operations

Chris Clucas* shows how the seeds of today's sophisticated LNG carrier training regime were sown right at the start of this enterprising and challenging new industry

However tentative it may have been in its earliest days, LNG transportation took hold quickly and went on to become a great success – both technically and commercially. LNG offered a clean and attractive alternative to gas derived from coal gasification or naphtha reforming and to other hydrocarbon fuels. The investment in liquefaction plant and shipping enabled companies to cash in on gas assets that were otherwise stranded or flared. This became increasingly important as environmental concerns developed and oil reserves became scarcer.

The pioneering exports from Algeria, Libya and Alaska were soon joined by those from Brunei, Abu Dhabi and Indonesia and within the short span of 10 years the global LNG trades had developed into the pattern we recognise today.

The subsequent expansion of these trades was more evolution than revolution. The industry favoured established commercial practices, proven liquefaction plant technology and reliable ship designs. Ship size increased only marginally over the first quarter of a century, in tandem with discreet rises in LNG production plant capacity. The conservative approach was understandable, as the industry gained familiarity with what is a challenging cargo and accommodated a relatively slow buildup in trade in the 1970s and 1980s.

LNG presents certain risks when carried as a cargo in significant volumes. Its vapours are flammable and its cryogenic carriage temperature of -162°C requires special precautions. The shipping industry realised early on that if LNG was to gain and maintain a place in the global energy mix, safety would have

LNG carrier training starts with an understanding of the basic physics and chemistry of natural gas



to be given top priority. A measure of the success of the LNG shipping industry's ongoing commitment to minimising risks is the exemplary safety record achieved over the past 50 years.

If asked what makes the LNG business unique and why a quality training regime is so important, there is no need to look beyond the ships themselves. From the birth of the industry LNG carriers have always been regarded as rather special. They are, in effect, a 'floating pipeline', linking gas exporters and importers where no pipeline alternative exists.

Also, given the very nature of the trade – which is closely linked to the fuel requirements of public utilities – the reliability of LNG deliveries has always been of paramount importance. The need to provide a continuous, seamless flow and to keep the supply chain functioning according to tight contractual terms is one of the key differences between LNG ships and most other liquefied gas carriers.

The highly engineered systems and equipment needed to contain and handle large volumes of valuable, cryogenic cargo make LNGCs expensive ships. In the early days it was possible to build seven (single-hull) very large crude carriers (VLCCs) for the price of a single LNGC. The high cost of entry ensures that the LNG domain is open only to the committed shipowner.

Early LNG carriers were steam turbine-driven vessels of relatively small size, in the 25,500–75,000m³ range. The relatively high cargo tank surface-to-volume ratio and the insulation technology at the time meant there was a comparatively high cargo boil-off gas rate to deal with. In order to avoid wasting this valuable product, it was used as propulsion system fuel in the ship's boilers. Because ship service speeds were usually chosen to match fuel availability, this led to service speeds that were higher than the average for the time.

Of course, most of the LNG carriers ordered today are dual-fuel motor ships and managing these propulsion systems requires a completely different set of engine room skills. At the same time, steam ships still account for the largest part of the fleet, so the industry's retention of a body of engine room staff familiar with the operation of steam turbines is essential.

Given the international nature of the shipping industry, it is perhaps surprising to note that IMO's first set of provisions aimed at standardising maritime training worldwide was not introduced until 1978. However, for gas carrier operators this Standards of Training, Certification and Watchkeeping (STCW) Convention proved to be an excellent example of joined-up thinking.

The 'Lakey Group' had just completed

the International Gas Carrier (IGC) Code under the auspices of IMO and the International Chamber of Shipping (ICS) had likewise just published the ICS Tanker Safety Guide (Liquefied Gas). The establishment of SIGTTO was to follow in 1979.

The IGC Code recognised that operations onboard many liquefied gas carriers involve product flows, something not usually encountered on other cargo ships. This situation is recognised in the IGC Code in a special chapter on operational requirements, an unusual inclusion for a code dedicated to design, construction and equipment standards.

The draft syllabus for gas carrier training in the STCW Convention was reviewed and amended by the Lakey Group. This contribution ensured that the training courses would match the gas carrier equipment requirements.

While STCW may have formalised and harmonised gas ship training, the practice had begun long before work started on the STCW Convention. The *Methane Pioneer* crew for the historic 1959 trial shipments were selected from the sea staff of Stephenson Clarke, a venerable British shipping company dating back to 1730. While this *Methane Pioneer* crew may have been much more familiar with the coastal coal trades, they were highly competent seamen.

Furthermore the cargo equipment on the vessel was handled exclusively by a team of chemical and gas engineers familiar with the liquefaction of natural gas and industrial air gases, including on behalf of the NASA space programme in the US. These engineers were augmented on the transatlantic runs to Canvey Island by some naval architects from the group that designed and built the ship's containment system.

There was so much at stake for this trial *Methane Pioneer* programme that training was seen as an essential and integral part of the process of transporting LNG by sea. This philosophy has been retained up to the present. Excellence in training goes hand-in-glove with excellence in operation, and smooth operations provide the LNG shipping industry with its license to operate. That commitment starts at the top, with a shipping company's senior management, and encompasses a variety of shore staff.

The key purpose of any LNG training course is to explain how to operate the ship safely. This in turn requires a certain level of understanding of the fundamental chemistry and physics of gases. After these basic concepts are understood, it is much



Chris Clucas

easier for officer trainees to comprehend how equipment functions and why cargo-handling operations are carried out in certain ways and sequences.

Familiarity with the cargo's chemistry and physics similarly facilitates an understanding of first aid, safety equipment and gas detection. An appreciation of the cryogenic nature of LNG also leads to an appreciation of the effects of a cargo spillage on the conventional parts of the ship's structure.

The standards laid down in IMO's STCW Convention are deemed to be the minimum acceptable for the shipping industry. To bridge the gap perceived to exist between classroom training and practical experience, SIGTTO led an initiative to develop 'competency standards' for LNG carrier crews some 10 years ago. A strong driver for this initiative was the accelerating pace of change in the LNG industry and the need to maintain operational standards during a period of rapid expansion.

The resultant SIGTTO Competency Standards set out the underpinning knowledge required and what the ship officer needs to know in order to achieve the effective performance required in carrying out a particular operation. The standards also recognise the interdependence of different departments, e.g. between the deck and engine room teams when gas vapour from the cargo tanks is supplied as fuel for the propulsion system.

This emphasis on 'input and output' in the SIGTTO Competency Standards was ahead of its time in many ways and is now seen as an effective way of setting out training standards. As part of the overall initiative, SIGTTO developed *Competency Standards for Steam Engineers*. The Society recognised the limited availability of guidance for

maritime educational faculties in setting up steam training courses. Quite simply, there are very few steam engineers available today who can serve as instructors and pass on their specialist practical experience.

Highly sophisticated cargo-handling simulators are an important part of today's training regime and, most recently, the applications have been made compatible with laptop computers. This development has brought highly realistic simulation training within even easier reach of LNG industry participants. Amongst other things, simulators enable students to become familiar with new technologies in a safe environment and to try out possible alternative scenarios that would be unthinkable onboard a trading LNGC.

The LNG shipping industry is poised at the start of another period of rapid expansion. While this will no doubt dilute overall experience levels, it will also open the market to further advances in technology. Innovation has already started to make itself apparent in recent years, in terms of floating LNG production vessels, small-scale LNG carriers, LNG bunkering vessels and LNG-powered ships of all types.

In such circumstances the demand for training will increase markedly. A sound LNGC training regime has been established over the past 50 years and is available for participants to not only make use of in the most appropriate way but also help fine-tune and update for the benefit of the industry as a whole. Seafarer training should not just be limited to the refining of operational skills. We also need to identify and nurture the leaders of the future.

** Group fleet director at Bernhard Schulte Shipmanagement Group, Chris Clucas has enjoyed a long and varied career in the LNG and LPG shipping business, including extensive experience delivering training courses around the world.*



Simulator training has an important role to play in the cadet's overall training programme



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LNGC fit-for-purpose assessments

Amongst the intangible benefits of ship vetting programmes are the improvements in the quality and safety of ships and crews that can accrue

The vetting of LNG carriers has not become an integral element of the operation of such vessels until relatively recently. In the early days LNG ships would be engaged on long-term projects shuttling cargoes between dedicated terminals, and charterers would be extremely familiar with the ships they employed and their general condition and performance.

In the late 1990s, however, spot cargoes and short-term contracts began to feature in the LNG trades, and vessels began to call at terminals they had not previously visited. In the circumstances charterers, buyers, terminal operators and sellers needed to assure themselves that the condition, operation and ownership of any third party vessel they were considering making use of was up to an acceptable standard.

For guidance the LNG industry turned to the oil tanker, chemical tanker and LPG carrier sectors, where short-term trading and spot voyage fixing was prevalent and where a sophisticated ship vetting regime was in place.

Companies involved in those sectors were acutely aware of the perils that attached to the employment of a tanker or LPG carrier subsequently found to be substandard. If such a vessel was to be involved in an accident that jeopardised lives, property and/or the marine environment, their reputations could be irretrievably damaged. They established vetting departments whose sole purpose was to assess the quality of ships and their management. This data could then be measured against their own in-house acceptance criteria to determine if a candidate ship should be selected.

In 1993 the Oil Companies International Marine Forum (OCIMF), the industry body representing users of tankers, developed the Ship Inspection Report (SIRE) system as a voluntary, industry-wide programme to assist in the vessel vetting process. SIRE is a very large database of up-to-date information about tankers, based on vessel inspections carried out by independent, third party specialists qualified and certified to undertake such work. While SIRE reports cover

the external condition of a ship and the standard of operations onboard, they are not structural surveys and do not cover inspections of internal or void spaces.

The SIRE system has been taken up by the LNG shipping community as an important vetting tool. Amongst other things, the use of SIRE as a centralised system helps reduce the number of ship inspections required and eases the burden on ship crews.

But SIRE inspections are only one part of any vetting programme. The vetting team will also make use of relevant vessel information arising from classification society records, port state inspections, flag administration data, casualty records and the previous operational performance of not only the ship itself but also other vessels in the same fleet.

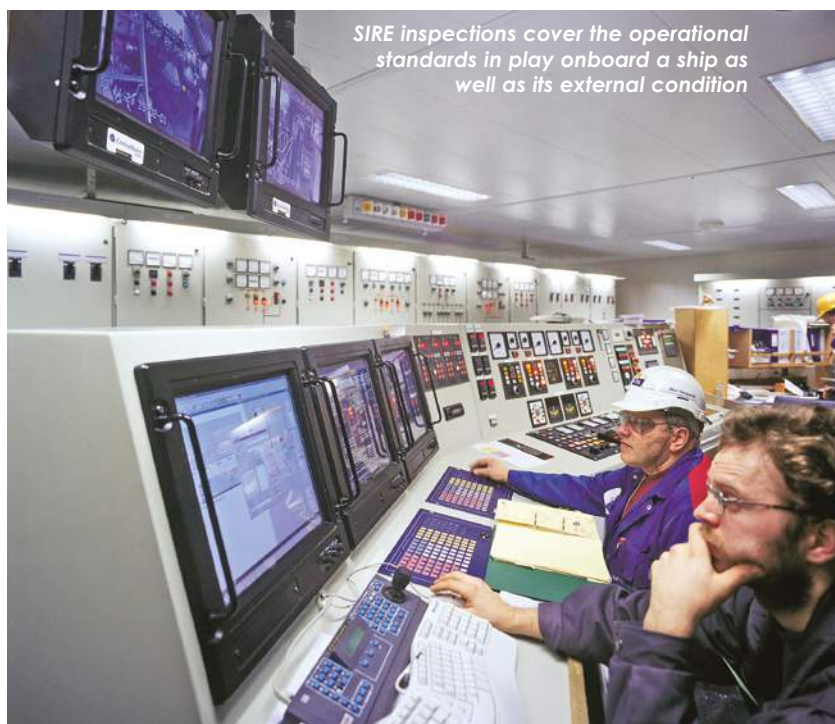
On a par with the condition of a vessel and the state of its operation is the standard of the vessel's management. On the vetting department's agenda will be a review of the management systems that the shipowner or operator has in place. Such reviews are carried out to assess the operational and technical competency of the company behind the vessel in question.

Another vetting consideration that has increased in importance in recent years, in tandem with the ageing of

the fleet in general and some of the pioneering vessels in particular, is the structural condition of ships. The earliest ships have been put through life extension refurbishments at around 20 years of age to provide them with another long lease of life. As part of these rigorous life extension projects, the class society overseeing the work will provide the vessel with a Condition Assessment Programme (CAP) rating.

More and more vetting departments are requiring a CAP rating of at least a certain minimum standard before vessels of a certain age, type or size will be considered for employment. Although age is not necessarily an indicator of ship quality, its structural condition needs to be taken into account in the vetting process.

The third key element in the LNG carrier vetting process, besides the assessments of the quality of a ship and its suitability for the intended use, is the question of ship/shore compatibility. Factors that need to be considered are compliance with local and national regulations; ship dimensions versus any terminal limitations; cargo-handling and mooring equipment; security arrangements; waterway restrictions; and weather conditions. Furthermore terminal feedback can be utilised in ship vetting assessments and the process can be reciprocal. **MC**



SIRE inspections cover the operational standards in play onboard a ship as well as its external condition



Borgøy and Bokn bunker with LNG at their home port of Kårstø

Escort tugs boost LNG port safety

In the operational cycle of an LNG carrier, vessels face the greatest level of risk at the ship/shore interface. It is here where gas ships come into close proximity with other port traffic and where the chances of a grounding or collision incident are at their highest. The ship/shore interface begins in the port approaches, when the LNG carrier takes on a pilot and begins the final leg of its voyage. The passage towards the terminal berth is carried out at a pre-agreed speed and with an exclusion zone in force around the vessel.

The other essential element of the LNG carrier berth approach is the tug escort. Escort tugs were deemed to be an eminently sensible safety measure for oil tankers navigating confined waters following the grounding of the crude oil carrier *Exxon Valdez* in Alaska's Prince William Sound in March 1989.

The concept was quickly taken up for the large number of new LNG terminals that were built in the 1990s and into the early years of the new century. The safety role of the escort tug is particularly important for LNG terminals as most such facilities are located outside inner harbour areas, often at exposed locations where fairly significant sea states may prevail.

An increasing number of LNG importers are specifying floating storage

Research into what LNG terminals require of their tugs has resulted in a breed of vessels with superior escort and seakeeping capabilities

and regasification units (FSRUs) as a means of fast-tracking LNG purchases at much lower cost than the shore receiving terminal option. Such FSRUs also tend to be placed on jetties in exposed locations and in some cases are moored to turret buoys in deep water at true offshore sites.

Another factor in the escort tug equation is ship size. LNG carriers have high freeboards and their overall size has been increasing in recent years, in tandem with the growth of the LNG industry, the expanding network of export and import terminals worldwide and the drive for economies of scale. 'Conventional size' LNGCs ordered 30 years ago were commonly of 125,000m³, whereas today cargo-carrying capacities of 170,000m³ are usually specified.

The combination of large LNG carriers and terminals at exposed locations calls for escort tugs with exceptional capabilities. LNG carrier owners and

terminal operators will typically ask tug operators, "Can you provide tugs that will safely bring the LNG carrier alongside and berth it in sea states with a significant wave height of up to a 3m?"

The goal of providing escort tugs that are fit for purpose was greatly facilitated by the SAFETUG joint industry project (JIP) coordinated by Marin in the Netherlands and supported by oil and gas companies, tug owners, major equipment suppliers and a few consulting naval architects.

Completed in 2010, the two-phase, five-year SAFETUG study provided the participants, by means of model testing, computational fluid dynamics (CFD) analyses and related research, with the basic tools to enable a reasonable prediction of the 'operability' of tugs in a specified sea state condition.

Although the experience of the tug master remains the key factor in safe operations, the JIP established a level of understanding that has allowed the design of better, safer and more capable tugs for hostile environments. One conclusion of SAFETUG was that attempting to handle the escorting of ships in conditions with significant wave heights greater than 3m is not likely to be successful, at least not with current tug designs.

In a typical escort tug operation at an

LNG terminal the arriving LNG carrier will be joined by four tugs in the outer port approaches. One of the quartet will be tethered to the stern of the gas ship and this vessel will be able to exert a braking or steering force in case of an emergency such as the LNGC losing power while en route. The escort tugs must be able to maintain a speed that enables the gas carrier to continue at its port approach speed of up to 10–12 knots.

Two principal escort tug design concepts have been developed. The first is the high-performance, 'skeg-forward' Voith tug while the second is the azimuthing stern drive (ASD), or Z-drive, escort tug with indirect towing capability. Following a rapid evolution in design, modern ASD tugs are able to generate significant indirect steering forces and thus provide a performance which is directly comparable to that of a Voith tug.

The latest ASD tugs make use of hull forms that are much improved on those of the early tugs of this type and they are also fitted with large 'escort skegs'. These design features, combined with a better understanding of the physics of escort operations, have proven that a properly designed ASD tug can fulfil all the requirements of a 'true' escort tug.

One naval architect firm that has devoted considerable effort to developing a range of effective ASD escort tug designs is Robert Allan Ltd of Vancouver on Canada's west coast. As part of the process, the company developed its own model testing programme, the initial focus being aimed solely at evaluating the hull characteristics that achieved the highest indirect forces. The Robert Allan research evaluated tug performance as a function of a range of design parameters, including basic hull geometry and proportions, sloped hull sides, sponsoned hull sides, skeg geometries and positions and tow-point position.

The company's investigations into optimised escort tug hull forms resulted in the development of the company's *RAstar* class vessels. This series now includes tugs from 27 to 39m in length, with bollard pulls (BPs) ranging from 70 to 120 tonnes. These designs have proven successful in numerous offshore/exposed terminal applications, particularly at LNG terminals.

For example, there are four *RAstar* 3600 tugs in operation for Smit Lamalco at the Balhaf export terminal of Yemen LNG, each with a BP of 90 tonnes, while Svitzer has six *RAstar* tugs in service at Milford Haven in South Wales, where Dragon LNG and South Hook LNG both

operate receiving terminals. The Milford Haven complement comprises four *RAstar* 3400 tugs, each with an 80-tonne BP, a 90-tonne BP *RAstar* 3600 tug and a 105-tonne BP *RAstar* 3900 vessel.

The most notable difference between typical harbour operations and those at offshore/exposed terminal locations is in the type of deck machinery, particularly the design of the main hawser winches. While there are a few tugs in harbour operations which have winches with a degree of 'render/recover' capability, it is essential to have this attribute in offshore applications. This is because wave-induced loads in the towline can easily exceed typical line breaking strengths, even with large margins in safe working loads.

A rather extreme example of this render/recover capability can be found on the tugs developed for operation at the Costa Azul LNG terminal on Mexico's Pacific Coast. The tugs are operated by Servicios Maritimos de Baja California of Mexico, a joint venture between Moran Towing and the Boluda group.

Because the terminal is located on a lee shore in an area exposed to Pacific swells, the owner's specification demanded that each tug and its winch must be able to sustain a constant line pull of 75 tonnes throughout the entire terminal approach in a 2m-plus significant swell. Markey Machinery of Seattle, Washington designed the 520kW, double-drum winch with Asymmetric Render/Recover™ capability fitted on

the four Costa Azul tugs. The winches are able to achieve the constant tension requirement in sea conditions with wave heights of up to 3m.

In common with many sectors of the shipping industry, the drive to reduce fuel consumption and harmful atmospheric emissions is also impacting the tug market, for both harbour and offshore applications. The load profile of an offshore terminal tug, with more extended use of higher power levels, can place such vessels in a more favourable position as regards early recovery of investments in hybrid or similar power configurations.

Over the past year the LNG power option has made a breakthrough in the escort tug sector. Buksér og Berging of Norway has recently put two LNG-fuelled tugs, *Borgøy* and *Bokn*, into service at the Kårstø gas terminal on the country's southwestern coast. Built by the Sanmar yard in Turkey, the vessels are on charter to Statoil and in service at a terminal that handles a larger volume of LPG and ethane tanker shipping than any other port in Europe. Each of the pair is powered by two Rolls-Royce Bergen lean-burn gas engines fuelled solely by LNG.

China State Shipbuilding's Huangpu yard is also building two LNG-fuelled escort tugs, each powered by twin Wärtsilä 34DF dual-fuel engines. The duo have been constructed for the state-owned China National Offshore Oil Corp (CNOOC) and for operation at the new Zhuhai LNG import terminal on the western flank of the Pearl River Delta. **MC**



The SAFETUG research yielded a new set of tools enabling the design of tugs tailored to the demands of each specific operating area

Sterling results from safety-first focus

The LNG shipping industry has built up an exemplary safety record over its 50-year history, and those few incidents that do occur provide valuable lessons

In the 50 years since they loaded their first commercial shipment, LNG carriers have safely delivered over 77,000 cargoes. These consignments all reached their destinations with no breach of a cargo containment system and with no onboard fatalities directly attributable to the cargo. This is a very impressive, in fact unprecedented, safety record for the carriage of liquid hydrocarbons by sea in bulk.

This exemplary safety record is due to several reasons. These include, but are not limited to, a strong, overarching safety philosophy; robust equipment and systems design; good operational and maintenance procedures; operating in excess of the minimum requirements and according to best practice guidelines; and high standards of training coupled with competency verification.

Amongst other factors that have contributed to LNG shipping's

remarkable safety record is the fact that the International Gas Carrier (IGC) Code was developed based on actual experiences in the early days of LNG transport and our industry's ability to share lessons learnt and to develop universally accepted best practices.

Credit also needs to be given to the pioneers who contributed first to the development of design standards and operating procedures during the early days of liquefied gas shipping and then to the development of the IGC Code, with its safety margins and safe design provisions. They played a key role in laying the foundation stones on which the industry's excellent safety performance has been built.

The pioneering cargo of LNG was carried across the Atlantic Ocean by the 5,000m³ *Methane Pioneer* at the start of a series of trial shipments in 1959. By 1964 the first purpose-built LNG carriers, the 27,400m³ *Methane Princess* and *Methane*

Progress, were in service under a 15-year gas purchase agreement signed by the UK and Algeria.

Since the early days of LNG transportation, there have been many changes to the industry. LNG vessel size has increased considerably, especially since the start of the new millennium. Whereas the average cargo-carrying capacity of a conventional LNG carrier was 125,000m³ up to the mid-1990s, it has been moving steadily upwards since then and such newbuildings now fall in the 160,000–175,000m³ size range.

The LNG carrier fleet also includes 31 Q-flex ships of 216,000m³ and 14 Q-max vessels of 266,000m³. These gas carriers were ordered a decade ago to help Qatar realise economy-of-scale benefits in shipping its cargoes to world markets. They remain by far the largest LNG carriers trading today.

Fleet growth has also picked up a head of steam over the past decade. The number of LNG carriers in the current fleet reached the 400-ship milestone in April 2014. With over 125 such vessels on order, the 500-ship mark is due to be attained in late 2016. The industry's record of achievement in terms of fleet growth is made all the more notable by the fact that it was not until 1997 that the LNG carrier fleet reached the 100-ship landmark.

LNG carriers are also amongst the most durable of all ships. Several have successfully traded up to and beyond their 40th year. In 2013 approximately 10 per cent of the LNG carrier fleet was in excess of 30 years of age. Due to the industry's requirement for a safe and reliable performance, rigorous maintenance routines and good housekeeping practices are given top priority on these high-value vessels.

Some older vessels have been converted into floating storage and regasification units (FSRUs), a modification which effectively gives the vessel a new lease of life. In addition a contract has recently been signed under which a 1975-built LNGC will be converted into a floating LNG production (FLNG) vessel. As a result of FSRU and FLNG conversions, it will not be long before some LNG ships go beyond 50 years of active service.

In the delivery of 77,000 cargoes some minor incidents and near misses have occurred within the overall fleet. The Society of International Gas Tanker and Terminal Operators (SIGTTO) maintains a highly detailed database of incidents which have taken place

Valuable lessons have been learned from those cargo-handling equipment incidents that have occurred at the ship/shore interface



onboard LNG vessels and within terminals. The data is analysed in the drive to identify causes and minimise the risk of recurrences.

Incidents to date have mainly involved problems with machinery and cargo-handling systems and equipment. The machinery incidents include loss of propulsion and other system failures and blackouts. Most of the cargo-handling incidents have occurred at the ship/shore interface, especially during connection and disconnection of the marine loading arms on the jetty.

LNG carriers have also been involved in three high-speed grounding incidents. Although the vessels suffered substantial bottom damage as a result of the groundings, in no case was a cargo containment system breached. There have also been other LNGC groundings in port areas when the vessels were proceeding at slower speeds. Again, containment systems have remained intact in each of these occurrences.

LNGCs have also been involved in a few collision incidents, including two in the last 18 months. In the first a Q-flex LNG carrier and a container ship collided in the Singapore Straits and in the second an LPG carrier and an LNG carrier came together in Tokyo Bay. *Methane Princess*, the first LNG carrier in commercial service, was struck by the vessel *Tower Princess* while berthed at the Canvey Island terminal in the UK and the impact necessitated repairs to the gas carrier's side shell. In another well-known incident *Norman Lady*, while proceeding through the Strait of Gibraltar, was, almost unbelievably, struck by a US Navy submarine as it rose to periscope depth.

As was the case with the grounding incidents, no LNG carrier containment system was compromised as a result of the collisions. This achievement is a legacy of the extra safety margins and safe separation distances built into the original rules governing the design of these vessels by the LNG shipping industry's founding fathers mentioned above.

As regards LNG terminals the most serious accident was the explosion that destroyed three of the six liquefaction trains at the Skikda export terminal in Algeria in 2004. The explosion occurred during a routine boiler maintenance operation and was due to insufficient purging of the boiler. Some 26 workers were killed by the blast and 74 injured. As with all incidents in the LNG sector, detailed investigations were carried out



The SIGTTO Competency Standards help cadets target what they need to know

and remedial measures introduced. In this case new plant designs eliminated the need for boilers, which have been replaced with more efficient gas-fuelled turbines and compressors.

The LNG industry continues to expand and introduce new technologies. Larger ships with new types of propulsion system are now in service and the fleet continues to grow apace. FSRUs are also now part of the industry and FLNG vessels are about to be. All these advances ensure that there are many challenges in the liquefied gas shipping and terminal industry today.

Not least of these challenges is the supply of ship crews, shore support staff and trainers to provide the required number of trained and competent staff needed in an era of unprecedented growth.

In respect of training, the SIGTTO competency standards for crews onboard both LNG and LPG vessels have become the industry best practice recommendation. The standards provide operators with guidance as to the specific competencies each individual should possess before serving in that rank. These standards are above and beyond the minimum requirements of IMO's Standards of Training Certification and Watchkeeping (STCW) Convention. There is similar competency guidance available for terminal operators and their staff.

Educating the public is extremely important for liquefied gas shipping, and the public needs to be made aware that gas carriers are not the "floating bombs" that some scare-mongers portray them to be. Public perception is often that an incident on a gas carrier will result in a

huge explosion that may harm people and property in the vicinity. The public needs to learn that these vessels are robust ships, soundly designed and constructed and well equipped with safety and emergency systems.

The public also needs to be aware that catastrophic events caused by hydrocarbon gases in the liquid phase are few. As an example, in a fire accident scenario refrigerated liquefied gas tanks can burn until the fuel they contain is consumed but they are highly unlikely to explode.

Liquefied gas cargo-handling procedures can be complex and the cargo itself is potentially hazardous. For these reasons, personnel operating gas carriers and gas berths require a thorough understanding of ship and shore equipment and cargo properties. They need to have available good operating procedures so as to avoid accidents, and emergency plans should be in place in case an accident does occur.

LNG is increasingly being carried as a cargo at sea in ISO containers on conventional container ships and the use of LNG as a marine fuel also brings with it new risks and fresh challenges. A robust safety regime has been established and it is incumbent upon the shipping industry to make appropriate use of it, and, where necessary, adapt it to suit particular circumstances.

We look forward to celebrating 50 years of commercial LNG shipping in October 2014 and also, in the same month, 35 years of SIGTTO. We also look forward to this very responsible industry continuing to ensure the safe transportation of liquefied gases by sea. **AC**

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*trains 1-4 (18 mtpa) under construction

Little Das Island makes a big LNG contribution

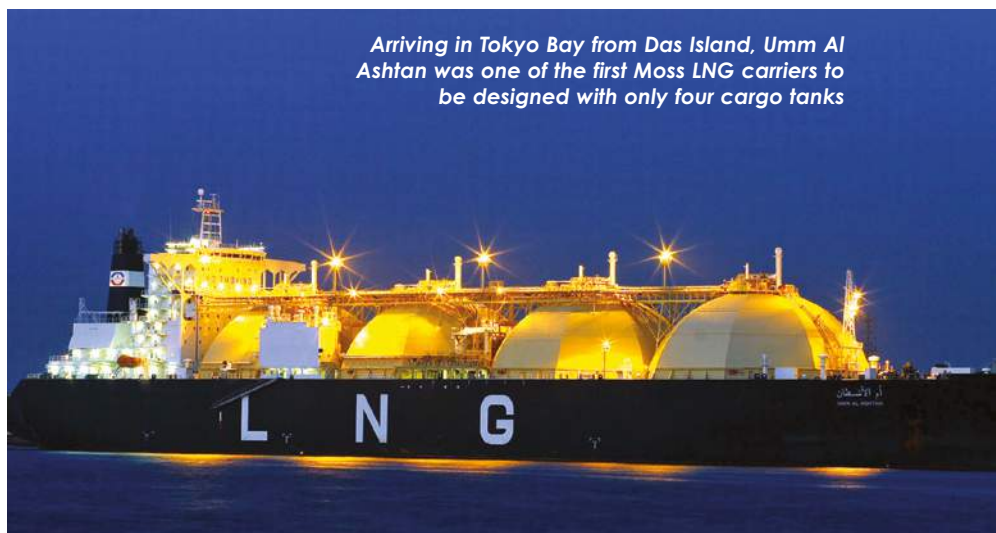
Located on a small, remote Gulf island, Abu Dhabi's 37-year-old terminal was the first LNG export complex to be built in the Middle East

In the early 1960s Sheikh Zayad Bin Sultan Al Nahyan, president of the United Arab Emirates and ruler of Abu Dhabi, and Sheikh Khalifa Bin Zayad Al Nahyan, the Abu Dhabi crown prince, decided that something needed to be done to halt the wasteful flaring of the associated gas that came with the country's rising oil production. They issued directives which called for the valuable gas to be captured and marketed.

The leadership's aspirations were fulfilled on 29 April 1977, when the 125,000m³ *Hilli* departed Das Island with the country's inaugural LNG cargo, bound for Japan. *Hilli* successfully discharged the shipment at the Sodegaura import terminal in Tokyo Bay on 14 May 1977. The LNG project helped bring the flaring of associated gas to an end.

Das Island is a small piece of land in the Gulf, 160km northwest of Abu Dhabi City, and its LNG plant is the first to be built in the Middle East. Covering only 2.5km² in the late 1960s, the island's footprint has been augmented with further tranches of reclaimed land over the years, parts of which have enabled the expansion of the liquefaction facilities and LNG storage capacity.

In 1972 Abu Dhabi National Oil Company (ADNOC) finalised a sales and purchase agreement (SPA) with Tokyo Electric Power Company (TEPCO) covering the delivery of 2 million tonnes per annum (mta) of LNG and 800,000 tonnes per annum (tpa) of LPG for 20 years. The following year Abu Dhabi Gas Liquefaction Company (ADGAS) was established to own and operate the Das Island LNG plant. The participants in this joint venture company are ADNOC, Mitsui, BP and Total.



Arriving in Tokyo Bay from Das Island, *Umm Al Ashtan* was one of the first Moss LNG carriers to be designed with only four cargo tanks

Three ships were built to service the Abu Dhabi project, all owned by Gotaas-Larsen Shipping. *Hilli* was delivered by Moss Rosenberg Værft of Stavanger, Norway, in December 1975 while sisterships *Gimi* and *Khannur* followed in June and July 1976, respectively. Each vessel sported six Moss spherical cargo tanks.

The trio was joined by a fourth vessel, the 1973-built, 88,000m³, spherical tank *Norman Lady*, which was owned by a Buries Markes/Leif Höegh joint venture. The fleet was chartered to Liquid Gas Shipping Company (LGSC), a firm that had been established to handle the carriage of Abu Dhabi LNG to Japan under a 20-year contract. LGSC itself was a joint venture, comprising BP, Compagnie Française des Pétroles (CFP), Mitsui and Bridgestone Liquefied Gas.

In 1980 another Gotaas-Larsen vessel of the Moss spherical tank type, the 126,000m³ *Golar Freeze*, joined the original quartet under a 15-year charter. *Golar Freeze* was completed at Howaldtswerke Deutsche Werft in Kiel, Germany, in February 1977.

In October 1990 ADNOC and TEPCO signed another SPA under which ADGAS would double its production and the Japanese would purchase the additional LNG cargoes for a further 25 years, from 1994. At this point ADGAS placed a contract for the construction of a third liquefaction train on Das Island as well as orders for eight new LNG carriers,

with four to be built in Japan and four in Finland. The newbuildings were to replace the older ships on the route.

The four 137,500m³ ships built in Japan were designed with five Moss spherical cargo tanks, and the construction was shared between three yards. As the lead yard, Mitsui Engineering and Shipbuilding in Chiba built the first and third ships, *Al Khaznah* and *Ghasha*. Kawasaki Heavy Industries in Sakaide constructed *Shahamah*, the second ship, while the final ship, *Ish*, was completed by the Nagasaki yard of Mitsubishi Heavy Industries. *Al Khaznah* loaded its first cargo at Das Island in August 1994.

The Finnish quartet were built at the new Kvaerner Masa-Yards shipbuilding facility in Turku. Each 135,000m³ in capacity, they were the first LNGCs to be built in Finland and amongst the first to incorporate a four Moss spherical cargo tank arrangement. The first pair, *Mubaraz* and *Mraweh*, were delivered in January and June 1996, while the final two, *Al Hamra* and *Umm Al Ashtan*, were completed in January and May 1997. The eight newest ships are managed by Abu Dhabi's National Gas Shipping Company (NGSCO).

All 13 ships that have been and are being used on the Das Island to Tokyo Bay run to serve the ADNOC/TEPCO agreements have had Moss spherical tanks. Furthermore they have fulfilled all their delivery obligations admirably, without any major interruptions. **SH**

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Bontang and Arun put Indonesia on the LNG map

Indonesia fast-tracked development of its gas fields and the construction of two major terminals to become the world's leading LNG export nation

Indonesia despatched its first LNG cargo, from the Bontang plant in East Kalimantan to the Senboku 2 terminal in Japan for Osaka Gas, in August 1977. This shipment, onboard *LNG Aquarius*, was made only five and one-half years after the discovery of gas in the nearby Badak gas field. The country's second LNG plant, at Arun in northern Sumatra, opened for business in October 1978, again with an inaugural cargo to Japan.

Pertamina, the Indonesian state oil and gas company, had signed long-term gas sale and purchase agreements with Japanese electricity and gas utility companies in December 1973 to initiate the country's involvement with LNG. Four new import terminals were built in Japan for this new trade. The Senboku 2 terminal served Osaka Gas and Kansai Electric, Chita was for Chubu Electric and Tobata was for Kyushu Electric, while Nippon Steel and Kansai Electric made use of the new Himeji facility.

Pertamina and Burmah Gas Transport signed a 20-year transport contract for this trade in September 1973, following which Burmah placed an order for seven 125,000m³ LNG carriers at the General Dynamics Quincy shipyard in Massachusetts. The ships, known as the *LNG Aquarius* series after the lead vessel, had five Moss spherical cargo tanks each. *LNG Aquarius* was the first purpose-built LNGC to be delivered from a US yard. All seven ships were US-manned and flagged and were operated by Energy Transportation Corp.

In 1981 Pertamina and the Japanese utilities signed an extension to the 1973 supply contract. This spurred orders for seven additional Moss LNGCs of 125,000m³ at three Japanese shipyards. The ships were delivered between August 1983 and April 1985 and were the first Japanese-flag LNGCs. Kawasaki Heavy Industries (KHI) built *Bishu Maru* and *Kotawaka Maru*. Mitsubishi Heavy Industries (MHI) completed the trio of *Banshu Maru*, *Echigo Maru* and *Dewa Maru*, while Mitsui Engineering and

Shipbuilding (MES) handed over *Senshu Maru* and *Wakaba Maru*.

The ships were owned by various consortia of Japanese companies, all of whom were to become major players in the carriage of Japanese LNG imports during the years that followed. Ownership of the vessels was shared between Japan Line, K Line, Mitsui OSK Lines (MOL), NYK, Showa Line and YS Line. Two new operating companies were formed to serve each of the Indonesian terminals; Badak LNG Transport had three ships in its fleet and Arun LNG Transport four.

The new phase of the Indonesia-Japan trade began in August 1983 when *Bishu Maru* delivered a cargo from the Bontang terminal to Chita for Chubu Electric Power. In the following month *Echigo Maru* loaded its first cargo at the Arun plant for delivery to Niigata on behalf of Tohoku Electric Power.

Pertamina and Korea Gas Corp (Kogas) signed an LNG supply contract in 1983. Upon completion of Korea's first import terminal, at Pyeong Taek, Kogas began importing LNG from Indonesia in 1986. The inaugural Korean cargo arrived onboard the 129,000m³, Moss spherical tank *Golar Spirit*. Completed by KHI in September 1981, the ship was the first LNG carrier to be built in Japan.

In March 1987 Pertamina and Chinese Petroleum Corp (CPC) signed an LNG supply contract covering the delivery of 1.5 million tonnes per annum (mta) of Indonesian LNG to CPC and Taiwan Power for 20 years from 1990. To fulfil this contract a 137,000m³ LNGC was ordered at MHI in Japan. *Ekaputra* was delivered in January 1990 to Cometco Shipping, a joint venture between Mitsui OSK and Indonesia's PT Humpuss Group.

The smallest LNGC built with Moss spherical cargo tanks, the 19,100m³ *Surya Aki*, opened up a new trade from Indonesia to smaller receiving terminals in Japan in 1996. In February

that year the three-tank ship was delivered by KHI's Sakaide yard to MCGC International in fulfilment of a supply contract signed by Pertamina and MOL on behalf of several small Japanese gas companies. *Surya Aki* transported LNG from Bontang to the Hatsukaichi terminal for Hiroshima Gas, to Kagoshima for Nippon Gas and to Senboku for Osaka Gas.

In their heyday Bontang's eight liquefaction trains and Arun's six provided Indonesia with a clear lead at the top of the LNG exporters league table. However, dwindling gas supplies have meant that output at both facilities has been on the decline over the past decade. Although a third LNG export terminal, at Tangguh, was brought onstream in 2009 and two medium-scale liquefaction plants are now under construction in Sulawesi, this new capacity does not match the extent to which output from Bontang and Arun has been shrinking.

Ironically LNG is poised to play an even greater role in the country's energy mix in the years ahead. Several LNG receiving terminals are being built to enable the delivery of gas to the archipelago's diverse population and industrial centres. One of the receiving terminals is Arun, which is being reconfigured to enable cargo discharges. While cargoes to date have been sourced from the country's own LNG terminals, Indonesia is currently negotiating its first supplies of imported LNG. **SH**



LNG Aquarius got the ball rolling for Indonesia on its path to the top of the LNG exporters league table



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Slow-build at Bintulu pays dividends for Malaysia



Tenaga Empat and Tenaga Satu, two of the earliest LNG carriers built for MISC, are now on station at the Malacca import terminal as floating storage units

In 2003, 20 years and seven liquefaction trains after the first such unit came onstream at Bintulu, Malaysia became the world's second largest LNG exporter

When Malaysia's first liquefaction train came onstream at Bintulu in the state of Sarawak in 1983, it was only the ninth LNG export plant to be commissioned. It was also the third such facility on the island of Borneo, joining Brunei's Lumut and Indonesia's Bontang terminals.

As with the Lumut project, Shell as well as Japanese buyers and financial institutions played key roles in bringing LNG to Malaysia. The energy major had discovered substantial reserves of gas in fields off the coast of Sarawak in the late 1960s but a decade was to go by before steps were taken to exploit this wealth. In 1978 Tokyo Gas and Tokyo Electric Power Co (Tepco) initialled purchase contracts covering the output from the planned Malaysia LNG (MLNG) scheme. MLNG was to be a three-train facility with a total production capacity of 6 million tonnes per annum (mta) of LNG.

Under the terms of the sales agreements, Malaysia would have control of the shipping element and would deliver cargoes to Japan on an ex-ship basis. Nominated to own and operate the required vessels, Malaysia International Shipping Corp (MISC) ordered five 130,000m³ GTT No 88 membrane tank LNG carriers at two French shipyards. The newbuildings were delivered in 1981 and 1982 and the MLNG plant loaded its first cargo in January 1983.

More gas was found, as were buyers,

for a new three-train plant at the Bintulu complex. Termed MLNG 2, this project came onstream in 1995. The process was replicated once again and the two-train MLNG 3 project at Bintulu was commissioned in 2003, the year Malaysia moved past Algeria to become the second biggest LNG exporter in the world. The new production units and debottlenecking of the existing trains have boosted total export capacity at Bintulu to 25.7 mta. The complex boasts six 65,000m³ storage tanks and one of 120,000m³.

The MISC LNG carrier fleet grew in tandem with the country's production capacity. The delivery of the 157,600m³ *Seri Balqis* in March 2009 by Mitsubishi Heavy Industries completed the most recent phase of MISC's fleet buildup. MISC now has an LNGC fleet of 29 vessels, two of which were recently removed from seagoing service for conversion to floating storage units (FSUs). The pair are now positioned at the Malacca jetty-based regasification facility, playing a key role in the operation of Malaysia's first LNG import terminal.

MISC is a subsidiary of Petronas, the Malaysian state oil and gas company and the majority shareholder and operator of MLNG, MLNG 2 and MLNG 3. The shipowner provides Petronas with the transport capacity and flexibility to ensure a secure and reliable supply of Bintulu LNG to its full range of contracted buyers.

Although the majority of the MISC

ships are engaged in the carriage of Bintulu cargoes under direct charters with Petronas, the shipowner has been diversifying its range of activities and client base over the past decade. One of the new customers is Asean LNG Trading Co Ltd (ALICO), a company established in 2003 by Petronas to secure the shipping necessary as it develops its own portfolio of LNG activities outside Malaysia.

Expansion work is not finished at Bintulu. Petronas has recently sanctioned the construction of a ninth liquefaction train at the site. When commissioned in the first quarter of 2016, Train 9 will boost LNG production capacity at Bintulu to 29.3 mta. Of liquefaction complexes worldwide, only Ras Laffan in Qatar, with 14 trains now in place, has a larger LNG output.

Amongst the various LNG projects with which Petronas is involved are two floating production (FLNG) vessels currently under construction in Korea. At the moment, the first FLNG vessel is yet to enter service and Petronas is behind two of the five such vessels under construction or being converted.

On delivery in 2015 and 2018, the two Petronas FLNG vessels will be positioned in Malaysian coastal waters offshore Sarawak and Sabah to enable the development of marginal-size gas fields. The commissioning of the two FLNG projects will boost Malaysia's production capacity to 32 mta. **MC**



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Land down under comes up trumps

The North West Shelf project, Australia's first LNG scheme, is celebrating its 25th anniversary this year and setting a fine example for the country's many new schemes

The big event in the world of LNG in 1989 was the start-up of Australia's North West Shelf (NWS) liquefaction plant, the world's 10th baseload LNG export facility. The inaugural cargo departed the new Withnell Bay terminal, on the Burrup Peninsula near Karratha, 1,500 km north of Perth, on 28 July.

The first cargo was entrusted to the 125,000m³ *Northwest Sanderling*, a ship which Mitsubishi had delivered six months ahead of schedule. The US\$9.36 billion, two-train NWS project itself was commissioned two months earlier than originally planned. Sales of LNG from the new Woodside-operated plant, to eight Japanese utilities for a period of 20 years, were due to climb to their peak level of 6 million tonnes per annum (mta) by 1993 when a third NWS train was due for completion.

Northwest Sanderling carried the inaugural cargo to the Sodegaura terminal in Tokyo Bay, some 7,000km and 11 days distant, on behalf of Tokyo Gas and Tokyo Electric. The series of spherical tank ships that were built to transport LNG from Withnell Bay to Japan were the first vessels of this type

to be provided with only four cargo tanks. All previous ships built with Moss spheres were designed with five, or occasionally six, such tanks.

The cargo tank arrangement gave the NWS vessels a greater beam – 47.2m – than any LNG carrier yet built. The ships' aluminium cargo tanks are almost 40m in diameter. The four cargo tank configuration made the ships cheaper to build and repair and easier to operate than a five-tank tank ship.

The same month that *Northwest Sanderling* departed with the inaugural cargo, the NWS project partners ordered the final two of the seven 125,000m³ ships needed to service the project. Contracted at the Mitsui and Mitsubishi shipyards, each of the ships cost US\$200 million. The NWS project ship scheduling called for each LNG carrier to make 14 voyages per year, for a fleet total of 100 voyages per year when all seven vessels were in service from 1993 onwards.

The phased start-up of the NWS project did little to add to global LNG trade levels in 1989 itself. As a result, worldwide movements increased only marginally during the year, to top

the 44 mta mark, or about double the 1980 trade volume. Japan had already established its credentials as the world's leading LNG import nation by 1989, and 69 per cent of the LNG moved by sea that year was discharged at Japanese receiving terminals. LNG imports met about 10 per cent of the country's total energy requirements in 1989.

Today the NWS venture remains Australia's largest hydrocarbons project. Over the past 20 years the original three trains were debottlenecked and two further trains were added at the plant, boosting the total capacity to 16.3 mta. The modular construction techniques used with Train 5 represent a first for the LNG industry. The project also uses pipeline deliveries to meet 65 per cent of Western Australia's gas supply needs.

The expansion work has included the provision of a second jetty, and cargo loadings have climbed to the 200 per annum mark. Exports are now also shipped to long-term customers in China and Korea as well as to buyers around the world on an occasional, spot basis.

The original 20-year contract that the NWS project had with the eight Japanese utilities expired in March 2009. Rather than continue with a similar arrangement, it was left to each individual utility to renegotiate its own follow-up sales contact. The original Japanese buyers adopted a more flexible approach during these contract renewal talks and most finalised medium-term agreements, of 10-12 years duration. In addition, because several renewals are on a free-on-board (FOB) rather than an ex-ship basis, the Japanese utilities are playing a greater role in arranging the shipping requirements than was the case in the past. **MC**



The NWS project's Karratha terminal is despatching cargoes to customers in Asia at the rate of four per week

Atlantic Basin enjoys a reviving LNG decade



The Atlantic Basin LNG trades enjoyed a rebirth in 1999, with the commissioning of the first new liquefaction plants in the region in 25 years

As the 20th century drew to a close the LNG industry was rubbing the sleep out of its eyes and about to embark upon a decade of unprecedented growth. Asia was putting behind it the economic crisis of the late 1990s that had temporarily slowed its strong forward progress and the first new Atlantic Basin liquefaction trains in 25 years were about to be commissioned.

In 1999 the global trade in LNG reached 90.8 million tonnes (mt), 8.4 per cent ahead of the previous year. The Asian market, namely imports by Japan, Korea and Taiwan, accounted for 76 per cent of the world total. Indonesia was the leading exporter, with shipments of 28.3 mt, then Algeria with 18.8 mt, Malaysia 14.9 mt, Australia 7.1 mt, Brunei 6.1 mt, Qatar 4.9 mt and Abu Dhabi 4.7 mt.

The LNG trade surge in 1999 was abetted by the commissioning of six new production trains. Three of the units were built for two new Atlantic Basin export projects. The first of the pair opened in Trinidad in July. When the 125,000m³ *Matthew* loaded the first cargo, for shipment to the Everett receiving terminal in Boston, it marked

the commencement of operations at only the second LNG liquefaction plant in the western hemisphere. North America's first LNG export terminal, at Kenai in Alaska, had come onstream 30 years earlier, in 1969.

The new US\$1 billion, one-train, 3 million tonnes per annum (mta) LNG liquefaction plant at Point Fortin in southwestern Trinidad, known as the Atlantic LNG project, still represents the largest, single investment in the Caribbean. It was also the first new, baseload LNG project in the Atlantic Basin in 25 years. With the loading of the *Matthew* cargo, Trinidad became the world's 10th LNG export nation.

The inaugural Point Fortin cargo represented the culmination of a six-year programme in which adequate gas reserves were proven; innovative contracting mechanisms were employed in finalising gas purchase agreements; a greenfield LNG export plant was built; and shipping arrangements secured. The then existing LNG projects had taken, on average, twice that long to bring to fruition. Cabot LNG of the US, the operator of the Everett terminal and a company which had recently been acquired by Tractebel, was contracted to

purchase 60 per cent of the Atlantic LNG Train 1 output, while Enagas of Spain had secured the remaining 40 per cent.

The commissioning of the Trinidad plant, coupled with an increase in demand for natural gas in the US, particularly for power generation, and an increase in US natural gas prices, prompted renewed interest in LNG in that country. Decisions were made to reactivate two mothballed US LNG receiving terminals, Elba Island eventually returning to service in 2001 and Cove Point in 2003.

The increasing demand for natural gas and the availability of adequate gas reserves around the coast of Trinidad had already ensured that Atlantic LNG would not be a single-train operation. Even before Train 1 was commissioned, engineering studies had been completed for two further 3 mta trains at Point Fortin and sale and purchase agreements (SPAs) finalised for their output.

Spain had agreed to buy 3.75 mta of the additional Trinidad LNG and contracts had been put out to tender for four 138,000m³ LNG carriers to serve this trade. Deliveries were to begin in the first quarter of 2002. Under the terms of a second SPA,

for output from Trains 2 and 3, 1.5 mta of LNG was earmarked for the reactivated Elba Island terminal in Georgia. As 1999 was drawing to a close, the partners in the Trinidad project were pushing ahead with plans to market the output from a possible fourth 3 mta train at Point Fortin.

On the other side of the Atlantic the US\$3.8 billion, two-train Nigeria LNG (NLNG) project finally came onstream in October 1999, some 34 years after it was first proposed by Conch. The 1976-built, 122,000m³ *LNG Lagos* departed the Bonny Island export terminal at Finima in Rivers State with the inaugural cargo, for delivery to Montoir in France on behalf of Italy's Enel.

The other customers of NLNG Trains 1 and 2 were Enagas of Spain, Botas of Turkey and Transgas of Portugal. Over the following years the Enel cargoes were discharged at the Montoir terminal in France due to lack of capacity at Italy's then only LNG import terminal – at Panigaglia terminal near La Spezia. Under this arrangement France made an equivalent amount of pipeline gas available to Italy to compensate.

The original partners in NLNG were the Nigerian government, Shell, Elf and Agip. On commissioning, each of the two trains at Bonny Island had a capacity of 2.7 mta. The growing demand for LNG and the availability of significant gas reserves in the vicinity of Bonny Island ensured that the decision to construct a third train at the terminal was taken six months before the first two came onstream.

In the event the third, similar-sized train was to be commissioned in November 2002, three months ahead of schedule. Once underway, the build-up at Bonny Island was rapid. By February 2001 NLNG had loaded its 100th export cargo and the 400th cargo was discharged at Montoir in September 2003, again by *LNG Lagos*.

Spain, a major purchaser of LNG from Trinidad and the first two Nigerian trains, also made a major commitment in terms of the output from NLNG Train 3, signing up to take 75 per cent of the 2.7 mta that would be produced by the unit. Like their counterparts in Trinidad, the companies behind the Nigerian project were quick to plan even farther ahead, having tabled proposals for Trains 4 and 5 at Bonny before the end of 1999.

In August 1999, as part of the build-up of the fleet needed to carry Nigerian cargoes, Bonny Gas Transport, a

subsidiary of Nigeria LNG, ordered two 138,000m³ spherical tank LNG carriers at Hyundai Heavy Industries. These were the first LNG carriers to be ordered in Korea for foreign owners.

Algeria, the first country to export LNG, also had taken steps to improve its offering to the Atlantic Basin LNG market in the late 1990s. The country's export volume had dropped to 12.8 million tonnes in 1995 and its ageing production facilities were in need of a revamp. The wide-ranging refurbishment programme implemented by the government in response succeeded in boosting overall production capacity back up to the 21 mta level by 1999. A good level of utilisation was achieved, as Algeria despatched 18.8 mt to customers around the Atlantic Rim and in the Mediterranean over the course of the year.

At the end of 1999 the world LNG carrier fleet stood at 114 vessels while there were 28 ships on order at nine different shipyards. Some of the consultancies specialising in LNG trade forecasting got caught up in the buoyant mood prevailing in 1999 and predicted, in their optimistic case scenario, that there would be a need for a further 100 new LNG carriers over the coming decade, bringing the fleet up to the 250-ship mark by 2010.

In the event the pundits were not optimistic enough, as there were 350 vessels in the global LNG carrier fleet by the end of 2009. To be fair, there was no way of predicting what a topsy-turvy decade it would turn out to be. No one was in a position to fully appreciate either the extent to which the hunger for gas would drive the market or the ability

of Qatar's ambitious export programme to meet that demand. The US shale gas revolution, unforeseen in 1999, turned out to have a bigger impact still.

The Atlantic Basin LNG market did indeed blossom during the first decade of the new millennium. Shipments to the US, Spain and the UK in particular surged and three new liquefaction plants were built – two in Egypt and one in Norway – to help cater for the growing regional demand. Furthermore Qatar brought six new 7.8 mta Super Trains into service and a significant part of the output from these facilities was earmarked for shipment through the Suez Canal to Europe and the US.

The honeymoon was short-lived, however. The exploitation of shale gas resources in the US meant that the country's imports peaked in 2007, at 16.2 mt, and then fell away sharply. Europe's imports did not top out until 2011, when they reached 64.8 mt. The continent's purchases have slumped steadily since then, as the recession following the 2008 banking crisis bit deeply and soaring Asian demand and gas prices sucked available cargoes eastwards. Europe's LNG imports fell to 33.9 mt in 2013, a nine-year low.

The Atlantic Basin LNG trades over the coming decade will be very much different from those envisaged when the plants in Trinidad and Nigeria commenced operations. The US is poised to become a major LNG exporter while Europe is struggling to rediscover its appetite for LNG. No doubt European imports will revive but, failing a geopolitical crisis of some sort, it will be a long, drawn out process. **MC**



Matthew loaded the inaugural Atlantic LNG cargo in July 1999

Qatar redefines the art of the possible

Qatar started out ambitiously in its drive to provide a world-class LNG delivery capability, and went on to set new standards in LNG production and transport

Superlatives are required to describe every aspect of Qatar's involvement with LNG. The country possesses the largest single concentration of gas yet discovered, the North Dome field, and has built the world's biggest LNG export complex, at Ras Laffan, to bring that gas to world markets.

The cargoes are transported by Nakilat, owner and operator of the world's largest fleet of LNG carriers. Furthermore that fleet features 31 Q-flex ships of 216,000m³ and 14 Q-max ships of 266,000m³, the only LNGCs over 200,000m³ in size.

Amongst the 14 liquefaction units operating at Ras Laffan on behalf of Qatargas and RasGas, the country's two LNG exporters, are six Super Trains, each able to produce 7.8 million tonnes per annum (mta) of LNG. This is the highest capacity of any such production facility in the industry. Ras Laffan is able to

produce an aggregate 77 mta, three times more than Malaysia, its next nearest rival at the top of the LNG exporters league. The port has been operating at, or close to, capacity in recent years, despatching approximately 1,000 LNG cargoes per annum to customers worldwide.

The Gulf emirate's LNG adventure began in December 1996 when the 135,000m³ LNG carrier *Al Zubarah* loaded Ras Laffan's first export cargo. *Al Zubarah* is the lead tanker of a 10-ship fleet of spherical tank vessels built to deliver 6 mta of Qatari LNG to Japan over a contracted period of 25 years. Delivered by Mitsui Engineering & Shipbuilding, *Al Zubarah* was the 49th LNG carrier to be built to the Kvaerner Moss spherical tank design out of a world fleet of 90 such ships in service at the time.

Chubu Electric signed up for the full output but 2 mta of the total was purchased on behalf of seven other Japanese utility companies. Although

this scheme, dubbed Qatargas 1, was the world's most ambitious LNG shipping project at the time, it represented only the beginning of Qatar's plans to capitalise on the North Dome gas reserves.

Even before the US\$800 million Qatargas 1 grassroots complex, which featured three 2 mta liquefaction trains and three 85,000m³ storage tanks, was in service another Ras Laffan project had been agreed. In October 1995 Korea Gas Corp (Kogas) signed a contract with Ras Laffan LNG Co (RasGas) for the purchase of 2.4 mta of Qatari LNG for 25 years commencing in 1999, and later exercised an option to purchase an additional 2.4 mta, beginning in the year 2000. The RasGas 1 complex was to feature two 3.3 mta liquefaction trains and two 140,000m³ LNG storage tanks at the port to service the initial contract levels.

The RasGas 1 project is a 70/30 joint venture between Qatar General Petroleum Co and Mobil. The Mobil share was to become an ExxonMobil share when the two energy majors merged in 1999. ExxonMobil is also one of the shareholders in the Qatargas 1 scheme and was to hold stakes in several subsequent Ras Laffan LNG export projects mounted by Qatargas and RasGas. Qatar Petroleum possesses a controlling share in all the Qatargas and RasGas LNG export projects.

The shipping arrangements for the RasGas 1 project were to be similar to those for Qatargas 1 in that they would be the responsibility of the gas

Mozah, the first of 14 Q-max ships to be delivered, on sea trials off Korea's southern coast



Ras Laffan loads an average of 20 cargoes per week



purchaser. In August 1996 orders were placed, against Kogas charters, for six 135,000m³ LNG carriers at four Korean shipyards: Hyundai Heavy Industries (HHI) was to build two ships for Hyundai Merchant Marine; Daewoo Shipbuilding & Marine Engineering (DSME) one ship for Korea Line and one for Yukong Line; Hanjin Heavy Industries one ship for Hanjin Shipping; and Samsung Heavy Industries (SHI) the final vessel for Yukong Line.

The Hyundai ships were built with Moss spherical tanks while the four other ships sported membrane tanks of either the Technigaz or Gaz Transport type. All the vessels were constructed for the then-competitive price of approximately US\$220 million each and were delivered over the 1998-2000 period. These RasGas 1 vessels were the first LNG carriers to be built in Korean yards. A seventh Korean-built and operated ship was later ordered to meet the transport needs of the full 4.8 mta Kogas contract.

The RasGas 1/Kogas agreement was inaugurated on schedule in August 1999 when the 135,000m³ *SK Summit* loaded the first of 1,900 cargoes scheduled for delivery to the Korean utility over the 25-year life of the scheme.

In those early days Qatar was also negotiating a possible LNG export deal with Enron, the self-styled “world’s first gas major”. Enron was seeking to purchase 5 mta for the Dabhol power plant it was building in India. However, Enron was already running into trouble with the Maharashtra state government over energy pricing, and the LNG terminal adjacent to the power plant was not completed at that time. Enron filed for bankruptcy in late 2001, the biggest collapse in US corporate history.

It was not long before an Indian LNG

project did emerge. In March 2001 a third Qatari LNG company – RasGas 2 – was established to supply 7.5 mta of LNG to the Indian utility Petronet for 25 years, commencing in late 2003. RasGas 2 built two LNG production trains, each of 4.7 mta, at Ras Laffan to meet the needs of this new agreement. At the time, the Petronet deal was the world’s largest LNG sale with a single customer, while the two RasGas 2 trains were to be the world’s largest, at least for a short period.

Even then there were no plans to ease back. Qatargas was pressing ahead with a proposal to add a fourth liquefaction train and boost its production capacity to 9.2 mta by 2003. In April 2001 Qatargas announced a one-off deal with Spain for the sale of up to 1.5 mt of LNG, and a few months later RasGas signed a sales agreement with Italy calling for the supply of 3.5 mta of LNG for 25 years to a new offshore LNG receiving facility in the North Adriatic, beginning in 2005.

The latter arrangement represented the first long-term LNG sales contract signed between a Middle East supplier and a European importer. The Adriatic LNG terminal was an offshore gravity-based structure, the industry’s first such facility, and Qatar Petroleum and Exxon Mobil were to become the major shareholders in the venture.

By 2000 LNG shipments to overseas customers of Qatargas and RasGas had climbed to 10.4 mt. Within the space of four years Qatar had become the fourth largest LNG exporter in the world and was achieving annual gas sales revenues of US\$2.5 billion. This was only an initial step in the growth curve, however. The country was targeting production levels of 30 mta by 2007, at which point it would be the top LNG

export nation and LNG revenues would exceed those from oil for the first time.

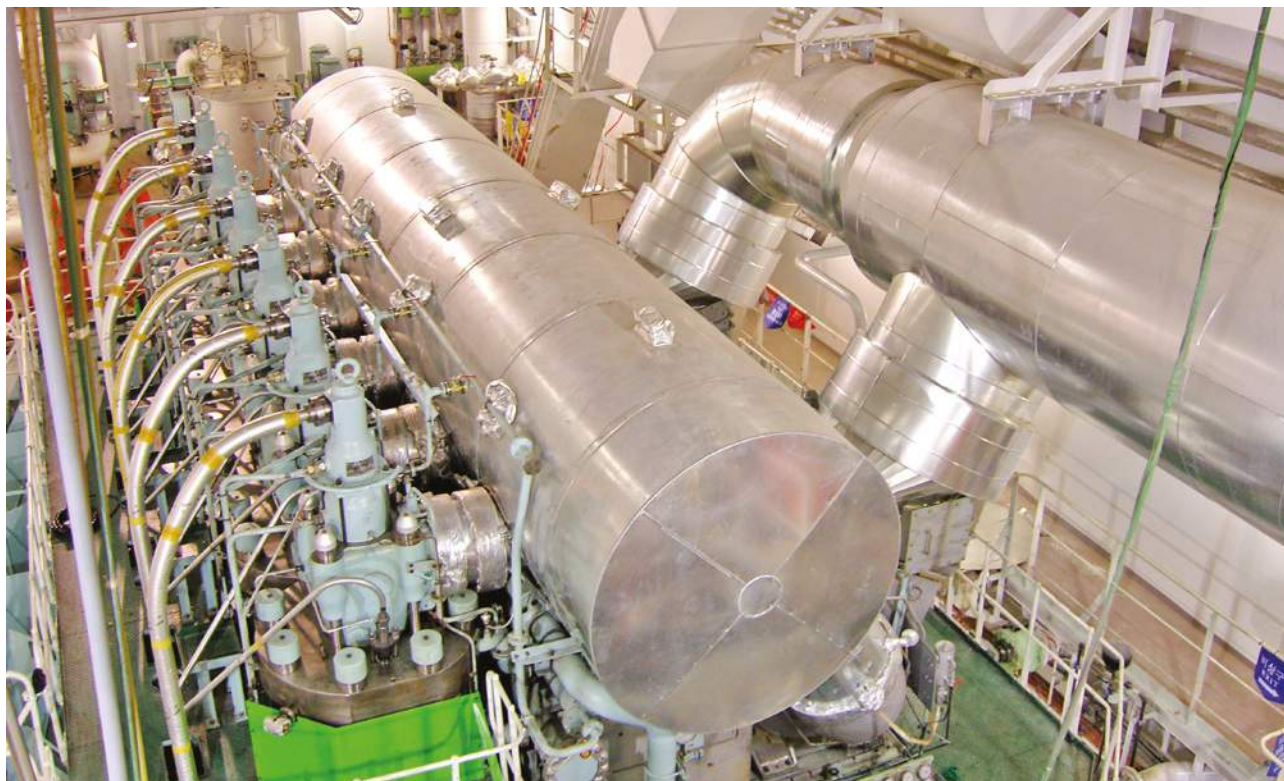
The Adriatic LNG project also marked the first in which Qatar was to secure control of the full supply chain, including making deliveries ex-ship. In addition to its majority shareholding in the receiving terminal, RasGas made arrangements to charter four LNGC newbuildings to transport cargoes to Italy.

Qatar Gas Transport Co Ltd (QGTC), or Nakilat, was established as a joint stock company in 2004 by the state of Qatar to provide shipping and marine-related services, including in the transport of the country’s gas exports. Nakilat took an ownership interest in the four Adriatic LNG ships as well as five further conventional size LNG carriers built for other Ras Laffan export projects. Amongst the marine services provided by Nakilat, in tandem with foreign partners, are a harbour towing and mooring operation and a ship repair yard at Ras Laffan.

Of the 45 Q-flex and Q-max ships mentioned above, 25 are wholly owned by Nakilat and 20 are part-owned. The three Korean yards of DSME, HHI and SHI recorded a remarkable shipbuilding achievement by delivering the full complement of Q-flex and Q-max vessels within the space of 34 months, between October 2007 and August 2010.

The 45 LNG carriers were constructed at a cost of US\$12.5 billion and three societies – ABS, DNV and LR – were involved in classing the fleet. The 19 DSME-built ships have GTT No 96 membrane tanks while the eight vessels constructed by HHI and 18 by SHI have GTT Mark III membrane tanks.

The Q-flex and Q-max ships, which are all chartered by either Qatargas or RasGas, have enabled Qatar to achieve



The possibility of converting Q-flex and Q-max ships to dual-fuel running on a fleetwide basis is under review

improved economies of scale in the delivery of LNG to its customers. The four Qatargas and two RasGas Super Trains in place at Ras Laffan have also contributed to this capability. These facilities have built Ras Laffan's production capacity to today's level of 77 mta from 14 trains.

The technical management of the 25 Q-flex and Q-max ships fully owned by Nakilat is the responsibility of Shell International Trading and Shipping Company (STASCO). Under the master services agreement signed by Nakilat and Shell, STASCO is assisting the Qatari owner in managing its LNG carrier fleet and recruiting and training seafarers. Further, the partnership agreement calls for Nakilat to assume full responsibility for the management of the fleet within a timeframe of 8-12-years.

The Q-flex and Q-max vessels were designed and ordered when oil prices were low and those for gas high. The situation resulted in a ship design which is unique for LNG carriers, i.e. a pair of conventional, oil-burning, low-speed diesel engines for each vessel in tandem with a powerful reliquefaction plant which processes cargo boil-off gas and returns it to the tanks as LNG.

Hamworthy provided the reliquefaction plants for the Q-flex ships and Cryostar those for the Q-max vessels. It was decided at the design stage that each of the large ships had to be

provided with two reliquefaction plants to provide a full measure of redundancy. Because the reliquefaction plants are computer-controlled when in service rather than operated manually, additional redundancy is provided through backup monitoring and control systems. For emergencies, to dispose of excess gas if the full cargo reliquefaction capability is down, each vessel is provided with a gas combustion unit (GCU).

All the Q-flex and Q-max ships are built with five cargo tanks, in contrast to the four tanks on conventional size LNG carriers. As many of the conventional size LNG ships now being ordered are of 170,000m³ and above, there is not much difference in cargo-carrying capacity between an individual cargo tank on one of these ships and one on a Q-flex vessel. Amongst other things, the five-tank arrangement reduces the risk of cargo sloshing damage. The longitudinal strength of the big LNG carriers is such that the ships are capable of handling any combination of full or empty cargo tanks.

As is the case with several of the liquefaction projects at Ras Laffan, the key principals behind the development of the designs for the Q-flex and Q-max ships were ExxonMobil and Qatar Petroleum. The pair established the Qatargas Operating Company Ltd to oversee the design and supervise the construction of the Q-flex and Q-max

fleet. At the busiest time of the newbuild project Qatargas Operating Co had 150 people on its payroll.

Qatargas Operating Co believed that one of the key advantages of providing high-capacity reliquefaction plants for the Q-flex and Q-max vessels was that it disentangled the issue of cargo tank pressures from the ship's fuel cycle. Nevertheless fuel is the major cost item for Qatargas and RasGas, as charterers of the vessels. Oil bunkers are now expensive relative to natural gas, to the extent that conversion of the existing MAN engines on the Q-flex and Q-max ships to dual-fuel running is being considered.

In 2015, as a test case, the two engines on one of the Q-max vessels will be converted in a project likely to require 40 days in drydock to complete and an expenditure of US\$15-20 million. The results of this trial will determine whether the conversion of the whole or a further part of the 45-ship fleet is feasible.

In the meantime most new LNG receiving terminals coming onstream worldwide are designed to accommodate ships of up to the Q-max size and many existing facilities not previously sized for such vessels have now been suitably modified. In recent years one-third of all LNG moving by sea originated in Qatar and in 2013 shipments from Ras Laffan reached 25 of the world's 29 LNG-importing countries. **MC**



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Regas vessels streamline route to LNG imports

In the space of 10 years regasification vessels have established themselves as a strong, low-cost and fast-track alternative to shore-based receiving terminals

In 2000 El Paso Corporation began to explore the novel concept of shipboard LNG regasification. Known US gas reserves were dwindling at the same time that domestic consumption was rising and LNG imports were recognised as the best way of bridging any future gaps between supply and demand.

El Paso's theory was that an offshore offloading system could be designed and built at far less cost than a shore-based facility and that, by delivering the product offshore in its gaseous state using a regasification vessel, expensive shore-based facilities could be eliminated from the transport equation. A regas vessel-based receiving facility would also enable LNG imports to begin more quickly than would be the case if a new shore terminal had to be built.

The company chose the Gulf of Mexico for its initial installation, selecting a site 180km off the US Gulf Coast at the Louisiana/Texas border as the location of a deepwater port named Gulf Gateway Energy Bridge. The 'port' itself would be invisible except for a small marker buoy fixed to a submerged turret loading (STL) buoy, itself linked to a subsea pipeline via umbilicals. A similar technology had been utilised for handling oil cargoes offshore in the North Sea for a decade.

On arrival at the sea marker the regasification vessel would pull up the STL buoy and connect it to a moonpool arrangement in its bow. Regasification units mounted on the ship would then begin to process the LNG and pump the resultant natural gas to the shore grid via the subsea pipeline link.

The regas vessel would be supplied by LNG delivery tankers, and cargoes would be transferred in the open sea in a ship-to-ship (STS) operation using flexible cryogenic hoses. Because the regas vessel would be, to all intents and purposes, a conventional LNG carrier fitted with suitable regasification equipment, the ship

could proceed to the export terminal to load cargo itself or even serve in the LNG trades until that time its regasification services were required.

In 2002 El Paso agreed to take on long-term charter three 138,000m³ regasification vessels that Exmar of Belgium would order at Daewoo Shipbuilding & Marine Engineering (DSME) in Korea. The vessels, which were priced at approximately US\$270 million each, would be owned and operated by Exmar. Advanced Production and Loading AS (APL) of Norway was contracted to provide the STL buoy required for the Gulf Gateway Energy Bridge deepwater port facility.

At about this time El Paso Corp had need to raise cash and it was decided that the Energy Bridge technology would be one of the assets put up for sale. Although one or two majors considered the offering, they decided to pass.

It was at this point that George Kaiser, an Oklahoma billionaire who had a strong belief in a bright future for natural gas in the US, stepped in to buy the technology and take over the

Energy Bridge commitments made by El Paso. As part of the package Kathleen Eisbrenner and her El Paso team who had developed the concept moved over to join Kaiser's newly established Excelerate Energy.

Excelerate Energy and Exmar went on to develop a strong relationship over the past decade and to record many regasification vessel 'firsts' in the process. Excelerate now has a fleet of nine DSME-built regas ships, the latest being the 173,400m³ *Experience*, delivered in April 2014. The other components of the fleet are the original three 138,000m³ ships and five vessels of 151,000m³. All are managed by Exmar, and both the Belgian shipowner and Excelerate hold 50 per cent stakes in four of the regas ships. Excelerate fully owns the remaining five.

The Gulf Gateway facility was inaugurated in March 2005 with the delivery of a part cargo from the 138,000m³ *Excelsior*, the industry's first regas vessel. All that had been needed to bring the port onstream, besides the STL buoy, were some short lengths of pipe to a metering station installed on a nearby unused platform and to the existing gas pipeline network in the US Gulf. Gulf Gateway proved its resilience later in the year when Hurricane Katrina passed through the Gulf and the facility was the only terminal in the area that remained



Italy's FSRU Toscana project has extended the offshore regasification technology envelope

operational throughout.

Excelerate went on to install a similar facility, Northeast Gateway, on the US eastern seaboard, off the coast of Massachusetts. But at this point the US shale gas revolution was beginning and the country's need for gas imports evaporated virtually overnight. Although the US Gateways were little used, Excelerate's solution was much sought after elsewhere, proving the underlying strength of the floating regas vessel concept.

The configuration that has proved most popular is the company's GasPort arrangement, in which the regas vessel is berthed at a dedicated jetty, either permanently or for a dedicated import season each year. GasPorts are usually provided with jetty-mounted loading arms for LNG transfers from the delivery tanker.

The next milestone for the Excelerate vessels was the first commercial STS transfer of LNG. This happened in the US Gulf in August 2006 and involved the transshipment of a partial cargo between two of the company's regas vessels. This was followed in February 2007 by the first commercial transshipment of a full cargo, at Scapa Flow in the UK's Orkney Islands. The receiving vessel, *Excelsior*, then proceeded to inaugurate the Teesside GasPort terminal by discharging the first regasified LNG directly into the UK national grid.

In June 2008 the Bahia Blanca GasPort in Argentina received South America's first LNG cargo. Further GasPorts were commissioned in Kuwait in August 2009 and at Escobar on the Paraná River in Argentina in 2011. Because of the restricted water depth at Escobar, the operation requires STS transfers in the mouth of the nearby River Plate to enable the delivery of part cargoes to the terminal's regas vessel in conventional size LNG carriers.

The other major players in the regasification vessel sector are Golar and Höegh LNG. Golar made its entry into the field with conversions of its existing ships. Five such conversions have been carried out to date and the company continues to own and operate four of the vessels as jetty-based floating storage and regasification units (FSRUs). Two are working in Brazil, one in Dubai and one in Indonesia. The first conversion, of the 129,000m³, 1981-built *Golar Spirit* by the Keppel yard in Singapore, was completed in June 2008 and enabled Brazil's first LNG imports.



Excelerate Energy is now carrying out over 100 STS transfers a year in support of its regas vessel operations

The fifth Golar FSRU conversion, of the 138,800m³, 2004-built, spherical tank *Golar Frost*, was the most ambitious. The ship was sold to the Italian company OLT Toscana and renamed *FSRU Toscana*. The modification work was undertaken by Drydocks World Dubai and involved the removal of the vessel's propulsion system and the installation of not only regasification equipment but also a sophisticated turret yoke bow mooring system and deck-mounted loading arms. Designed to remain on station for 20 years, the FSRU marked a further breakthrough for offshore LNG when it went into service at a location off the Tuscany coast in autumn 2013.

Golar has extended its commitment to the regas sector through newbuildings. Three such vessels were ordered at Samsung Heavy Industries (SHI) in Korea in recent years. The first of these, the 170,000m³ *Golar Igloo*, has been delivered and has gone into service in Kuwait while the 160,000m³ *Golar Eskimo* is scheduled to go on station at Aqaba in spring 2015 to enable Jordan to commence LNG imports. The third FSRU newbuilding, the 170,000m³ *Golar Tundra*, is scheduled for late 2015 completion. Golar is providing its newbuildings with regasification equipment capable of processing up to 5.5 million tonnes per annum (mta) of LNG.

Höegh LNG currently has two 145,000m³ regas vessels on charter to GDF Suez. *GDF Suez Cape Ann* is serving as a receiving terminal at Tianjin in China while *GDF Suez*

Neptune is earmarked for a similar, albeit temporary, role at Montevideo for Uruguay's GNL Sayago project. The vessel will eventually be replaced by a 263,000m³ FSRU that Mitsui OSK Lines (MOL) currently has under construction at DSME.

Höegh LNG has also been active on the newbuilding front. The shipowner has recently taken delivery of the first two of four 170,000m³ FSRUs contracted at Hyundai Heavy Industries. The pair are being employed under long-term contracts as Indonesia's second and Lithuania's first LNG receiving terminal, respectively.

The MOL FSRU will be the largest such vessel when completed in 2016. Another newcomer besides MOL to the regas ship sector is BW Gas. The company has two 170,000m³ vessels on order at SHI in Korea, the first of which is scheduled to go into service in the Dominican Republic on delivery in 2015. Exmar is building on its expertise in the sector and is promoting its non-propelled, barge-mounted regas floater design. The first such unit is under construction at the Wison yard in China.

Regasification vessels have come a long way in the space of 10 years. As of end-2013 there were 20 regasification projects in service or under construction, and global floating regasification capacity had reached 44.3 mta of LNG, 34 per cent ahead of the previous year, in nine countries. By the end of 2015 a further eight LNG importing nations are expected to have regasification vessel-based terminals in place. **MC**

Gaz de France Energy, now GDF Suez Global Energy, is the first LNG carrier to be ordered with a DFDE propulsion system



The blossoming of LNGC propulsion

Until a decade ago there was no serious alternative to steam turbines for LNGC propulsion. Today shipowners have four viable options available

LNG carriers have been the last redoubt of the marine steam turbine industry. Until the early years of the new millennium every LNG carrier newbuilding was specified with a steam turbine propulsion system. While all other sectors of commercial shipping had long since been seduced by the greater propulsive efficiencies of diesel engines, LNG owners had stuck with steam turbines for several reasons, most notably their dual-fuel capabilities.

Cargo boil-off gas (BOG) generated during the course of an LNG carrier voyage can be burned in a steam vessel's boilers as readily as fuel oil to generate steam. In addition turbines have proved to be extremely reliable throughout the history of LNG carrier operations. Their low maintenance

requirements are another attribute.

Steam turbines are also able to handle any excess cargo boil-off gas by means of dumping surplus steam to the seawater-cooled condenser in the engine room. This capability means that low propulsion system loads pose no undue problems. It also obviates the need for expensive ancillary equipment such as reliquefaction plants and gas combustion units (GCUs).

However, just over a decade ago, on the verge of a major new growth phase for the LNG industry, Gaz de France (now GDF Suez) took the brave step of choosing a new LNGC propulsion system. The LNG industry was pushing to cut costs and improve efficiencies along the transport chain in order to improve the economics of gas projects. Ship propulsion had been identified as an area of potential savings, and investigative work on alternatives to steam turbines on LNG ships had been intensifying.

Through its Gazocéan shipowning subsidiary, Gaz de France ordered the first three LNGCs to be powered by dual-fuel diesel-electric propulsion (DFDE) systems. The newbuilding contract for the 74,130m³ *GDF Suez Global Energy* was placed with Chantiers

de l'Atlantique in February 2002 while orders for two 153,500m³ sisters, *Provalys* and *Gaselys*, were placed with the same yard in September 2003 and July 2004, respectively. Complications with the innovative membrane containment system also specified for the three vessels delayed their delivery but they were all in service by March 2007.

Gaz de France was in a good position to pioneer DFDE propulsion because of the company's control of the supply chains on which the vessels would operate. The three ships loaded cargoes at export plants where GDF Suez had contracted supplies and delivered them to company-owned receiving terminals in France.

Nevertheless, despite the 'in-house' nature of the employment, it was still a courageous move for an industry that was notoriously conservative. Gaz de France had been impressed by the performance of Wärtsilä's 50DF dual-fuel test engine and decided that, given the level of reliability and redundancy provided by the propulsion system, its improved efficiency compared to steam turbines would yield significant cost savings over the life of the vessels.

GDF Suez Global Energy was specified with four six-cylinder Wärtsilä 50DF dual-fuel engines which provide an aggregate power of 22.8MW and a service speed of 17.5 knots. In normal operating conditions natural BOG is complemented, when required, by forced BOG for use as fuel. The engines can run on marine diesel oil in situations where no gas is available.

The DFDE propulsion system quickly proved its ability and from the mid-2000s onwards the LNG shipowner community switched to DFDE systems for the greater part of its newbuilding requirement. Underpinning this shift was a growing awareness that DFDE systems outperform steam turbines on cost, emission levels, fuel consumption, flexibility, redundancy and efficiency. The propulsive efficiency of a steam turbine at full load, for example, is unlikely to exceed 30 per cent whereas a 40 per cent rating is typical for a DFDE system.

As of mid-2014, although there were 274 steam-powered LNGCs in service, the DFDE contingent had climbed to 67 ships and is growing much more rapidly. Of the 120 LNG vessels on order on 1 July 2014, 98 were specified with DFDE propulsion systems, 10 with steam, nine with low-speed dual-fuel engines and four with oil-fired diesels.

There is also a significant group of LNG vessels in service that do not utilise cargo BOG for propulsion. These are the 31 Q-flex and 14 Q-max ships delivered over the 2007-2010 period to Nakilat of Qatar. At 216,000m³ and 266,000m³, respectively, they are the largest LNGCs in the world.

When they were ordered the price of oil was relatively low and that of gas on the high side. Qatargas and RasGas, the vessels' charterers, reviewed their options at the design stage and decided that a pair of oil-burning, two-stroke diesels, in combination with a powerful reliquefaction plant to process BOG and ensure the delivery of full cargoes, offered the optimum economic solution for the Q-fleets and Q-maxes.

As the ships were being delivered, however, the oil and gas pricing trends reversed, casting doubt on the wisdom of the propulsion system choice. The fuel price quandary has persisted, to the extent that Qatargas has decided to convert one of its Q-max vessels to dual-fuel running early in 2015 as a test case. Depending on the results, the propulsion systems on further Q-flex and Q-max ships could be similarly modified.

The conversion involves altering the configuration of the two MAN ME low-speed diesels on the ship to the engine manufacturer's ME-GI gas injection type of unit. Gas is introduced into the engine at high pressure and the diesel displacement rate can be as high as 95 per cent, leaving diesel's contribution as a pilot fuel at 5 per cent. MAN is seeking to reduce the amount of diesel pilot fuel required to

as little as 3 per cent.

MAN Diesel & Turbo reports that its ME-GI engine is not susceptible to the methane slip that other gas-burning engines have to contend with and, as such, represents an environment-friendly propulsion system choice. Furthermore the low-speed, gas-injection engine has a higher drive train efficiency than the DFDE configuration and, on the whole, is a less complex propulsion system.

The ME-GI engine has now also made a breakthrough into the LNGC newbuilding market, as the result of a December 2012 order by Teekay at Daewoo Shipbuilding & Marine Engineering (DSME) for a pair of 173,400m³ ships. The shipowner has since exercised several options at the yard and will now have five ships in this series built with ME-GI propulsion systems. More recently two other shipowners have specified ME-GI engines for the pairs of LNGCs they have contracted.

ME-GI engines units have also been specified for eight LNG-powered container ships and car carriers currently under construction. MAN is taking the technology a stage further by developing alternative dual-fuel versions that run on LPG, methanol and ethane.

Each of the Teekay LNG carriers will have two 5G70ME-GI ultra-long-stroke, G-type engines, and MAN points out that the G-type's longer stroke enables a reduction in engine speed and the use of larger diameter propellers. Such a configuration results in an especially high level of propulsion system efficiency. The engine manufacturer states that in recent years its conventional, heavy fuel oil-burning G-type unit has gained the fastest market acceptance of any engine in its portfolio.

That is not the end of LNGC propulsion system innovation. In November 2013 Wärtsilä unveiled its low-speed contribution to the melting pot. The 6RT-flex50DF is a new, low-pressure, two-stroke, dual-fuel gas engine. The engine manufacturer explains that in the gas-burning mode the 6RT-flex50DF is compliant with the IMO Tier III emission requirements without the need for nitrogen oxide (NO_x) abatement equipment.

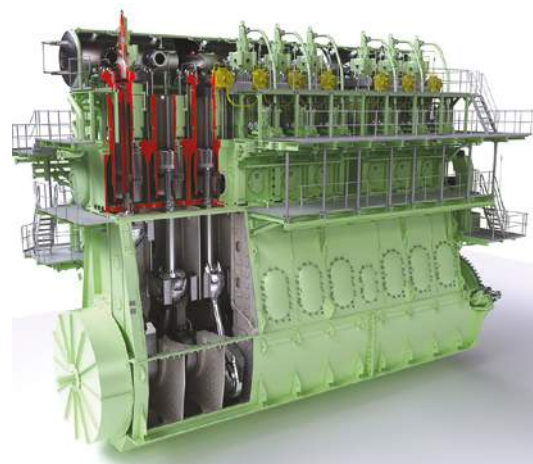
Furthermore it is claimed that the engine will provide capital expenditure savings of between 15 and 20 per cent compared to other two-stroke gas engine technologies currently on the market. This is due, not least, to the fact that the

6RT-flex50DF can run solely on gas across the entire load range, thus obviating the need for an exhaust gas cleaning system. Also, because only low-pressure gas compression is required, the LNG and gas-handling system is substantially simpler and of lower cost than a high-pressure gas delivery system with heavy-duty compressors.

Within days of the official launch of the engine, Terntank Rederi A/S, a Danish-flag tanker operator, selected Wärtsilä RT-flex50DF engines for two 15,000 dwt, LNG-powered product tankers it ordered from the Avic Dingheng yard in China for service in the Baltic Sea. The engine was also chosen to power a 14,000m³ coastal LNG carrier contracted in China in March 2014.

While orders for steam-driven LNGCs have become a comparatively rare occurrence over the past decade, there has been a modest resurgence of interest in this propulsion system in recent years. It is hanging on to a small segment of the newbuilding market as a result of the ultra steam turbine (UST) technology introduced by Mitsubishi Heavy Industries (MHI) in 2007.

UST, which promises a 15 per cent higher propulsion system efficiency than a conventional turbine, has been chosen for eight LNG carriers ordered at MHI in recent years by Japanese owners as well as for a series of four LNGCs contracted by Petronas of Malaysia at Hyundai Heavy Industries in Korea. The first of the MHI newbuildings is set to enter service in the latter part of 2014 while the Petronas order marks the first market success for Mitsubishi's UST system outside Japan. Petronas holds an option for four additional LNGCs of this design at Hyundai. *MC*



The first LNG carrier powered by an MAN ME-GI two-stroke gas injection engine will take to the sea in 2016



Nine out of the 10 ships in the Dynagas fleet are ice class 1A vessels

New players make the LNG leap

Independent owners have taken the opportunity offered by a surge in trade volumes over the past decade to establish a sizeable presence in LNG shipping

The stakes are formidable for shipowners in the LNG sector. Newbuilding costs set the bar high for entry into the business and the lack of a long-term charter exposes the newcomer to the vagaries of the market and, potentially, if no immediate business is forthcoming, a rapid drawdown of available funds and financier goodwill. On the other side of the coin, if a lucrative term contract can be secured, the shipowner could be assured of a steady revenue stream not likely to be encountered in many other sectors of shipping.

In the early days of the LNG industry national shipping lines in the export countries became involved with the transport of their cargoes as soon as they were able, usually making use of the LNG carrier expertise of one of their international oil company project partners in the drive to get up to the necessary speed.

In the two top LNG importing countries, Japan and Korea, the leading shipping lines have long played a major role in those projects where cargoes are purchased on a free-on-board (FOB) basis. In Japan in particular, Mitsui OSK Lines, NYK and K Line have built a significant presence. Their pattern of

sharing ownership stakes in individual ships and vessel management amongst the vast pool of vessels they operate on behalf of a range of Japanese utility companies is well established. The expertise of the Japanese trio is also now much sought after internationally, to the extent that they participate in a number of LNG shipping ventures outside Japan, both singly and in various combinations.

A decade ago the rather limited LNGC owner community was completed by a handful of independent owners, including Golar and Leif Höegh, with a long involvement in LNG transport. Their presence was relatively marginal, reflecting the slow pace at which the LNG industry had been expanding up to that point and the limited room to manoeuvre due to the presence of national shipping interests.

The new millennium brought with it the first sustained wave of growth in the LNG sector, both in terms of new projects and the expansion of the LNGC fleet. The surge opened up opportunities for new owners to become involved and a small group, with experience of LPG carrier and oil tanker operations, were quick to seize the opportunity. Most notable amongst the newcomers

were Exmar, Maersk, Knutsen OAS and Bergesen, now BW Gas.

As described in the article on page 92, Exmar carved out a niche in the regasification vessel sector in tandem with Exxcelerate Energy. BW Gas, Knutsen OAS and Maersk built up their fleets through newbuildings backed by long-term charters. In the case of BW Gas the employment for their vessels was provided by Nigeria LNG and GDF Suez while Knutsen operated its newbuildings on behalf of Stream in Spain. RasGas of Qatar was the charterer of Maersk's first LNG carriers.

The expansion of the LNG trades in the first decade of the new millennium was so great that there was room for yet more new players. The second wave can be summed up as the late arrival of Teekay and the emergence of the Greeks.

Teekay, a significant presence in the oil tanker and offshore sectors, announced that it was seeking to become involved in LNG shipping in late 2003. Within months it had secured an entrée through the acquisition of Tapias, Spain's leading tanker company, with its four LNGCs and nine Suezmax tankers. This was quickly followed by an order for three 151,700m³ newbuildings at Daewoo

Shipbuilding & Marine Engineering (DSME) in tandem with Nakilat and for charter to RasGas.

Over the past decade Teekay has built its fleet through newbuildings and acquisitions, to the extent that it now owns or part owns 34 LNG carriers. Amongst the ships purchased were the four vessels from the fleet that Maersk sold as it exited the LNG sector. Teekay's fleet is now the third largest in LNG shipping.

Teekay's current LNGC orderbook includes five 173,400m³ ships building at DSME that will be the first LNG ships to be powered by two-stroke, dual-fuel diesel engines with high-pressure gas injection. DSME is also constructing six 172,400m³ icebreaking LNG carriers for a joint venture comprising Teekay and China LNG Shipping (CLNG). The latter sextet will be engaged in carrying Yamal LNG export cargoes from Sabetta in the Russian Arctic.

Although their entry into the LNG carrier field has been slow to materialise, Greek shipowners have been making up for lost time. The Greeks have always had a powerful presence in international shipping. Sixty years ago they helped lay the foundations for the modern tanker industry with the purchase of World War II-surplus T-2 tankers from the US government at knockdown prices. Larger-than-life entrepreneurs, or magnates, like Aristotle Onassis, Stavros Niarchos and George Livanos, emerged in the process. Today Greek independent owners, including some of the most famous names in shipping, control 20 per cent of the world's tonnage.

Greek involvement with LNG carriers began about 10 years ago when the Peter Livanos-controlled GasLog operation took on the technical management of a series of newbuildings for the BG Group. John Angelicoussis then upped the stakes by ordering five LNGCs, which were delivered during the 2005-07 period to his Maran Gas operation. Four of the ships are jointly owned with Nakilat and on long-term charter to the RasGas 2 project.

GasLog now has 15 LNG carriers in service and 10 on order. Fourteen of the vessels in the company's in-service fleet are serving on multi-year charters while the remaining ship is currently engaged on a short-duration contract. The fleet also includes six ships that the company was previously managing on behalf of BG Group. They will remain on long-term charters with BG.

Maran Gas has also continued to be

active in the newbuilding market. The company has 18 LNGCs on order, all of which will have TFDE propulsion systems. Fourteen of the total have been fixed on long-term charters with BG Group.

On delivery the newbuilding complement will join the 12 LNGCs that Maran Gas currently has in service. Eight ships in the existing fleet are jointly owned by Nakilat of Qatar. Maran Gas holds a 60 per cent stake in the joint venture controlling these ships and Nakilat the remaining 40 per cent.

Other Greek owners active in LNG transport are Dynagas, Tsakos Energy Navigation (TEN), Cardiff Marine, Thenamaris, Almi Gas and Alpha Shipping. Owned by George Procopioiu, Dynagas has seven LNG carriers in service and three on order. Of this complement, only the inaugural vessel, the 2007-built *Clean Energy*, does not have an ice class 1A notation. Two of the company's ships, *Ob River* and *Arctic Aurora*, are the only LNG carriers to have completed passages of the Northern Sea Route between Europe and Asia along Russia's Arctic coast.

Thenamaris, a leading operator of product tankers, joined the LNG sector with an order for three 160,000m³ vessels at Samsung Heavy Industries. The trio, which will initially be technically managed and crewed by Bernard Schulte Shipmanagement, are currently delivering and all are expected to be in service by the end of 2014.

Cardiff Marine, controlled by George Economou, made its entrance into the

LNG arena with a ship acquisition.

The company purchased the 145,000m³ *Muscat LNG* from Oman Shipping and renamed it *Fuji LNG*. Cardiff Marine went on to order four 159,800m³ LNGCs at DSME and the first of these, *Corcovado LNG*, was delivered in spring 2014.

Tsakos Energy Navigation has one ship in service, the 150,000m³ *Neo Energy*, delivered by Hyundai Heavy Industries in 2007, and a 174,000m³ vessel on order at the same yard. The newbuilding, to be named *Maria Energy*, is due for completion in early 2016.

Costas Fostiropoulos has ordered a pair of 160,000m³ LNGCs for his Almi Gas operation at DSME, a shipbuilder with which the owner has enjoyed a long association. Both newbuildings are due for delivery in 2015.

The last of the Greek newcomers to the LNGC field is Christos Kanellakis, owner of Alpha Tankers. The original play was a contract for a 160,000m³ vessel at STX Offshore & Shipbuilding, following the conversion of an original order for a pair of capesize bulk carriers. An option was later exercised for a second LNGC but this has now been dropped. The Alpha Tankers newbuilding is due to be handed over early in 2015.

Between them the eight Greek shipowners have 38 active LNG carriers and 40 on order. When the last of the current orderbook is delivered, the Greek fleet will aggregate 78 LNG ships. That is quite a performance, considering that the first of these vessels only entered service in July 2005. **MC**

Al Areesh is one of a trio of ships that were the first newbuildings to be contracted by Teekay







Delivered in early 2014, the 160,000m³ Cool Runner is helping push up the average ship size in the LNGC fleet

High-resolution snapshot of the global LNG trade

GIIGNL's annual LNG industry reviews not only pinpoint all the notable trade, fleet and terminal developments but also provide some surprising insights

The annual compilation of trade, fleet and terminal statistics published by the International Group of Liquefied Natural Gas Importers (GIIGNL) provides a succinct yet comprehensive overview of the state of the LNG industry for that particular year as well as a record of the most notable achievements and developments over the 12-month period. Because the organisation has been maintaining its log of all LNG carrier voyages and cargo discharges completed each year for some considerable time, it is in a position to look back and trace how the global LNG trades and infrastructure have developed and, also, discern emerging trends.

The latest GIIGNL report, *The LNG Industry in 2013*, reports that the world trade in LNG last year was 236.9 million tonnes (mt). A review of the GIIGNL reports of 10 and 20 years ago shows that the comparable figures for 2003 were 125.2 mt while 61 mt was traded in 1993. LNG shipments have doubled over each of the last two decades and over the last 20 years international movements of LNG have grown by about 7 per cent per year on average. At the end of 2013 approximately 10 per cent of global demand for gas was met by LNG.

In recent years the number of countries and players involved in the LNG trades has increased dramatically. As regards importers, 29 countries received LNG in 2013, compared with 13 countries in 2003. A total of 104 LNG receiving terminals, including 15 floating storage and regasification units (FSRUs), were in operation at the end of 2013, compared with 46 in 2003 and 31 in 1993.

On the supply side, seven new countries have joined the ranks of LNG exporters since 2003. Egypt commenced

exporting LNG in 2005, Equatorial Guinea and Norway in 2007, Russia and Yemen in 2009, Peru in 2010 and Angola in 2013. There were 86 liquefaction trains in operation in 17 LNG exporting countries at the end of 2013. Qatar has the greatest concentration of liquefaction capacity, with 14 trains able to produce an aggregate 77 million tonnes per annum (mta) in place at its Ras Laffan complex. Malaysia is in second place, the eight trains at Bintulu being able to produce a combined 25.7 mta.

The main feature of LNG trade in the last 10 years has been the tremendous growth in Asian demand. LNG volumes shipped to the region have more than doubled over the period, climbing from 83 mt in 2003 to 178 mt in 2013. Whereas Asia accounted for 66 per cent of global LNG imports 10 years ago, the region was the destination for 75 per cent of global movements of LNG in 2013.

Meanwhile Europe's share of world LNG purchases declined from 24 per cent in 2003 to 14 per cent in 2013 while imports in the Americas remained stable at around 9 per cent. The decrease in US imports was offset by rising volumes of LNG shipped to South America.

In terms of supply sources, the Middle East remained the biggest LNG export region in 2013, with shipments of 98.3 mt being equal to a 41.5 per cent market share. The 87.9 mt exported from the Asia-Pacific region represented 37.1 per cent of total shipments worldwide.

In 2013 Qatar supplied 33 per cent of all LNG traded worldwide, followed by Malaysia with an 11 per cent market share and Australia 10 per cent. Shipments to the four North East Asia import nations of Japan, Korea, China and Taiwan accounted for 67 per cent of all LNG moved by sea in 2013.

Collating this import and export data

LNG Shipping at 50 | LNG today and tomorrow

shows that the two major LNG trade flows are currently that from the Middle East to the Asia-Pacific region and intra-Asia-Pacific movements.

Switching to the LNG carrier fleet, at the end of 2013 there were 393 such ships compared with 152 in 2003 and 76 in 1993. The orderbook as of end-2013, at 113 vessels, indicates a surge in fleet growth over the next three years.

The average capacity of an LNG carrier has risen progressively over the period under review, from 102,000m³ in 1993 to 117,000m³ in 2003 and 143,000m³ in 2013. Of the end-2013 fleet, 91 per cent of the ships had a capacity above 90,000m³ while 14 per cent were above 170 000m³ in size.

In comparison to the LNG carrier fleet of 10 years ago, today's is younger. At the end of 2013 some 66 per cent of the ships in the fleet were less than 10 years old. The comparative figure for the fleet of 10 years ago was 45 per cent. In terms of containment systems, 68 per cent of the LNG vessels in service at the end of 2013 were equipped with a membrane system, versus only 47 per cent in 2003.

The emergence of new importers and exporters over the 50 years of commercial LNG shipping operations has created an elaborate matrix of shipping patterns. At the end of 2013 the world LNG trade involved 168 'flows' (country-to-country trades) over 423 sea transportation routes (port-to-port routes).

Focusing on more recent trade developments, 2013 was the third consecutive year of stagnation in global movements of LNG. In 2012 trade retreated by 1.9 per cent, to 236.3 mt. Although 2013 did mark a return to growth, it was only a marginal expansion of 0.3 per cent. Of the total trade in LNG last year, 65 mt, or 27 per cent, was traded on a spot or short-term basis.

While the demand for LNG is robust, very little new liquefaction capacity has been commissioned in recent years. Shipowners have derived some benefit from an increase in long-distance shipments from the Atlantic Basin to Asia following the March 2011 earthquake, which forced the closure of Japan's nuclear reactors. However, the pace of LNG carrier newbuilding deliveries has been picking up over the last 18 months and the fleet is facing a short period of oversupply, until the next wave of new LNG liquefaction capacity starts coming onstream in 2015.

Most notable amongst the new supplies of LNG poised to enter the market are seven projects in Australia. Between them the facilities will be able to produce an aggregate 65 mta of LNG when at full throttle. All seven are scheduled to be up and running by 2017.

Australia will be followed by the US. The Department of Energy has so far granted seven proposed plants approval for the export of LNG to countries with which the US does not have a free trade agreement. The total capacity of these facilities will be 62.5 mta and the first,

Sabine Pass, is under construction and due to begin loading cargoes in early 2016. By the end of the decade the US is likely to be the third largest LNG exporter, behind Australia and Qatar.

Beyond the emerging Australia and US projects, a range of ambitious LNG export schemes is being developed in Canada and East Africa, with production startups targeted for the end of the decade.

As GIIGNL points out, 2013 can be considered to be a transition year for the LNG industry. Although final



Singapore was added to the list of LNG import nations in 2013



One-third of the global trade in LNG is currently loaded at the port of Ras Laffan



FSRUs are the option of choice for a growing proportion of new LNG import terminals

investment decisions were made on only three projects – Yamal LNG in the Russian Arctic and two expansions of existing facilities – they will provide another 29 mta of production capacity.

Slack demand for LNG in Europe, due to the region's lingering economic recession and the availability of alternative pipeline supplies, was compensated for by a strengthening need for gas in Brazil and Argentina. Operators of a number of European LNG import terminals played a part by continuing with innovative transactions in the search for business, including re-loadings, two-port loadings and ship-to-ship transfers. Of the 78 re-load cargoes despatched worldwide in 2013, Spanish terminals were responsible for 40 and the Zeebrugge facility in Belgium 20.

As part of the subtle shift in trading patterns, China and Korea, too, also recorded notable increases in LNG import volumes. China has moved up quickly through the ranks to become the world's third largest LNG importer.

After commissioning four new LNG import terminals over the past year China has four further receiving facilities under construction, with a combined capacity of 12 mta. Worldwide there are more than 25 import terminal projects, both newbuilds and expansions, underway. Most, if not all, should be in service by the end of 2015.

The popularity of floating storage and regasification units (FSRUs) as a means of fast-tracking LNG imports at comparatively low cost has skyrocketed in recent years. Almost one-half the new import terminals under construction will utilise FSRUs. Four FSRUs were completed in 2013 while three further such units were delivered in the first half of 2014.

The LNG carrier fleet completed 3,998 laden voyages last year. Japan's 26 receiving terminals accounted for 1,532

LNG INDUSTRY GROWTH OVER THE PAST 20 YEARS			
	1993	2003	2013
Liquefaction plants	11	15	26
Receiving terminals	31	46	104
Number of exporting countries	8	12	17
Number of importing countries	9	13	29
LNG carriers	76	152	393
LNG imports (million tonnes)	61.0	125.2	236.9

of the total, or one less cargo than in 2012. That is equivalent to just over four shiploads per day, or 30 per week.

China received 260 cargoes in 2013, up from 206 the previous year, while deliveries to the Southern Cone of Brazil, Argentina and Chile totalled 224, a 24 per cent rise on a year earlier. Interestingly there were 82 LNG cargoes delivered to the South East Asia quartet of Indonesia, Malaysia, Singapore and Thailand and 53 to the Middle East, more specifically Dubai, Kuwait and Israel. Israel and Malaysia are the two new LNG import nations of 2013.

While setting the scene for the buoyant times ahead, GIIGNL's *The LNG Industry in 2013* publication also looked back to report that since the first commercial LNG delivery in 1964, over 75,000 cargoes had been delivered without loss. That end-2013 total is currently being added to at the rate of about 340 cargoes per month. **J-YR**

LNG EXPORTERS		
Country	Volume (million tonnes)	Change 2012-13 (%)
Algeria	10.81	-3.5
Angola	0.33	N/A
Egypt	2.66	-43.9
Eq Guinea	3.77	4.2
Nigeria	16.47	-15.9
Norway	3.05	-7.8
Trinidad	13.67	1.5
Atlantic Basin (Total)	50.76	-9.2
Abu Dhabi	5.08	-10.2
Oman	8.35	2.5
Qatar	78.02	2.1
Yemen	6.82	39.4
Middle East (Total)	98.28	3.4
Australia	22.41	7.3
Brunei	7.01	2.8
Indonesia	18.36	-3.2
Malaysia	25.14	6.0
Peru	4.25	10.1
Russia	10.69	-1.6
Pacific Basin (Total)	87.86	3.0
World (Total)	236.91	0.3

Source: GIIGNL

LNG WORLD TRADE 2013		
LNG IMPORTERS		
Country	Volume (million tonnes)	Change 2012-13 (%)
Belgium	1.19	-34.7
France	5.94	-17.2
Greece	0.45	-40.4
Italy	4.05	-21.6
Netherlands	0.36	-35.4
Portugal	1.49	-1.6
Spain	9.13	-36.9
Turkey	4.40	-21.9
UK	6.91	-33.4
Europe (Total)	33.93	-28.5
Argentina	4.72	40.4
Brazil	4.15	53.7
Chile	2.61	-5.5
Dominican Rep	0.84	-9.0
Mexico	5.67	61.2
Puerto Rico	1.16	20.3
Canada	0.76	-42.0
USA	1.90	-38.7
Americas (Total)	21.81	17.1
China	18.60	27.0
India	13.05	-1.7
Indonesia	1.43	98.6
Japan	87.98	-0.1
Korea	40.39	9.8
Malaysia	1.50	N/A
Singapore	0.91	N/A
Taiwan	1272	0.4
Thailand	1.45	41.9
Asia (Total)	178.04	6.5
Dubai	1.15	10.0
Israel	0.40	N/A
Kuwait	1.59	-20.4
Middle East (Total)	3.14	3.4
World (Total)	236.91	0.3

Source: GIIGNL

Exporters ready to meet the greatest of expectations

Eight countries have joined the LNG exporters league over the past decade, boosting the membership of this club to 20. Egypt began shipping LNG to world markets in 2005, Equatorial Guinea and Norway in 2007, Russia and Yemen in 2009, Peru in 2010, Angola in 2013 and Papua New Guinea in 2014.

The Sakhalin 2 project in Russia, with exports of 10 million tonnes per annum (mta) of LNG, has been the most prolific of the newcomers. Egypt has two liquefaction plants, at Damietta and Idku but, after a brief initial flourish, the country's exports have slumped dramatically due to rapidly rising domestic demand. Damietta has been idled and loadings at Idku are fitful.

The rising requirements of LNG buyers worldwide have not been helped, as yet, by the Angola project. The plant's start-up has been dogged by technical problems and the facility is now shut until mid-2015 while major repairs are carried out.

The global financial crisis which broke in September 2008 not only temporarily dampened gas usage but also slowed investment in new LNG production capacity. The end-result is that the industry has been dealing with a sustained period of supply tightness. While the demand for gas is now greater than ever before, little new

The global trade in LNG is about to embark on a major new growth phase. The industry has all likely demand scenarios for the coming decade covered

liquefaction capacity has been coming onstream. The global trade in LNG has been stalled at the 240 mta mark for the past three years.

Gas consumers and LNGC owners are anxiously awaiting the commissioning of new LNG export plants. The additional volumes will ease pressure on gas prices and boost freight rates for an LNGC fleet which is currently negotiating its way through a period of sustained overtonnaging.

The new LNG flows will originate from Australia, the US, Russia, Canada and East Africa, in that order. Each of these countries and regions holds the promise of adding substantial quantities to the global LNG supply pool.

Deliveries from new Australian schemes are imminent. Beginning in September 2009 and over a period of 30 months, final investment decisions were taken to proceed with seven LNG export projects in the country. They are Gorgon, Queensland Curtis LNG (QCLNG), Australia Pacific LNG (APLNG), Gladstone LNG (GLNG), Wheatstone, Prelude and Ichthys. Between them, these liquefaction plants will provide 65 mta of new capacity and

propel Australia to the top of the LNG exporters league table.

Three of the new terminals – QCLNG, APLNG and GLNG – have been built adjacent to each other on Curtis Island in the port of Gladstone on Australia's east coast. Bechtel is constructing all three facilities and all will process coal seam gas piped from the vast Queensland coal fields. QCLNG is on track to load its inaugural LNG cargo in December 2014 while APLNG is scheduled for a mid-2015 start-up and GLNG "sometime in 2015".

Gorgon, a three-train facility with a 15.6 mta capacity and the largest of Australia's new projects, is also aiming for a mid-2015 commencement to operations. The other three schemes will follow a little later. Wheatstone is due onstream in 2016 while Ichthys has earmarked December 2016 as the date for loading the first cargo at its new Darwin plant.

Prelude is an offshore project being developed by Shell using a floating LNG (FLNG) production vessel. Samsung Heavy Industries in Korea is constructing the FLNG unit, and the plan is to install it in position in late



The QCLNG terminal is due to be the first of Australia's seven new export facilities to come onstream

2016. That will enable the first cargo to be loaded in early 2017.

Australia has further exploitable gas reserves but the country is a high-cost place to do business, and the new onshore projects have proved to be prone to cost and time overruns. The next new Australian LNG export initiatives are likely to be based on the use of FLNG vessels.

For the moment, attention has switched to the US as the next supplier of notable volumes of LNG. Until well into the previous decade the US was identified as an LNG import market of great potential and a string of receiving terminals were built along its Gulf Coast. Almost immediately these facilities were commissioned, however, the shale gas phenomenon broke and the need for imports evaporated.

Today the emphasis is on LNG exports and monetising the sizeable reserves of shale gas that are surplus to domestic requirements. Over 25 proposed US LNG export projects have been submitted to the country's relevant regulatory agencies for authorisation. Many of the schemes that have been put forward are based on the addition of liquefaction trains at idle import terminals where use can be made of existing storage tanks and marine jetty facilities.

The opening of the Panama Canal's enlarged lock system in late 2015 will facilitate the delivery of US cargoes in 'Pacific-max' LNG carriers of 170,000m³ to Asia. Many of the US plans are based on tolling agreements whereby customers line up their own gas supplies, contract the appointed export terminal to process them and make their own shipping arrangements. Korea, China and particularly Japan have been lining up significant purchases of US gas under such arrangements.

In August 2014 Cameron LNG became only the second of the proposed US export initiatives, after Sabine Pass, to have its developers make a final investment decision (FID) to proceed. The timetable calls for the three 4 mta trains at the existing Louisiana terminal to be commissioned in 2018 and for full production to be reached in 2019. Having received the last of its necessary clearances in July 2014, Freeport LNG is expected to reach an FID on its project imminently.

Sabine Pass has a two-year jump on its US competitors, the decisions for the first two 5 mta trains at its Louisiana terminal having been taken in July 2012



Graphic shows four of the six trains planned for Sabine Pass in place

and for the second two in May 2013. Construction work on Trains 1 and 2 is advancing well and they both could be producing LNG by late 2015.

The jury is still out on the volume of LNG that the US will ultimately be exporting. The big attractions of US LNG are the large quantities of competitively priced shale gas available, the security of supply and the storage tank capacity and marine jetty facilities already in place.

Taken in aggregate the volume offered by all the export terminals that have been proposed is nearing the current level of the global trade in LNG. That would not only be far too great for the market to absorb but also go against political will in a country sensitive to energy self-sufficiency issues. Many of the estimates for the likely quantity of US exports by 2025 instead fall within the more reasonable but still substantial 60–70 mta range.

US exports will also be in competition with the LNG cargoes that Canada, Russia and East Africa are seeking to make available to world markets by the early 2020s. Like the US, Western Canada is rich in shale gas and gas from other unconventional sources, and to date over 20 proposals have been put forward for projects that would liquefy gas from Alberta and British Columbia at terminals to be built along the coast of British Columbia.

Major international companies are involved in several of the proposed Canadian schemes and a number of preliminary sales agreements have been signed with leading gas buyers in China, Korea and Japan. Chinese buyers have expressed particular interest in Canadian LNG and its relative proximity to their growing network of import terminals. Some of the Canadian proposals involve notably large volumes of LNG.

As yet, however, no Canadian project has reached the FID stage and the

spectre of competing sources of supply looms large. In Russia the developers of the 16.5 mta Yamal LNG project reached such a decision in December 2013, and an agreement to add a third 5 mta train at the Sakhalin 2 plant in the Russian Far East has also been finalised.

Beyond that, Gazprom is seeking to build a 10 mta terminal at Vladivostok and to begin shipping in early 2019. Rosneft has also tabled a plan for a liquefaction plant on Russia's Pacific coast. The 5 mta, single-train facility would be built in conjunction with ExxonMobil and, like the Sakhalin 2 plant, located on Sakhalin Island. A 2018 start-up is targeted.

The final contender wishing to participate in the next wave of LNG supply is East Africa or, more precisely, Mozambique and Tanzania. Large deposits of gas have recently been discovered off the coastlines of both countries and LNG project development plans are well underway.

Mozambique is seeking to start exports at the rate of 10 mta and, bearing in mind the number of competitors targeting the same markets, to commence shipments by 2019/2020. That would require an FID on the project go-ahead by late 2014 or early 2015.

Tanzania also anticipates getting its LNG export train rolling with a two-train liquefaction plant but is running a year behind its southern neighbour. Project developers BG, Statoil, ExxonMobil and Ophir are looking at an FID in 2016 to enable the plant to come onstream in the early 2020s.

The future looks bright for LNG production, and a number of heavyweight projects are set to come onstream in the years ahead. There is enough capacity to meet all likely market requirements, and Canada, in particular, has the resources in hand to meet the additional volumes entailed in the most optimistic demand scenarios. *MC*

Time is nigh for floating LNG production

Five FLNG vessel projects are underway and developers of upwards of 20 further such schemes are working towards final investment decisions

It is ironic that the first LNG to be liquefied for transportation by sea, as described in the *Methane Pioneer* article on page 10, was produced on a floating barge in the Louisiana bayous some 55 years ago. The industry has had to wait for over half a century since that historic moment but the first production of commercial quantities of LNG on a floating vessel is now only a matter of months away. The five projects currently underway – comprising four newbuilding vessels and an LNG carrier conversion – bring the LNG industry full circle and launch it into a new era.

The FLNG conversion project is a late starter, having only been announced in summer 2014. Which of the four floating LNG production (FLNG) newbuilding vessels under construction will be the first to enter service has been the subject of some speculation. Shell contracted the first LNG ‘floater’ in May 2011, the 488m-long Prelude vessel which Samsung Heavy Industries (SHI) is building for positioning off Australia’s northwestern coast.

Prelude embraces many groundbreaking technologies and will be the world’s largest floating, man-made structure upon completion. However, such is the scale of the project that it will not be ready to enter into service until early 2017.

A more modest newbuilding is the 300m-long FLNG vessel that Petronas ordered at Daewoo Shipbuilding and Marine Engineering (DSME) in early 2012 for what it terms its PFLNG 1 project. The scheme calls for the vessel to be positioned in shallow water about 180km off the coast of Bintulu in the Malaysian state of Sarawak in order to liquefy gas from the Kanowit field. In contrast to the Prelude LNG production



The technology behind Prelude, a vessel of many superlatives, is set to be replicated in many new FLNG projects

capacity of 3.6 mta, PFLNG 1 will be able to liquefy 1.2 mta. The Malaysian unit is scheduled to commence LNG production in late 2015.

In February 2014 Petronas sanctioned a second floating LNG project for Malaysian waters. The PFLNG2 vessel will be built at SHI and have a capacity to produce 1.5 mta. It is due to go into service in 2018 off the coast of Sabah, where it will process gas from the Rotan field.

The smallest of the four FLNG vessels under construction is that being developed by Exmar for a 15-year charter with Pacific Rubiales and positioning at Tolú on Colombia’s Caribbean coast. The non-propelled vessel, named FLNG Caribbean and termed a floating liquefaction regasification and storage unit (FLRSU), was ordered at the Wison yard in China in June 2012 and is scheduled to be providing LNG, at a rate of 0.5 mta, by the second quarter of 2015.

The recently announced conversion project involves the fitting of four modular liquefaction trains on Golar LNG’s 1975-built, 125,000m³, spherical tank LNG carrier *Hilli*. The work, which will be carried out at Keppel Shipyard in Singapore, will provide the vessel with a liquefaction capacity of 2.2–2.8 mta. Black & Veatch’s proprietary Prico liquefaction technology will be utilised and the conversion project is due for completion in the first quarter of 2017.

Golar holds options with Keppel covering similar conversions on two

other of its older LNG carriers. The shipowner has not yet finalised a charter deal for *Hilli* in its new role but is in negotiations with several potential customers.

On paper it looks like the Exmar FLRSU will be the first past the finishing line. However, the contenders will not be claiming a place in the history books until the first cargo from their floater is transhipped. Experience has shown that it is best not to take anything for granted when new technologies are being applied.

The five committed FLNG projects look set to be the first batch of many similar initiatives. Floating production is poised to follow in the footsteps established by the LNG industry’s adoption of the floating storage and regasification unit (FSRU) concept over the past decade. Having said that, the technologies involved in LNG regasification are much less complex than those involved in its liquefaction, so FLNG will never match the extent and the pace of the FSRU take-up.

Nevertheless the welcome given by the LNG industry to floating regasification shows how quickly innovative technologies can be adopted and accepted in the modern era. Just as importantly, floating regasification has been quick to prove that major cost savings can accrue from offshore solutions. When the regasification cost element of delivered gas via an FSRU comes in at one-third

that of gas processed at a shore-based import terminal, the benefits are not difficult to appreciate.

The US has eight and Australia seven FLNG schemes on the drawing board. The developers of the majority of these projects are currently engaged in preliminary engineering work with a view to commissioning full front-end engineering and design (FEED) studies. A successful outcome, along with the necessary permits and gas sales agreements in place, would enable a final investment decision (FID) to be taken in 2015–16 and their projects to transship the first LNG to delivery tankers in 2018–2019.

Most of the US and Australian initiatives are based on floaters with relatively large, single train liquefaction capacities, of 3–4 mta, to enable the export of sizeable quantities of gas. The US projects, for example, are competing with numerous shore-based terminal schemes to export the same shale gas resources.

In Australia the offshore fields targeted by the FLNG community hold significant reserves, and floating production offers a lower cost, fast-track alternative to the construction of a shore-based export terminal and an associated, long-distance, subsea gas pipeline.

Sometimes, however, even an FLNG proposal in Australia is found not to be commercially justified. In summer 2014 GDF Suez and Santos decided to shelve their planned Bonaparte FLNG scheme rather than press on to the FEED stage, citing the questionable economics of the project.

Shell is a partner in a number of Australia's prospective FLNG developments, and in these cases the energy major's Prelude technology has been chosen as the route to project realisation. The concept is based on solid foundations, Shell having researched its FLNG options for 15 years and devoted 1.6 million man-hours to work on the engineering challenges before deciding on the Prelude design and equipment.

Prelude will be moored using the world's largest turret yoke arrangement 200km from the nearest land off Australia's northwest coast, an area prone to seasonal cyclones. The Prelude FLNG vessel is being designed for not only an uninterrupted service life of 20 years at this location but also a further 20 years at another potential offshore gas field development.

Making the Prelude concept more

widely available will be facilitated by the fact that Shell has entered into a master service agreement with Technip and Samsung covering the design, construction and installation of multiple FLNG facilities over a period of up to 15 years.

Smaller scale units are also well represented amongst the FLNG schemes under development. It is estimated that there are over 650 remote offshore fields with between 0.5 and 5 trillion cubic feet (tcf) of stranded gas that would be ripe for development with small-scale, barge-mounted liquefaction plants.

The combination of liquefaction plants of modular construction and simple barge-shaped hulls, especially when the facility is moored in nearshore waters, helps ensure that the investment cost per tonne of LNG produced is much below the equivalents for both a large-scale FLNG project and a shore-based export terminal. Exmar's small FLRSU, for example, is expected to cost US\$300 million, complete with topsides.

The Exmar FLRSU, which is due to be positioned at a dedicated jetty located 3km off Colombia's Caribbean coast, is illustrative of the effect such a vessel can have on a region's LNG supply chain. The FLRSU will work in tandem with a floating storage unit (FSU) also moored at the jetty, transferring LNG to the FSU as it is liquefied.

It is likely that initially the terminal will export full LNGC cargoes of 140,000–160,000m³, depending on the sizes of the FSU and the delivery tanker, to the international spot market once every six weeks. Eventually, once the region's customers have their LNG receiving infrastructure in place, the FLRSU will supply the small-scale

power generation markets of Central America and the Caribbean using coastal LNG carriers.

Exmar has established a strategic alliance with Black & Veatch, the supplier of the FLRSU's liquefaction plant technology, and Wison, the builder of the vessel, to explore further opportunities for the small-scale FLNG technology the partnership has developed.

One of the principal advantages of the FLNG approach to bringing LNG to market is that the entire vessel can be built under controlled conditions by experienced and skilled workers at a dedicated yard. In doing so the cost overruns, construction problems and inclement weather conditions often encountered at shore terminal building sites can be avoided.

Yard construction of an FLNG vessel also enables the building schedule to be accelerated through replication and efficiency shortcuts, again to the benefit of the overall budget. Financing arrangements are usually facilitated by yard construction, and the overall project will benefit from the lessons learned from previous projects of a similar nature.

The FLNG projects involving the vessels under construction are based on the side-by-side method of offloading LNG to the LNG shuttle carrier. The next frontier, for projects in more inhospitable waters, will be the adoption of the tandem offloading method. For the moment, however, the homework has been done, the foundation FLNG vessels are currently under construction and a raft of investment decisions on new projects is imminent. The FLNG era has begun. **MC**



The FLNG Caribbean project is poised to show what is possible with small, barge-mounted liquefaction units

Coastal LNGCs come into their own

Only a decade old, coastal LNG carriers are poised to help a major extension of the LNG supply chain at the small-scale end of the spectrum

The delivery of the 6,500m³ *Coral Anthelia* to Anthony Veder and the 2,500m³ *Kakayu Maru* to Tsurumi in 2013 raised the complement of coastal LNG carriers worldwide to 16 vessels. Another four such ships are on order, all building in China and earmarked for gas distribution duties along the country's long coastline. Three of the vessels are in the 28–30,000m³ size range and, on delivery in 2015, will be the largest coastal LNG carriers yet built.

This fleet of small-scale LNG carriers is only a decade old. It has emerged to facilitate the extension of the LNG supply chain and to bring the benefits of this clean-burning, competitively priced fuel to a much wider range of customers. The main market drivers for small-scale LNG are the growing use of gas as marine fuel and the need to supply remote residential communities, power stations and commercial ventures not connected to the pipeline grid.

Predicting the size of the coastal LNG carrier fleet 10 years hence and the pace at which it will grow pose challenges but it is safe to say that the influence being exerted by the current market drivers will continue to strengthen. New delivery routes, terminal facilities, bunker depots and fuelling stations are being developed and naval architects'

drawing boards around the world are filling up with coastal LNGC design concepts. A number of newbuilding projects have been mooted and several are poised to materialise.

All the coastal LNG carriers built to date have IMO Type C insulated, pressure vessel cargo tanks fitted horizontally in the vessel. The Type C tanks are either cylindrical or bilobe in shape and stainless steel and aluminium have been used as tank materials. With Type C tanks there is no need for the cargo containment system to have a secondary barrier. Ship designs with alternative containment systems, including GTT membrane tanks, have been developed but as yet only Type C tanks have been specified.

Various types of propulsion system have been utilised on small-scale LNG carriers, including dual-fuel arrangements which enable the use of cargo boil-off gas as vessel fuel. When dual-fuel plant is specified, back-up arrangements, such as a reliquefaction plant or gas combustion unit, must be in place either to handle excess boil-off gas or for emergencies when there are problems with the propulsion system.

While the new reality of an extended LNG supply chain is getting closer, there are still parts of the existing coastal LNG

carrier fleet that are not fully employed in the trade. Eight of the ships are designed as multipurpose gas carriers, with the ability to carry ethylene and LPG as well as LNG. This flexibility has helped the operators achieve high utilisation rates for the vessels until that time they are needed for LNG distribution duties. The current strength of the ethylene trades has been a boon in this respect.

The largest of the coastal LNG carriers currently in service, the 15,600m³ *Coral Energy*, is fully dedicated to the trade. The vessel was built by Neptun Werft of Rostock in Germany, part of the Meyer Group, for Anthony Veder, and Skangass, the vessel's long-term charterer, worked closely with the principals in the design of the vessel. The ability to load LNG at large terminals and deliver cargoes to all sizes of terminals by means of a dual manifold arrangement was a key design consideration.

Anthony Veder describes *Coral Energy* as the world's first direct-drive, dual-fuel, ice-class 1A LNG carrier. The ship's Wärtsilä dual-fuel engine is linked directly to the propeller, thus avoiding the power losses that can arise with diesel-electric drive systems. The 1A ice class rating means that the vessel will be able to function in the Baltic Sea throughout the winter months.

Coral Energy has been delivering cargoes loaded at the Skangass liquefaction plant in Stavanger's Risavika harbour to receiving terminals at Fredrikstad in Norway and Nynäshamn in Sweden. Until the European LNG distribution and bunkering markets get up to speed the Risavika plant has spare capacity, and *Coral Energy* has also been facilitating product sales by transporting LNG offered by Skangass on the spot market.

IM Skaugen operates four LNG



Coral Energy loads LNG at the Skangass terminal in Stavanger's Risavika harbour

carriers of 10,000m³ and two of 12,000m³ as part of its Norgas fleet. All six ships are able to carry ethylene and LPG as well as LNG and have been primarily employed in the petrochemical gas trades since their delivery from Chinese shipyards over the 2009-11 period. The vessels have conventional propulsion systems and are fitted with a new type of reliquefaction plant developed to handle LNG boil-off gas.

One of the Skaugen vessels, the 10,000m³ *Norgas Innovation*, had a taste of things to come when it delivered a domestic Chinese LNG cargo recently. The shipment was transported from the Dalian import terminal in northern China to the Jovo Group's new LNG terminal in the southern port of Dongguan in Guangdong province.

The Jovo terminal, which features two 80,000m³ storage tanks, is China's second coastal LNG receiving terminal. A third small-scale terminal is under construction and proposals have been tabled for an additional eight such facilities in China. Both Jovo and the operator of the Dalian terminal are affiliates of China National Petroleum Corp (CNPC).

IM Skaugen is reported to be considering contracting up to four additional LNG/ethylene/LPG carriers in China. A 17,000m³ cargo-carrying capacity has been mooted for the new vessels, as has been the ability to run the ships on LNG cargo boil-off gas.

Bijlsma, a member of the Veka Group in the Netherlands, built the 1,100m³ *Pioneer Knutsen*, the smallest coastal LNG carrier, in 2004. That vessel, which is fitted with a dual-fuel propulsion system, has performed non-stop LNG distribution services along the Norwegian coast on charter to Gasnor over the past 10 years.

Veka has devoted time to developing its LNG vessel design portfolio in recent

years and is now marketing its concepts for an inland waterway LNG carrier, a coastal LNG carrier and a seagoing LNG bunkering vessel also able to transport oil fuel bunkers. The coastal LNG carrier design features two Type C cargo tanks of 2,000m³ each.

TGE Marine of Bonn in Germany is another company which has developed a portfolio of LNG distribution vessel designs based on the use of Type C tanks. TGE Marine is supplying the bilobe cargo tanks and cargo-handling plant for the three 28-30,000m³ coastal LNG carriers building in China. The TGE package comes complete with tank supports that have been redesigned in order to accommodate cargo tank expansion and shrinkage due to temperature variations.

Japan has five 2,500m³ coastal LNG carriers in service, all built by Kawasaki Heavy Industries (KHI) and all engaged in loading cargoes at certain of the country's import terminals for distribution to the smaller regional terminals in locations where the demand for gas is more limited. Two of the vessels are engaged in transporting LNG in the Seto Inland Sea area in southern Japan while the remaining three load cargoes supplied by Tokyo Gas at the Sodegaura terminal in Tokyo Bay for the 850km run up the country's northeastern coast to Hachinohe and Hakodate.

All the ships are fitted with a pair of aluminium Type C tanks covered with 330mm of Kawasaki Panel insulation and are powered by conventional diesel engines. The containment system design accommodates pressure build-up during the course of the short voyages. The tanks have a design pressure of 3 barg (3,100 kPa) and are able to contain all the cargo boil-off gas that is generated. Voyages to Hakodate take around 48 hours, which is well within the tanks'

seven-day design allowance before venting is required.

Japan is now looking beyond this fleet to its future small-scale needs and is considering larger capacity vessels for 'milk run' distribution operations as well as LNG bunker vessels. As the builder of all the country's small-scale LNG tankers to date, KHI is leading the design review and amongst the options under consideration is the use of LNG-fuelled vessels.

Capacities up to 10,000m³ are being considered for the milk run LNG carriers while a design for a 6,000m³ LNG bunker vessel has also been developed by the shipbuilder. The milk run distribution tanker would be engaged on somewhat longer voyages, so the pressure build-up would be greater than that on the existing ships. KHI reports that a 6,000m³ Type C aluminium cargo tank with a design pressure of 8 barg (8,100 kPa) is feasible as an alternative.

The option of going for tanks with a lower design pressure and burning boil-off gas in the ship's propulsion system comes with the challenges of finding the necessary skilled engineering officers to man the ships and designing a scaled-down gas combustion unit for any excess boil-off gas that might be generated on the ship.

The gas shipping sector has been able to utilise the expertise gained in the design and construction of ethylene carriers in the initial designs for coastal LNG carriers. Indeed one-half of the small-scale LNG carriers are multipurpose vessels with the ability to also carry ethylene. The industry has also tackled the challenges associated with the design of larger cargo tanks and the handling of boil-off gas in relation to the fuel needs of the propulsion system. The scene is set for a flourishing of small-scale LNG shipping. **MC**



LNG bunkering market beckons

The use of LNG as marine fuel is poised to become an important new market. The extent of the breakthrough is dependent on many variables

As of 1 May 2014 there were 52 gas-fuelled vessels that are not LNG carriers in service and 57 such vessels on order. The majority of this 102-ship fleet are either currently sailing in emission control areas (ECAs) or will be upon delivery.

The allowable sulphur content of fuel used by ships sailing in ECAs will be reduced from 1 to 0.1 per cent as of 1 January 2015. Not surprisingly this restriction is creating considerable interest in the use of LNG as marine fuel in the North and Baltic Seas and North American coastal waters – the three regions which are currently designated ECA zones.

LNG is one of three options available to shipowners seeking to ensure compliance with the increasingly strict requirements governing ship atmospheric pollution. Alternatively ships can be either switched to running on low-sulphur marine diesel oil (MDO) fuel or fitted with an exhaust gas scrubber to enable the continued use of heavy fuel oil.

All the options have advantages and disadvantages but it is acknowledged that the use of LNG entails higher upfront costs in providing the necessary systems for a newbuilding than those associated with the two alternatives. On the other hand burning LNG ensures compliance with all existing and likely clean air regulations and holds the promise of lower lifecycle costs, due not least to reduced maintenance costs. That potential increases with any widening of the gap between oil and gas prices that may occur.

Most of the existing LNG-fuelled ships are Norwegian-flag vessels sailing in Norwegian coastal waters. The country's government incentivised shipowners to opt for LNG as marine fuel through benefits deriving from a nitrogen oxide (NOx) emissions fund that was established a decade ago. The inducements were backed by the ready availability of North Sea gas and a rapidly

developed LNG bunkering infrastructure that is supplied by coastal LNG carriers and a fleet of cryogenic road tankers.

LNG World Shipping published a list showing all the ships in the in-service and on-order fleets as of 1 May 2014. The catalogue of ships on order highlights the extent to which the use of LNG as marine fuel is spreading out from Norway. It is not only going global but also encompassing many more ship types than the cross-fjord ferries and offshore supply vessels (OSVs) that feature prominently in the current Norwegian fleet. As well as car/passenger ferries and OSVs, the on-order listing also includes container ships, roll-on/roll-off cargo vessels, gas carriers, product/chemical tankers, car carriers, tugs, a bulk carrier and an icebreaker.

Norway has provided the ideal springboard for the breakout of LNG bunkering into other parts of Scandinavia and Northern Europe. Sweden, Finland and Denmark are pressing ahead with small-scale terminal and fuelling station

projects while the Fluxys LNG import terminal in the Belgian port of Zeebrugge and the Gate facility at Rotterdam in the Netherlands are engaged in the provision of dedicated jetties to enable the loading of small LNG carriers and bunker vessels. Both ports, along with Antwerp, are likely to host their own LNG bunker vessel operation within the next two years. Several other European ports are embarking on similar initiatives.

Progress with the provision of LNG bunkering arrangements in the region are being reinforced by the European Union's commitment to the use of LNG as marine fuel. This commitment takes the form of both the strict environmental legislation it promulgates and the subsidies on offer to initiatives that support its Trans-European Network-Transport (TEN-T) programme. Measures have also been introduced to promote the use of LNG to propel vessels sailing on the Rhine-Main-Danube inland waterway system.

Shell is playing an important role in the advances being made in Europe. The energy major has acquired Gasnor, the Norwegian LNG distribution company, and is building upon the network already in place. Shell will be the foundation customer of the new breakbulk LNG facility being built at the Gate import terminal in Rotterdam and is chartering two LNG-powered inland waterway tankers currently sailing on the Rhine.

Another notable feature of the LNG-powered ship orderbook is the progress now being made in North America. The region's operators have contracted 19 LNG-fuelled vessels, comprising 16 for



A converted Norwegian ferry now working in Stockholm, Seagas is the world's first dedicated LNG bunkering vessel

service in the US and three for Canada. The availability of plentiful supplies of competitively priced gas in the two countries and their ECA status will spur further orders in the region in the years ahead.

The US orderbook includes 10 large container ships – both newbuildings and conversions – that are taking LNG fuelling into new realms in terms of installed horsepower, gas consumption and bunkering arrangements.

One country that is currently only marginally represented on the list of LNG-fuelled vessels in service and on order is China. However, that situation is poised to change dramatically. The government is supporting the use of LNG as a transportation fuel in an effort to tackle the air pollution that beleaguers the country.

The current tally shows that China has two Chinese-built, LNG-powered tugs in service and two similar vessels on order. However, the country has in place a wide-ranging and growing LNG distribution infrastructure which includes a larger number of cryogenic road tankers, tank containers and vehicle fuel tanks than any other nation.

Modified versions of these vehicle LNG fuel tanks have been fitted to a number of fishing and inland waterway vessels in China as part of a trial programme to assess the viability of dual-fuel running. Numerous local companies are reportedly on the verge of constructing fuelling stations for the Yangtze and other rivers as well as LNG-fuelled river vessels that will utilise these depots. In addition domestic shipyards are currently building three coastal LNG carriers of 30,000m³ each for use in carrying LNG to small shoreside distribution terminals and riverside fuelling stations planned for the country.

The current, fast-changing situation for LNG-powered vessels worldwide begs the question as to how big this fleet will be five or 10 years from now. However much research is carried out to underpin a forecast, any estimate has to be qualified by the plethora of variables that come into play. Will any new ECAs will be created? Will the reduced global sulphur cap for heavy fuel oil be implemented in 2020 or 2025? How will the prices of competing fuels evolve and what impact will refinery technologies have on their ability to increase the production of middle distillate fuels? When will individual sectors of the world shipping fleet fall due for rejuvenation?

In DNV GL's own analysis of the



Gasnor has carried out approximately 20,000 LNG bunkering operations in Norway over the past decade

global potential for LNG fuel, the class society concludes, in its median case scenario, there will be 1,800 LNG-powered vessels in service by 2020, comprising 1,100 newbuildings and 700 conversions. MAN Diesel & Turbo believes there could be as many as 2,000 gas-powered vessels consuming 15 million tonnes of LNG by 2020. In this, the “most likely” of the MAN outcomes, LNG would displace approximately 8 per cent of the global shipping fleet's current consumption of liquid oil fuel.

In March 2014 Lloyd's Register (LR) issued the results of its own investigation into the worldwide potential for LNG as bunker fuel. Entitled *Global Marine Fuel Trends 2030*, the study encompassed three major global economic scenarios and concluded that, in its 'status quo' scenario, LNG will account for about 11 per cent of the world bunker market in 2030. Heavy fuel oil will remain the dominant driver of ship engines, commanding a market share of about 66 per cent.

LR points out that the use of LNG would be greater but for the comparatively young age of much of the world fleet. One sector that is ageing and has not experienced any notable infusions of newbuilding tonnage of late is that comprising chemical and small product tankers. LR states that LNG could be powering over 30 per cent of small tankers by 2030.

It is vital that this nascent LNG-fuelled vessel fleet is provided with an internationally agreed set of rules governing LNG bunkering, including aspects such as ship design and equipment, transfer arrangements and operational safety. Harmonised requirements will give shipowners the level playing field they need to

underpin their investments and provide users of LNG-fuelled ships with a base upon which they can build a safety performance record every bit as exemplary as that established by the LNG carrier sector.

A unified regulatory regime will also assist maritime authorities in dealing with the extremely diverse industry that is beginning to emerge. Administrations are being requested to review an ever-increasing number of LNG-fuelled vessel concept designs that span a full range of vessel types and encompass different types of gas-burning engines, gas treatment equipment and bunker tank design and location. Port and coastal state authorities charged with verifying the safety of a ship's LNG bunkering arrangement and its ability to perform as required also have a vested interest in the availability of a single, common regime against which they can test compliance.

The maritime industry is working hard on the development of such an instrument – in the form of IMO's *International Code for Ships using Gas or other Low Flash-Point Fuels (IGF Code)*. Efforts to finalise the IGF Code have been prioritised and a spring 2015 adoption date has been targeted. This would allow the new regime to become mandatory some time in the first half 2017. Once the work on the use of LNG, methanol and low flash point diesel fuels is complete, other fuels such as LPG and hydrogen will be addressed.

The causes of global harmony, sound design and reliable operations will be greatly facilitated by the Society for Gas as a Marine Fuel. SGMF is a new non-governmental organisation (NGO) established to promote safety and industry best practice in the use of LNG as a marine fuel. **MC**



New horizons beckon for the LNG shipping industry in the icy waters of the Russian Arctic

Arctic Pilot Project – an early precursor to Yamal LNG

Although stillborn, Canada's Arctic Pilot Project of 35 years ago set a precedent that is now being followed up with the first icebreaking LNGCs

The Arctic Pilot Project (APP) was launched to determine if there was a technically and economically feasible way of delivering gas from the Canadian Arctic islands by ship. The shipping component of the scheme was to comprise two 140,000m³ icebreaking LNG carriers, operating year round. Loading was to take place at a terminal on Melville Island's Bridport Inlet while the delivery voyage would be across Lancaster Sound and between Baffin Island and Greenland across Baffin Bay and the Davis Strait out into the North Atlantic.

Panarctic Oils of Calgary had discovered the Drake field, with its 110 billion m³ of gas, in the Melville Island region in the late 1960s. Although Melville is not considered to be in the High Arctic, it does fall within what the Canadian Arctic Shipping Pollution Prevention (ASPP) regulations specify as Zone 6. Vessels navigating in this zone are required to be able to move unaided through ice 2-2.5m thick during the winter months.

APP was initiated by Petro Canada, as the overall project operator and manager, in early 1977. Melville Shipping Ltd, a consortium of three

shipping companies, joined the venture to provide technical resources and expertise for the shipping segment. The shipowners were Federal Commerce and Navigation of Montreal, Upper Lakes Shipping of Toronto and Canada Steamship Lines of Montreal.

The APP project itself had a precedent. In 1969 Exxon had converted its crude oil tanker *Manhattan* into an icebreaking vessel to prove the viability of North West Passage transits. More specifically the oil major had sought to evaluate the potential for Arctic tanker operations as a means of exploiting Alaska's North Slope oil field. In the event, although the tanker successfully navigated the route, carrying a single, token barrel of oil on the return voyage, it was an expensive exercise and a pipeline across Alaska was deemed to be more economically feasible.

The challenge of discovering a sea route along the North West Passage through the Canadian Arctic has excited entrepreneurs and explorers alike for centuries. The challenge was just as real for the interests behind APP, bearing in mind the need for a year-round solution for large, sophisticated ships.

Shipbuilders, consultants, ice specialists and equipment manufacturers with experience in LNG ship construction flocked to Canada to promote their capabilities. This frenzied competition prompted a range of research programmes worldwide in the search for the optimum icebreaking LNG carrier design.

Because there were no class or regulatory rules in place governing the design and construction of LNG carriers for operations in such a hostile environment, designers were left to formulate their own specifications. No LNG ship of the proposed size had yet been built and the cargo sloshing phenomenon was not understood to anything like the extent it is today.

An additional challenge was the choice of material and thickness for the low-temperature steels to be used for the hull ice belts. Another design consideration was the fact that the vessels would spend 70 per cent of their time in open water en route to and from the proposed Canadian east coast receiving terminal.

Not surprisingly under the

circumstances, the tendency is to err on the side of caution and a conservative approach to the design of the vessels was taken. It was decided to build the ships as Arctic Class 7 icebreaking LNG carriers according to the ASPP classification. This specifies the steel grades required for hull ice belts. For the ships in question there would be six ice belt areas, covering the stern and bow, the mid-body, the upper and lower transition and the lower bow.

The naval architects proposed a hull shape which featured a propulsion-efficient aft-end, a mid-body with tapered lower sides and an icebreaking fore-end. Hull resistance in open water and in ice, including first year ridge ice, was studied, as was vessel manoeuvrability in ice. Model tests were carried out at the Wärtsilä Arctic Design and Marketing (WADAM) ice basin, the Hamburg Ship Model Basin (HSVA) and in Canada at Arctec and the National Research Centre's hydrodynamic laboratories.

After a thorough review of all the options, the designers narrowed down the vessels' cargo containment system to a choice between spherical and membrane tanks. The propulsion system favoured by the APP team was particularly adventurous for the time. Gas turbines burning cargo boil-off gas, with electrical transmission of power to three fixed-pitch propellers, got the vote. The arrangement featured an 8.0m diameter centreline propeller and two 7.5m diameter wing propellers.

The design team believed an electric transmission system would provide a superior performance in ice-covered waters due to the high torques available at low propeller/shaft speeds and the excellent response times. Also it was appreciated that gas turbines offered

improved performance in a low-temperature environment.

In the event, despite the steep learning curve, APP did not proceed. A combination of falling oil prices, poor market demand, an economic recession and a lack of political confidence ensured that the curtain was drawn on the initiative in 1982. Quite simply APP was a project ahead of its time. But some seeds were sown.

Today the LNG industry is focused on the northern Russian port of Sabetta, where Yamal LNG is poised to become the world's first Arctic LNG project. Blessed with rich gas deposits nearby, Sabetta is located at the mouth of the Ob River and is icebound for nine months of the year. The US\$27 billion scheme, which has been given the go-ahead, will require a fleet of 16 icebreaking LNG carriers of 172,000m³ each to ensure the delivery of gas along the Northern Sea Route on a year-round basis to customers in Asia and Europe. The ships will be delivered over the 2016-18 period, and when Yamal is operating at full capacity a laden LNGC will depart Sabetta every 38 hours.

The Arc 7 ice class ships will be able to proceed through sea ice up to 2.1m thick and to operate in temperatures as low as -50°C. The intention is for the ships to sail eastbound to Asia during summer period, independent of any icebreaker escort, and to sail westbound to a transshipment point in Europe for the rest of the year. At this location LNG will be loaded onto conventional LNG carriers for the final leg of the delivery voyage.

This Yamal LNG icebreaking fleet, which will be shared amongst three shipowning consortia, will be built by Daewoo Shipbuilding and Marine Engineering (DSME) in Korea. Each ship will cost approximately

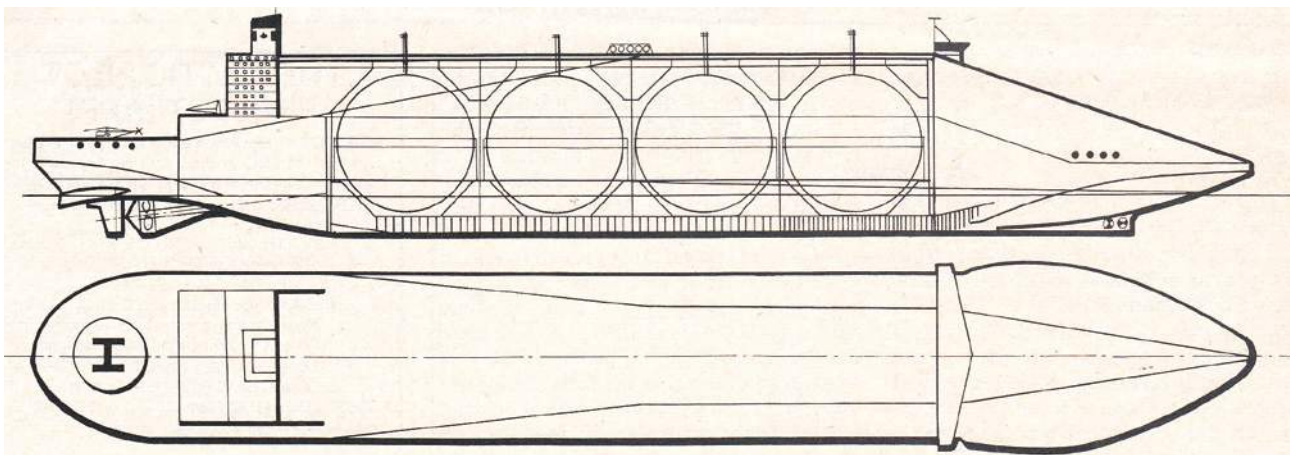


Daewoo will construct the 16-ship Yamal LNG fleet of 172,000m³ vessels

US\$310 million to construct and will be provided with a reinforced Gaztransport and Technigaz (GTT) No 96 membrane tank cargo containment system. A dual-fuel diesel-electric (DFDE) propulsion system has been chosen and at the end of the power train on each ship will be three Azipod propulsors.

The design of the Yamal LNGCs is based on Aker Arctic's 'double-acting' technology. The combination of the azimuthing propulsion pods and the icebreaking bow means that the vessels can break ice in both directions. However, they will be most effective as icebreakers when moving stern first, as the omnidirectional Azipods can be used not only to provide propulsive power but also to keep broken ice clear of the hull due to their wash effects.

Back in Canada the riches of the Drake field are still in position in the icy surrounds of Melville Island. Now, 32 years on since APP faltered, should our sights be once again focusing on this remote part of northern Canada? So much progress has been made with LNG carrier design in the intervening years that the task would be much easier this time around. *SH*



A 140,000m³, triple-screw vessel with four Moss tanks was one of the Arctic Pilot Project design options

Where will the industry be in 2029?

LNG Shipping at 50 had the opportunity to ask a panel of experts* to predict the state of play in 2029, on the occasion of SIGTTO's 50th anniversary

LNG Shipping at 50: The global trade in LNG is currently around the 240 million tonnes per annum (mta) mark. What do you think the trade level will be in 2029 (approximately) and why?

Andrew Clifton: It will probably be around double that, if not more. Demand is rising and is likely to continue to do so for environmental, cost and security of supply reasons. The two countries with the largest reserves of natural gas, Russia and Iran, currently have just one export terminal between them. Once these vast reserves come onstream, along with the export projects planned for the US, British Columbia, East Africa, the eastern Mediterranean, the Arctic and Australia, the world's LNG production profile will look very different to that of today. Of course, not all proposed projects will be built but those that go ahead will mean a significant boost to world output.

Jean-Yves Robin: Global trade could be in the 400–425 mta range. This figure is arrived at because export plants traditionally work at an 85 per cent utilisation rate while liquefaction capacity worldwide could reach the 450–500 mta level.

Bill Wayne: My guess would be about 400 mta. The drivers are an increasing awareness that gas will have a key role to play in a world of low CO₂ emissions and the possibility that significant quantities in the form of LNG could be utilised as marine fuel. It is worth noting that the global market for marine bunker fuel oil stands at 300 mta. Just a 15 per cent swing, which seems a fairly conservative estimate, would require an extra 40 mta of LNG production. Moderating influences on this gas demand are the traditional issues of high capital cost requirements and perceived risks in doing business in some countries with access to undeveloped reserves.

Ed Carr: I don't have a figure in mind, but it is logical to think that natural gas will continue to be the fossil fuel of choice into the foreseeable future, primarily for power generation but also for domestic use such as heating and cooking, particularly in emerging markets. The use of gas as a petrochemical feedstock is also driving demand. Indonesia and South America are good examples of LNG markets that did not exist 10 years ago. Furthermore the threat of geopolitical disruptions to pipeline deliveries will prompt decision makers to put in place LNG import infrastructure as a hedge against supply interruptions.

Chris Clucas: Extrapolation of statistics from the past 10 years suggests a level of around 425 mta, or about 80 per cent ahead of the current trade volume. The positive factors include world population and economic growth, environmental concerns and plentiful supplies of gas. On the other side of the coin are the imponderables. As the late Malcolm Peebles memorably commented at one Gastech conference, the LNG industry has seen numerous demand forecasts, and the only consistent factor is that they are always wrong! No doubt my comments above have just added to the tally.

LNG Shipping at 50: Do you expect any breakthroughs in terms of new containment systems over the next 15 years?

Andrew Clifton: The main containment systems in use today are unlikely to be easily displaced. They are proven, well-established and have stood the test of time. The drive towards increased efficiency will continue, with a particular focus on better insulation to ensure lower natural boil-off gas (BOG) rates, in tandem with improvements in engine efficiency and the resultant



Andrew Clifton

lower requirement for BOG as fuel. For floating terminal projects there may be a trend towards greater use of Moss spheres or self-supporting, prismatic IMO Type B (SPB) tanks. The new, enlarged Panama Canal locks will determine the maximum size for future LNG vessels – about 175,000m³ for membrane tank ships and 160,000m³ for Moss ships for a maximum beam of 49m.

Bill Wayne: No, I think there will be continual evolutionary development of established systems, mainly for lower BOG rates. There are high entry barriers to completely new containment systems, and backing a novel design is regarded as being a significant technological risk. To gain acceptance, a new design must be either significantly cheaper, quicker to build or, preferably, both.

Ed Carr: I believe that SPB will make a comeback, now that the JMU yard in Japan has received several orders for SPB tank vessels and has been able to reduce costs by using more automated welding. The displacement tonnage disadvantage of SPB ships has more or less been negated by the fact that many terminals have upgraded to accept Q-flex and Q-max size vessels. At 177,000m³, conventional LNG carriers with Moss tanks have probably reached their maximum size, although spherical tank vessels of greater capacity could be used in offshore applications. I can't imagine shipowners or charterers taking a chance on a new membrane or hybrid containment system just to save the GTT license fee. For that to happen there would need to be risk sharing, and we don't see much of that in today's business. Also, a deep-pocketed project participant willing to take that risk

would be required. Having said that, it is interesting to note that ExxonMobil used a new tank design for its Adriatic LNG offshore terminal.

Chris Clucas: Possible increases in ship capacity could lead to an evolution of the current integral membrane, independent prismatic and independent spherical tank containment systems. Nirvana is still the internal insulation system but failures of the concept early in the industry's history seem to have discouraged any serious work on this idea. However, new materials yet to be discovered may make such an internal insulation system feasible.

LNG Shipping at 50: What do you think will be the LNG propulsion system of choice in 2029?

Andrew Clifton: I think technology will bring further changes. When dual-fuel diesel-electric (DFDE) engines were first ordered in the early part of the new millennium, no-one was talking about two-stroke gas injection (ME-GI) engines. Recently such vessels have been ordered. There will still be steam ships trading in 2029. Pressures to lower fuel consumption, increase engine efficiencies and control system emissions will push technology in different directions. The industry will learn from the performance of the early ME-GI engines and the use of LNG as a marine fuel on conventional ships and develop accordingly.

Jean-Yves Robin: Given the LNG industry's traditional reluctance to take risks or innovate at too fast a pace, I do not expect a great change from the modern engines now being chosen for newbuildings. The current large orderbook for LNG ships and the propulsion systems that have been specified for these vessels provide a good indication of the direction the industry is taking.

Bill Wayne: Low-speed, two-stroke, dual-fuel diesel engines with low-pressure gas injection. The principal driver for this particular choice of propulsion system is IMO's Energy Efficiency Design Index (EEDI) initiative, and hence fuel economy. Technically a neat design of combined cycle gas turbine could be interesting, but there is no advanced aero-derivative base engine to build the system around. Modern engines, such as the Rolls-Royce MT 90, are all too powerful for the needs.

Ed Carr: I think there will continue to be a market for all three propulsion systems. Steam, and now ultra steam, turbines have their advocates due to the system's reliability and the ease of handling BOG at low speeds. DFDE, and TFDE, lends itself to flexible machinery space layouts and specific applications like the use of azipod propulsors. The downside is the high maintenance costs. ME-GI engines, once proven in service, will be attractive to projects where the cost of fuel is a significant issue in the scheme's overall economics. However, many trading models only use their ships at full speed for a portion of time and low speed means a requirement to handle BOG. That means either adding an expensive reliquefaction plant or disposing of BOG via a gas combustion unit (GCU).

Chris Clucas: The same system as used for normal merchant ships, because such ships are also likely to be running on LNG! Although it is difficult to envisage what may happen in the next 15 years, fuel cell technology looks promising. Also, conventional two-stroke diesels have proved reliable under the very demanding conditions at sea, which is one factor that will not change. A simple and reliable propulsion system will be the key requirement, plus the ability to burn clean fuel efficiently so as to be in compliance with EEDI requirements and not cause environmental pollution.

LNG Shipping at 50: To what extent do you think the LNG industry will rely on floating LNG production in 2029?

Andrew Clifton: Five years ago there was no FLNG vessel on order and now we have four such units under construction and several more FLNG projects under serious discussion. It is inevitable that a reasonable percentage of the world's production in 2029 will be FLNG-derived. The challenges associated with building an LNG export terminal at a greenfield onshore site, especially in a remote area with labour and local content issues, are huge. Project economics will determine the final choice. Operating an FLNG unit comes with its own challenges, including the provision of onshore support, onsite train maintenance and handling various weather scenarios.

Jean-Yves Robin: Of the 230 mta of additional liquefaction capacity likely to come onstream between now and



Jean-Yves Robin

2029, not more than 15–20 per cent, or 35–45 mta, will be FLNG-derived. Most extensions of existing plant, brownfield projects, schemes with adequate onshore infrastructure and projects in areas where a high local content is required will rely on traditional shore-based export terminals.

Bill Wayne: Not much. I think FLNG will remain a niche product so long as there are sufficient reserves which can be developed with reasonable ease using traditional onshore plants. The main driver for FLNG is the elimination of the costly subsea line back to shore. Additionally, projects such as Prelude make sense due to the very high engineering, procurement and construction costs associated with developing onshore facilities in Australia.

Ed Carr: It really depends on the price of LNG. On a per tonne basis, offshore projects are almost always significantly more expensive than onshore projects, but any decision will be site-dependent. While there will be some floating LNG production going forward, I think it will be the exception rather than the rule.

Chris Clucas: To a significant extent. There will be an increasing need to use our offshore energy resources, and FLNG offers the opportunity to exploit small, stranded gas resources.

LNG Shipping at 50: To what extent do you think small-scale LNG, including the use of LNG as marine fuel, will be established by 2029?

Andrew Clifton: The delivery of smaller parcels of LNG to receivers who are not currently able to handle LNG will become much more common

and small coastal LNG vessels will be required in greater numbers. The extent to which LNG is used as a marine fuel and the speed of its take-up will depend on when IMO's global sulphur cap restrictions enter into force. By 2029 I would expect that a substantial worldwide LNG bunkering infrastructure will be largely in place, enabling many deepsea vessels to bunker with LNG. Small-scale LNG will be an integral part of this supply chain.

Jean-Yves Robin: Small-scale LNG, primarily for the supply of LNG as transportation fuel, could grow rapidly from 2020 onwards, to reach around 40 mta by 2029. That would be equivalent to around 10 per cent of the total LNG market at that time. Both environmental (air pollution) and economic drivers (fuel price differentials and the cost of complying with IMO restrictions) are the underlying reasons.

Bill Wayne: I think there is quite a lot of potential here, particularly for vessels trading extensively in emission control areas (ECAs). I am less sure of the case for ships serving on long-haul, deepsea trade routes.

Ed Carr: The extent to which LNG as marine fuel is taken up will depend on price, supply and the continued spread of stricter emission control requirements. Look for ships operating in current ECAs, namely the Baltic and North Seas and North American coastal waters, to lead the way. They will be followed by vessels on long-haul, fixed routes, like large container ships sailing between Asia and Europe.

Chris Clucas: Having recently been appointed the founder president of the Society for Gas as Marine Fuel (SGMF), I would say completely! The business is already starting to happen and I am sure you will be hearing about orders for new LNG bunker delivery tankers very shortly.

LNG Shipping at 50: What do you think is the greatest challenge that the LNG industry will face over the next 15 years? What is the best way to meet this challenge?

Andrew Clifton: I believe it is two related issues which SIGTTO has been dealing with since the Society was formed – manning and safety. The remarkable safety record that

LNG shipping has achieved needs to be protected and maintained; it is, in effect, our license to operate. Increases in activity bring increased risks and these need to be mitigated through appropriate control measures, including continuing to operate to best practice and not just the minimum requirements. Existing industry members need to ensure that new entrants embrace the high standards and practices the LNG shipping community has operated to these past 50 years. The industry also needs to continue to invest in training; there is no other solution to the skills shortage. Also, the focus must not be just on ship staff. Having sufficient numbers of shore support staff and trainers of the appropriate quality is vital too.

Jean-Yves Robin: There are many challenges. These include the uncertainty of demand in the Atlantic Basin, a potential breakthrough of unconventional gas in China and India, and competition from large pipelines into Asia. However, the major challenge within the LNG industry itself is the increasing cost of new investment stemming from factors such as environmental requirements, shortages of qualified personnel, and labour and material costs.

General market and political pressures to keep the level of energy prices low on the one hand and cost escalations on the other could squeeze margins over extended periods of time.

Bill Wayne: In an age where society is increasingly suspicious of large companies, and recognising that LNG projects will, for cost reasons, remain the preserve of such companies, the challenge of getting society, government and regulatory support for new projects remains significant. To have a chance of success it is vital that the industry's reputation for reliability and safety are strongly maintained.

Ed Carr: Finding, training and developing adequate human resources to handle the growth. But also continuing a safety culture where no accident is acceptable.

Chris Clucas: Skills – in all areas, ashore and at sea. The best way to meet this challenge is through training and much better harnessing of educated engineering talent from our colleges and universities. Historically the LNG industry has been a rather 'start-stop'



Chris Clucas

sector, with many senior people leaving and not being replaced during the quieter parts of the business cycle. This is then followed by a mad panic and wage spiral a couple of years later when activity picks up. I was extremely fortunate to join the International Chamber of Shipping (ICS) just after graduating and chance brought me the opportunity to move into liquefied gas. It seems to me this sort of opportunity needs to be offered by some of our industry bodies. It is certainly on my agenda for SGMF and I have suggested this in the past to SIGTTO. The need exists in the companies that design and operate LNG plants, that manufacture LNG equipment and especially in those that man and operate LNG ships, where the entire sector faces a recruitment gap. Logic would suggest that general remuneration packages for LNG should be kept somewhat higher than comparable work in, say, oil or coal but this would probably be impossible in companies that work in all sectors.

LNG Shipping at 50: Do you foresee any other major changes taking place in the LNG industry over the next 15 years?

Andrew Clifton: More players in the industry mean more options and increased competition and expectations. The small, closed 'LNG club' is now part of history. The percentage of the world's fleet tied to specific projects is likely to be lower than it is today as the portfolio players use chartered/operated fleets to move their supply around. The way LNG is traded may also move away from the more traditional methods of the past. In addition we may see completely new uses for floating LNG such as integral power plants where

storage, regasification and power generation is all on one huge unit supplied by ship-to-ship (STS) transfers. Such a solution would be ideal for major engineering projects in isolated locations or for dealing with areas recovering from natural disasters.

Jean-Yves Robin: The LNG business model in the Pacific Basin is likely to continue evolving towards the structure seen in the Atlantic Basin. In other words Asia's traditional tramline model of long-term contracts and dedicated trade could gradually give way to a traded market and portfolio play, including by Asian companies. As a result by 2029 the current distinction between the business models of Atlantic-based and Pacific-based players would have all but disappeared.

Bill Wayne: There are a number of unknowns looking forward. How will the Chinese demand develop and will that bring Chinese capital into new projects? Will the premium, oil-linked price structure based on Japanese contracts continue, or will LNG develop its own, worldwide commodity pricing system. Despite this, I think we will still see projects underwritten by long-term contracts. While there may be some trend towards more short-term trade and, if you like, more commoditisation of LNG, I don't think it will be substantial. Basically, LNG projects are highly capital-intensive and banks want the security of long-term contracts for their financial support. Additionally most buyers are supplying markets where their host governments put stringent requirements on them concerning continuity of supply. One easy way to meet these is through long-term contracting for the major



Bill Wayne

proportion of their foreseeable demand. Recent political uncertainties around security of supply, such as could arise due to the current Russia/Ukraine situation, may well bring more countries into the LNG users' club.

Ed Carr: I expect that more and more LNG will be sold on a trading basis with long-term contracts becoming less common. Shipowners will be challenged by shorter time charter periods.

Chris Clucas: More new companies entering the business, especially traders. The larger the market, the more opportunity for arbitrage trading. This is certainly not unique to LNG.

LNG Shipping at 50: Do you think the roles of SIGTTO and GIIGNL will change in any way over the next 15 years?

Andrew Clifton: I think both organisations will grow from strength to strength as the world's focus on LNG increases. Both organisations are likely to be bigger, with more resources dealing with more activities. The importance of highly specialised, experienced and respected industry bodies with years of experience serving their members cannot be underestimated. On the basis that SIGTTO had 130 members 10 years ago and has 190 today, I will hazard a guess and say we will have 300 members by 2029!

Jean-Yves Robin: With expansion of the numbers of players active on the LNG scene, and in particular because of the development of small-scale LNG, safety will become an even more important focus for associations like SIGTTO and GIIGNL. With the objectives of safety, operational excellence and product-lobbying in mind, we might consider assembling an industry group that incorporates all the players in the LNG supply chain, from liquefaction down to suppliers of LNG in the small-scale market. If GIIGNL develops in such a direction, the membership could grow significantly.

Bill Wayne: I think we will see more of the same roles. There will undoubtedly be new challenges but the key role of the associations as the voice of the industry and, indeed, as the champions of the industry, will continue. On membership, I think SIGTTO's will grow by about 10



Ed Carr

per cent. While new projects bring in new players, we often see consolidation taking place after a period, with some of the new players being absorbed by existing large players. For GIIGNL, I would put it a bit higher because I think more countries will be joining the LNG users' club, and this means more importers.

Ed Carr: As the LNG business expands going forward, I think there will be more and more demand for the services of the two organisations, especially in the form of technical information. Membership will continue to expand with the business but it is hard to put a number on it.

Chris Clucas: There will be more members in locations remote from the organisations' head offices. So there will have to be more local meetings, and travel requirements will be greater than at present despite the growing use of video-link technology. In short, both SIGTTO and GIIGNL will become more global.

**Andrew Clifton is general manager of SIGTTO*

Jean-Yves Robin is general delegate of GIIGNL

Bill Wayne is a former general manager of SIGTTO and now director of Sewallis Consulting

Ed Carr is a director of BGT and has worked in the LNG industry, afloat and ashore, for 35 years

Chris Clucas is group fleet director with the Bernhard Schulte Shipmanagement Group

The interviewees would like to point out that the views expressed above are their personal opinions and not necessarily those of their organisations.



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LNG industry timeline

May 1915

Godfrey Cabot patented concept for "handling and transporting liquid gas" by river barge

1917

Small gas liquefaction plant built in West Virginia; main output was bottled ethane and propane

1940

Hope Natural Gas built pilot liquefaction plant in West Virginia

1941

First commercial liquefaction plant, a peakshaving facility, built in Cleveland, Ohio

1944

Failure of new, fourth LNG storage tank at Cleveland due to use of 3.5% nickel steel, also inadequate tank dykes; fire kills 128

1947

Dresser Industries built liquefaction plant near Moscow

1951

William Wood Prince launched idea of barging LNG from Louisiana up Mississippi River to Chicago for use in stockyards

1952

Great London Smog, and its 4,000 directly linked fatalities, set North Thames Gas Board on overseas search for natural gas

1956

French government authorised Worms Group to research transport of Algerian natural gas by sea

1957

Gazocéan established

1958

CB&I built flat-bottomed, aluminium LNG storage tank at Lake Charles in US

January 1959

5,000m³ *Methane Pioneer*, converted cargo ship, carried first of seven trial LNG shipments from Lake Charles, Louisiana to Canvey Island, UK

1960

Shell took 40% stake in Constock; company renamed Conch International Methane

November 1961

UK signed 15-year LNG sales contract with Algeria

1961

DNV engineer Bo Bengtsson developed concept of waffled membrane containment system; technology later acquired by Technigaz

1962

France signed a 15-year LNG sales contract with Algeria

Conversion of experimental ship *Beauvais* completed

1963

FMC developed the first loading arm for LNG

May 1964

630m³ *Pythagore*, experimental vessel with Technigaz tanks, went into service

October 1964

27,400 m³ *Methane Princess* transported first commercial LNG cargo, from CAMEL plant in Arzew, Algeria to Canvey Island, UK

October 1965

BP discovery of gas in UK sector of North Sea scuppered Conch plans for Nigeria/UK LNG project

Gaz Transport established

1967

US National Fire Protection Association adopted *NFPA 59A Standard for the Production, Storage, and Handling of LNG*

December 1968

Methane Pioneer delivered first US import cargo, from Algeria and discharging direct to LNG road tankers in Boston

November 1969

Japan, and Asia, received first LNG cargo, a shipment from Kenai, Alaska to Negishi terminal of Tokyo Gas

LNG Shipping at 50 | timeline

1969

Italy commenced LNG imports, at Panigaglia terminal

1970

Libya's Marsa el Brega terminal opened, despatching cargoes to Italy and Spain in four 41,000m³ LNGCs designed by Esso

November 1971

Distrigas LNG opened first US import terminal, at Everett, a suburb of Boston

December 1971

GIIGNL, with 19 members, held inaugural meeting

1971

Qatar's North Field discovered; deposit proved to be world's largest non-associated gas field

November 1972

Three-train Skikda plant in Algeria began producing LNG

December 1972

75,000m³ *Gadina* discharged Brunei's first export cargo, at the Senboku 1 terminal of Osaka Gas

1972

Fos Tonkin terminal commissioned

February 1973

Tokyo Gas commissioned Sodegaura terminal

Fire during repair of empty LNG peakshaving tank on Staten Island, New York dislodged concrete roof, killing 40 workers

November 1973

88,000m³ *Norman Lady*, first Moss tank LNGC, delivered

January 1975

La Ciotat completed 120,000m³, Technigaz Mk I vessel *Ben Franklin*, first LNGC over 100,000m³

1976

IMCO published *Code for the construction and equipment of ships carrying liquefied gases in bulk*

January 1977

Abu Dhabi became first Middle East LNG exporter when 125,000m³ *Hilli* loaded inaugural Das Island

cargo, for Tokyo Electric

July 1977

LNG *Aquarius*, of 125,000m³, loaded first Indonesian LNG export cargo, at Bontang for new Senboku 2 terminal of Osaka Gas

March 1978

Cove Point receiving terminal commissioned, launching the El Paso LNG project

US Natural Gas Policy Act lifted price controls on domestic natural gas discovered after 1977

September 1978

Elba Island terminal opened, with *El Paso Paul Kayser* cargo

October 1978

Arun, Indonesia's second export terminal, loaded first cargo

May 1979

Insulation faults found on first of three Conch 125,000m³ newbuildings at Avondale; trio declared constructive total losses

June 1979

Laden 125,000m³ *El Paso Paul Kayser* ran aground in the Straits of Gibraltar at full speed; no breach of containment system

1979

SIGTTO established in London with 9 founder members

April 1980

El Paso contracts terminated when Algeria and US fell out over gas pricing; Cove Point mothballed in 1981, Elba Island in 1982

November 1980

Brunei LNG delivered 1,000th cargo, to Sodegaura terminal

December 1980

Montoir receiving terminal at St Nazaire commissioned; France's third import facility

1980

US adopted comprehensive LNG safety regulations that include ship and terminal exclusion zone requirements

September 1981

Kawasaki completed 125,000m³ *Golar Spirit*, first Japanese-built LNGC

1981

UK ceased importing LNG on regular basis, until 1996 when new long-term contract with Algeria was agreed

September 1982

Panhandle's Trunkline import terminal in Louisiana received first cargo from Algeria

1982

Exxon exited Libya due to US trade embargo

February 1983

First Malaysian export cargo, from MLNG complex, arrived at Sodegaura terminal onboard *Tenaga Satu*

August 1983

Mitsubishi delivered *Echigo Maru*, its first LNGC

October 1983

Korea Gas Corp (Kogas) established

December 1983

Panhandle cancelled contract for Algerian LNG due to dispute over gas prices

1984

Japan purchased 72% of world's LNG

Indonesia became world No 1 LNG exporter, overtaking Algeria

1985

Tokyo Electric's Futtsu LNG terminal opened

May 1986

10,000th LNG cargo loaded, all but 20 on long-term contracts

June 1986

IGC Code entered into force for new gas ships

October 1986

Korea received first LNG shipment, at Pyeong Taek

July 1987

Zeebrugge LNG import terminal in Belgium opened

1987

US received no LNG imports, the first year since 1974 that this had happened

June 1988

Huelva import terminal received first cargo

1988

Indonesian exports accounted for 40% of world LNG trade

July 1989

Australia exported first LNG cargo, from North West Shelf project on 125,000m³ *Northwest Sanderling* to Sodegaura terminal

December 1989

Trunkline terminal reopened; Algerian purchases resumed

1989

Le Havre receiving terminal in France decommissioned

Cartagena terminal in Spain commissioned; country's third import facility

February 1990

Delivery of Algerian cargo to Canvey Island by *Methane Princess* was to be last LNG shipment to UK for 15 years

May 1990

Taiwan received first LNG shipment, from Indonesia onboard 137,000m³ *Ekaputra* at new Kaohsiung terminal

March 1993

Japanese utilities involved in vessel ownership for first time with delivery of *LNG Flora*

May 1993

MLNG despatched 1,000th cargo

June 1993

IHI delivered 87,500m³ *Polar Eagle*, first LNGC with SPB tanks; sistership *Arctic Sun* completed in December

November 1993

Saibu Gas became first mid-size Japanese utility to import LNG direct; Malaysian cargo arrived on 18,900m³ *Aman Bintulu*

LNG Shipping at 50 | timeline

June 1994

Hyundai Heavy Industries delivered 125,000m³ spherical tank *Hyundai Utopia*, first Korean-built LNGC

Gaz Transport and Technigaz merged operations to create Gaztransport & Technigaz SA (GTT)

August 1994

Turkey began importing LNG, with Algerian shipment to Marmara-Ereglisi terminal

1994

Use of Canvey Island as LNG import terminal formally terminated

May 1995

Three-train MLNG 2 complex at Bintulu commissioned

June 1995

Enron claimed it had achieved its goal of becoming “the world’s first natural gas major”

September 1995

Daewoo and Hanjin jointly completed their first LNGC and first Asian-built membrane ship, the 130,000m³ *Hanjin Pyeongtaek*

November 1996

Incheon, Korea’s second import terminal, opened

Mahgreb Europe Gasline opened

December 1996

Inaugural Qatar export cargo loaded, onboard 135,000m³ *Al Zubarah* for shipment to Chubu Electric’s Kawagoe terminal

1996

Japan inaugurated three new terminals, Hatsukaichi, Kagoshima and Sodeshi

Pyeong Taek in Korea became busiest receiving terminal, overtaking Sodegaura in Japan

February 1997

Methane Princess scrapped

25,000th LNG cargo delivered

March 1997

Algeria recommenced deliveries to Italy, to upgraded Panigaglia terminal under 20-year contract

October 1997

Small-scale Tjeldbergodden facility, Norway’s first LNG liquefaction plant, opened

January 1998

Tokyo Gas commissioned Ohgishima terminal, its third

1998

Algeria completed 10-year refurbishing of its four LNG plants

In-service LNGC fleet reached 100 vessels

July 1999

Atlantic LNG in Trinidad, western hemisphere’s second export project, came onstream

August 1999

RasGas 1, second Qatar export project, inaugurated

September 1999

Nigeria LNG Train 2 commenced production; Train 1 came onstream in February 2000

December 1999

Samsung completed 138,200m³ *SK Supreme*, its first LNGC and largest Technigaz Mark III ship yet

1999

Bontang Train 8 onstream; Indonesian LNG production peaked, at 28.5 mta level

February 2000

Revithoussa import terminal in Greece commissioned

April 2000

Oman LNG plant opened; Oman is 12th LNG exporter

July 2000

EcoEléctrica terminal in Puerto Rico received first cargo

October 2001

Elba Island terminal received first LNG cargo in 20 years, delivered by *Matthew*

December 2001

Enron filed for bankruptcy

February 2002

Wärtsilä won first marine order for its 50DF dual-fuel engines, for four six-cylinder units for 71,400m³ *Gaz de France Energy*

September 2002

Tongyeong, Korea's third terminal, received first cargo

November 2002

Nigeria LNG Train 3 commenced operations

February 2003

AES Andries terminal opened and Dominican Republic become 13th LNG importer

March 2003

MLNG Tiga despatched first cargo, to JAPEX

July 2003

Berge Boston (now *BW Suez Boston*) received shipping industry's first ever International Ship Security Certificate

Kawasaki delivered 2,500m³ *Shinju Maru No 1*, the world's first pressure buildup-type LNG carrier

August 2003

Cove Point in US received first commercial LNG cargo in 23 years; it had reopened for peakshaving operations in 1995

Bilbao, Spain's fourth terminal inaugurated

October 2003

Moss spherical tank 145,000m³ *Energy Frontier* became largest LNGC on delivery from Kawasaki

November 2003

Sines import terminal in Portugal commissioned; country is 14th LNG import nation

2003

Devon Energy in US launched shale gas era by drilling first well combining horizontal drilling and hydraulic fracturing technology

January 2004

Petronet imported India's first LNG cargo, at Dahej

April 2004

Three of six trains at Skikda, Algeria plant destroyed by explosion during boiler maintenance; 27 killed

December 2004

Hudong Zhonghua began work on first Chinese-built LNGC

Insulation imperfections detected in CS1 containment system during *Gaz de France Energy* gas trials; repairs delayed delivery

January 2005

138,000m³ *Excelsior*, world's first regas vessel, commissioned; in May Gulf Gateway, first deepwater LNG port, inaugurated

Single-train SEGAS plant at Damietta, Egypt commenced operations, with cargo lifted by 138,000m³ *Cádiz Knutsen*

April 2005

Shell's Hazira receiving terminal in India inaugurated

May 2005

Two-train, 7.2 mta Idku plant in Egypt commissioned

Sanha LPG FPSO, world's first purpose-built LPG FPSO, commenced operations

July 2005

Grain LNG reopened as import terminal, receiving first UK import cargo in 15 years

Posco's Gwangyang import facility, Korea's fourth, opened

December 2005

Qalhat LNG, third Omani train, despatched first cargo

January 2006

Mizushima, Japan's 26th receiving terminal, opened for business

February 2006

3.5 mta Darwin LNG export terminal loaded first cargo

April 2006

Dapeng LNG, China's first import terminal, entered service

SAGGAS receiving terminal in Sagunto, Spain inaugurated

August 2006

Altamira terminal opened, making Mexico 17th LNG importer

LNG Shipping at 50 | timeline

December 2006

Egegaz import terminal at Aliaga, Turkey's second, opened

2006

Qatar overtook Indonesia to become No 1 LNG exporter

February 2007

Excelsior and Exmar carried out first commercial ship-to-ship (STS) LNG transfer, at Scapa Flow

Teesside GasPort, world's first jettyside, regas vessel-based receiving terminal, inaugurated

Small-scale Hachinohe distribution terminal opened in Japan

May 2007

First cargo loaded at Equatorial Guinea's Bioko Island plant

El Ferrol, Spain's sixth import terminal, received first cargo

October 2007

4.3 mta Snøhvit project in Norway loaded inaugural cargo

December 2007

Al Gattara became first Q-flex ship to lift a cargo

2007

Panama Canal expansion project launched

April 2008

Sabine Pass and Freeport import terminals commissioned

Costa Azul, Mexico's second terminal, received first cargo

Dapeng Sun, first Chinese-built LNGC, delivered

June 2008

Bahia Blanca GasPort, South America's first LNG import facility, commissioned; first jettyside LNG STS transfer carried out

October 2008

Samsung delivered *Mozah*, first Q-max size LNGC

November 2008

Shanghai's small-scale Wuhaogou import

terminal opened

January 2009

Brazil imported first cargo, at FSRU-based Pecem terminal

February 2009

10 mta Sakhalin 2 export terminal despatched first cargo

March 2009

FSRU-based Guanabara Bay terminal opened

15.6 mta South Hook LNG import terminal commissioned

April 2009

Excelsior opened Northeast Gateway offshore import facility

May 2009

Fujian LNG, China's second import terminal, opened

June 2009

7.5 mta Canaport LNG import terminal came onstream

Chile commenced LNG imports, at Quintero LNG terminal

Cameron LNG received first commissioning cargo

July 2009

Taiwan opened second LNG import terminal, at Taichung

Tangguh LNG loaded first cargo

August 2009

Mina Al Ahmadi GasPort in Kuwait, Middle East's first LNG import terminal, entered service

Adriatic LNG, first offshore GBS-based terminal, opened

September 2009

Decision taken to proceed with 15 mta Gorgon LNG

October 2009

Fos Cavaou (Fosmax) received first cooldown cargo

Shanghai LNG, China's third baseload import terminal, opened

November 2009

Yemen became 17th export nation with loading of first cargo

December 2009

Decision made to proceed with 6.6 mta PNG LNG project

February 2010

CLNG placed industry's first LNGC order in two years, at Hudong

May 2010

Mejillones terminal in Chile received first commercial cargo

June 2010

4.5 mta Peru LNG export terminal entered into service, with shipment to Costa Azul, Mexico

August 2010

Cheniere sought permission to export up to 16 mta of LNG for 30 years from Sabine Pass import terminal

Nakilat took delivery of 266,000m³ *Rasheeda*, last of its 54-ship newbuilding programme

October 2010

Golden Pass import terminal in Texas received inaugural cargo

November 2010

QCLNG partners agreed to proceed with 8.5 mta project

December 2010

Golar Freeze, converted to FSRU, commissioned at Dubai

January 2011

GLNG partners agreed to proceed with 7.8 mta project

Grain LNG Phase 3 expansion boosted capacity to 14.8 mta

February 2011

Qatargas Train 7, 14th and last Ras Laffan train, commissioned

March 2011

Japan hit by magnitude 9.0 earthquake and tsunami; country's nuclear plants closed for safety

checks; country's annual LNG imports rise by 25% following the disaster

April 2011

Rudong terminal in China received first commissioning cargo

May 2011

Shell sanctioned Prelude, first floating LNG production project

Exmar and Pacific Rubiales agreed to build liquefaction barge for Colombia Caribbean coast

N-KOM yard carried out first LNGC repair job, on *Simaisma*

Sweden's small-scale Nynäshamn receiving terminal opened

June 2011

GNL Escobar GasPort, Argentina's second regas vessel-based receiving terminal, commenced operations

Dunkirk LNG import terminal project in France sanctioned

July 2011

APLNG partners agreed to proceed with 9 mta project

September 2011

Map Ta Phut, Thailand's first LNG import terminal, commenced commercial operations

Gate terminal in Rotterdam received first cargo; making the Netherlands the 26th LNG import nation

Wheatstone partners agreed to proceed with 8.9 mta project

October 2011

0.3 mta Skangass LNG liquefaction plant at Stavanger opened

November 2011

First cargo discharged at PetroChina's Dalian import terminal

Shin-Minato terminal in Sendai City, only Japanese LNG import facility damaged by March 2011 earthquake, reopened

January 2012

Inpex and Total sanctioned 8.4 mta Ichthys project

LNG Shipping at 50 | timeline

March 2012

Mexico's third import terminal, at Manzanillo, commissioned

April 2012

Australia's Pluto LNG project loaded its first cargo

Japanese island of Okinawa received first LNG cargo

May 2012

Indonesia inaugurated its first receiving terminal, *Nusantara Regas Satu*, the converted LNGC *Khannur*

July 2012

Cheniere decided to proceed with Trains 1 and 2 of Sabine Pass project; Trains 3 and 4 given go-ahead in May 2013

Shell acquired Gasnor, Norwegian LNG distribution company

September 2012

CNOOC's Zhejiang LNG terminal at Ningbo commissioned

October 2012

150,000m³ *Ob River* completed first passage of Northern Sea Route by a laden LNGC

Hokkaido Gas commissioned Ishikari import terminal

January 2013

Inaugural cargo discharged at 5 mta Dabhol terminal, India's third; planned start in April 2012 was aborted

February 2013

Operations at Damietta plant ceased due to lack of feed gas

March 2013

3.5 mta Singapore LNG terminal received first cargo

May 2013

Malacca LNG's jetty-based regasification terminal received first cargo

June 2013

Angola LNG despatched first commercial shipment

July 2013

New 4.5 mta train at Skikda, Algeria commenced operations

August 2013

Italy launched *FSRU Toscana* project at site off the coast near Livorno

Kochi, India's 4th terminal, received inaugural cargo

September 2013

Det Norske Veritas and Germanischer Lloyd merged

October 2013

Zhuhai, CNOOC's fifth and China's seventh import terminal, opened

Arctic Aurora delivered second Northern Sea Route cargo

November 2013

PetroChina opened third receiving facility, at Tangshan; China's eighth import terminal

CNOOC's Tianjin facility, China's first regas vessel-based terminal, started up, using 145,000m³ *GDF Suez Cape Ann*; China's ninth import terminal

December 2013

Yamal LNG partners agreed to proceed with 16.5 mta project

Inpex commissioned 1.5 mta Naoetsu receiving terminal

January 2014

Bahia, Brazil's third FSRU-based import terminal, opened

Israel became 30th LNG export nation with start of buoy-based FSRU operations off Hadera

May 2014

Papua New Guinea became 20th LNG export nation with entry into service of PNG LNG project

In-service LNGC fleet reached 400 vessels

July 2014

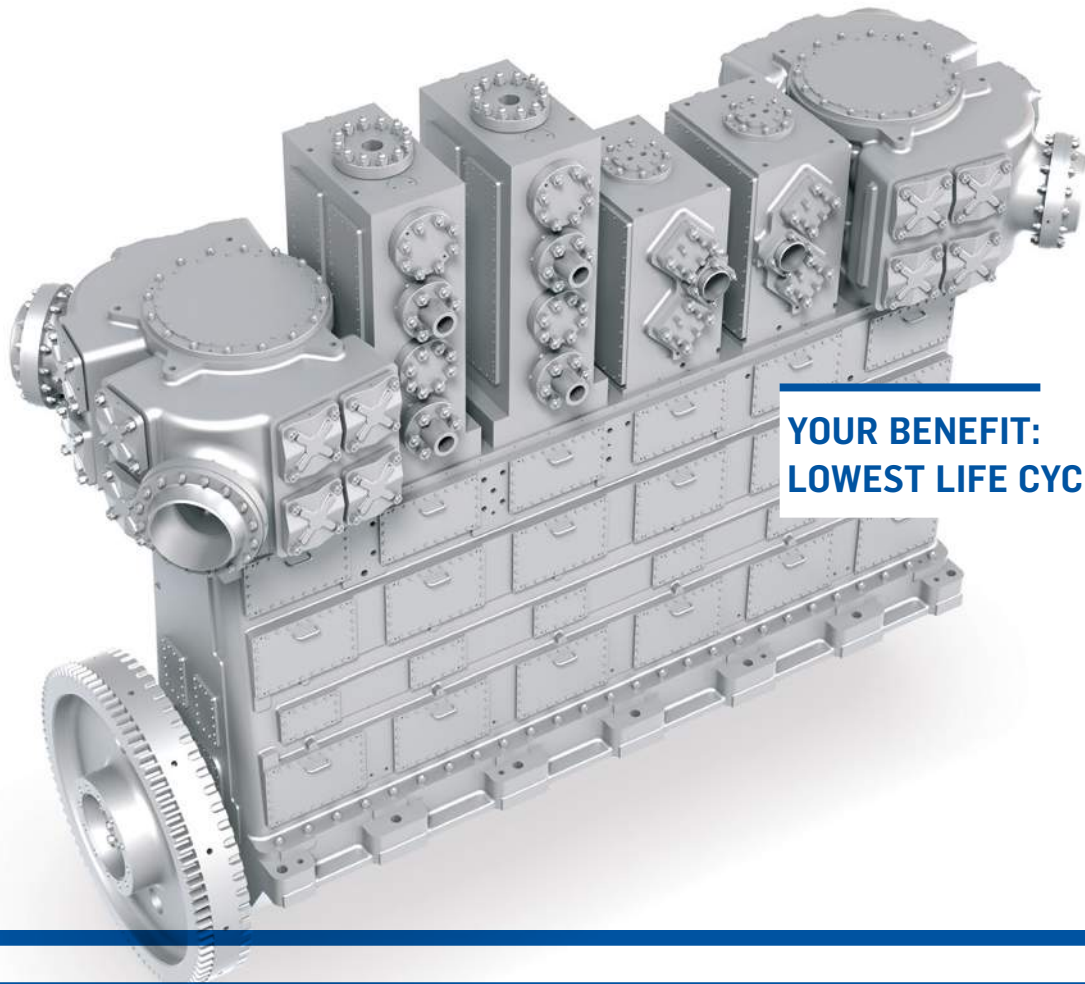
Kogas opened its fourth LNG terminal, at Samcheok

PGN FSRU Lampung went on station off southern Sumatra

August 2014

Hainan LNG, CNOOC's seventh and China's tenth import terminal, opened

Cameron LNG export project partners agreed to proceed.



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