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The Impact of Compressed Natural Gas Shipping upon Offshore Gas Development

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Abstract

This paper introduces the marine gas transport technology under development by EnerSea Transport LLC as it is being incorporated in a new ship concept. The new Compressed Natural Gas (CNG) transport system and ship design have global applicability and allow a new perspective on remote offshore oil and gas development. The paper explains how key considerations and challenges have been reflected in the design of the new ship and how that new gas ship concept opens a new world of maritime and offshore field development opportunities.

Introduction

Industry is beginning to recognize that technology allowing marine transport of Compressed Natural Gas (CNG) provides flexibility that changes the economics for marginal fields. This is especially true for gas fields in ultra-deep waters or locations remote from suitable markets. A new solution for handling, storing, and transporting gas is making many operators appreciate the breakthrough potential for marine CNG as a means to commercialize stranded gas in remote reservoirs around the world. A new class of ocean-going vessels and gas handling facilities will play key roles.

Through its Maritime Work Program, EnerSea Transport LLC and its strategic partners have developed an advanced ship design employing the proprietary Volume Optimized TRANsport and Storage (VOTRANS™) gas handling concepts. EnerSea Transport selected the world's leading maritime companies and a top energy company to form a team of unmatched engineering and project development capabilities. The leadership of EnerSea's team includes Kawasaki Kisen Kaisha, Ltd ("K"-Line) and Hyundai Heavy Industries (HHI) with strong professional support from Paragon Engineering Services Inc., the naval architects of Alan C. McClure Associates Inc., and ABS Consulting. This team has worked together with the American Bureau of Shipping (ABS) over the past year to create and verify a safe, practical ship design that provides the basis for launching the world's first fleet for CNG marine transport, opening the way for a new maritime energy transport industry.

CNG marine transport allows emerging, energy-hungry markets around the globe to access gas reserves that would otherwise remain stranded. As compared to other solutions for de-stranding of gas reserves (LNG & GTL technologies), the shipping of CNG offers a solution that significantly limits the wastage of gas resources that are needed in the emerging markets and the amount of captive investment required of operators. Such value-adding features make this breakthrough technology and the new class of ships attractive to gas and power players on a global scale.

FORGING THE DESIGN OF A NEW GAS CARRIER.

Market Influences.
EnerSea Transport has determined that clients and governments the world over are seeking a cost-effective solution to monetize stranded gas and deliver gas at higher efficiencies (% of original gas produced reaching the end users) than the currently practiced and evolving schemes for Liquefied Natural Gas (LNG) and Gas-To-Liquids (GTL) projects. As demonstrated in Figure 1, CNG marine transport is similar to pipelines in regards to how much of the valuable resource is conserved throughout the processes required to reach consumers. LNG requires about 2 to 3 times as much energy per unit of energy delivered (through liquefaction, boil-off, and re-gasification) compared to CNG and pipelines. GTL processes consume gas at levels that many countries would consider unacceptable. Not only is the lost energy unrecoverable, the more wasteful processes also generate undesirable quantities of CO_2 exhaust. While such considerations do not eliminate the commercial case for industry's move to add new LNG projects and GTL pilots, they do partially explain why there is such excitement about the future of CNG.

EnerSea Transport has evaluated numerous commercial opportunities where there are substantial economic advantages over either pipeline or LNG transport options. In general, CNG projects can be shown to have clear benefits for marine gas transport scenarios ranging from 400-5000km (ca. 200-2700nm) and for ultra-deep water production projects. The map in Figure 2 shows the global scope of major CNG opportunities in an energy hungry world (for example across the Mediterranean Sea or from Sakhalin Island to Japan and Korea). When smaller and emerging markets are considered, relatively short-haul supply-to-market pairs can be seen to cover most coast-wise populations of the world (even along many rivers).

To get the most value out of the relatively high investments in gas carrying ships, it is critical that the ships are kept in motion while the total round trip cycle time is minimized. The ships need to move the gas quickly, generally above 16knots (unless transport distances are relatively short, as in the Gulf of Mexico). Further, eliminating time in port, waiting for pilots or port berths, can significantly improve use of these valuable maritime assets. While allowing substantial savings on gas processing facilities at the terminals, CNG ships are more costly per unit of gas transported as compared to LNG ships because the cargo density is low. Therefore, CNG transport schemes are conceived to keep the ships at sea without entering ports. When EnerSea has been asked to propose a VOTRANS™ gas transport service to clients, the service usually involves offshore loading at the field with unloading near to the gas market but safely offshore. Such a loading/unloading scheme has been adopted as the basis for the ship design discussed in this paper.

Market assessments have determined that CNG ship designs should consider the need for transporting both lean, dry gas and rich associated gas from offshore fields. Fleet analyses have found that many of the most promising first project opportunities for international gas transport can be served by ships capable of transporting between 14-28x10^6scm(500-1,000mmscf). After EnerSea had generated a wide range of concepts over 18 months of engineering studies, it was necessary to select a specific cargo capacity to achieve the next meaningful step in concept evolution – a real, constructable ship design. For this purpose, a specific cargo containment system was defined to provide 75,000m^3 internal tank volume, giving a cargo capacity of 19 -23x10^6scm(680-800mmscf) of natural gas, depending on whether the gas is lean or rich in composition. This ship size fits a significant portion of the future market for international gas transport.

Principles for Optimization.

Natural gas is a complex fluid that exhibits non-ideal gas properties when compressed above 70bar (1000psi). The non-ideal characteristics can be accommodated by adjusting the "Ideal Gas Law" through the introduction of what is commonly called the "Z-factor". The gas industry has generated much documentation and many calculation models to estimate/predict the Z-factor effects in gas compression engineering. EnerSea's Volume-Optimized TRANsport and Storage (VOTRANS™) technology has recognized the relationship between the weight of containment systems and the Z-factor effect in gas storage design. By chilling gas to a suitably low temperature (usually well below 0ºC), it is possible to compress great quantities of gas into long tubular containers such that the ratio of the weight of the gas stored to the weight of the container is optimized. The cost of compression and the cost of the containers (and, therefore, the ships) can be greatly reduced by storing cold gas at relatively moderate pressures. These savings are somewhat offset by costs for refrigeration and insulation, but operational considerations and the sensitivity of cost effective ship design to the weight of CNG containers clearly reveals the value of lighter containers.

VOTRANS™ principles work well and generally apply to tubular containers of any material. However, due to the relative cost and proven reliability of steel pipe containers, the first generations of CNG ships will carry large diameter, high strength steel pipe tanks. EnerSea Transport has investigated many alternatives to high strength steel and has found them, especially pure composite tanks, to be uneconomic. Steel pipe tank modules are incorporated in the current ship design (Figure 3).

Cargo handling systems features.

In line with the need to limit the amount of time at the loading and unloading terminals, the VOTRANS™ ship is configured to include an efficient internal turret connection and loading system (similar to the APL shuttling loading system installed at Norway's Heidrun field, Figure 4). The shipboard gas handling system design assumes the gas arrives on board through the turret swivel system at a pressure that allows the gas to be injected at lower temperatures and pressures according to the described volume-optimization principles.

Loading is expected to take place at a rate corresponding to the production rate of the field being serviced such that the cargo containers are filled in 2-3 days. The delivery pressure from the in-field facilities determines how much pressure reduction and chilling is required at or on the ship. Fields producing dry gas at relatively high pressure to the CNG ship provide the opportunity to use the auto-refrigeration phenomenon of gas expansion to limit any chiller duty onboard. In the current design, it is assumed that the gas is supplied at moderate pressures and temperatures, so refrigeration equipment is required on board ship.

At the gas delivery terminal, it is desired to limit turnaround time. Therefore, the ship is provided with a liquid displacement system that ejects the cargo from storage in an efficient and controlled manner. Once the CNG ship is positively connected to the delivery terminal, gas is discharged through the internal turret to flowlines that tie into a subsea pipeline connection. Pumping capacity is designed to discharge the cargo within 24 hours. The displacement liquid is kept chilled and carried in insulated tanks forward with enough capacity to support a cascading displacement operation.

Shipboard gas handling facilities also include relief and venting systems appropriate to the upset and emergency conditions projected for the gas transport scenarios. Hazard management studies have investigated suitable responses for gas release scenarios.

Design Constraints.

The design of any vessel must be developed cost effectively while optimizing key constraints which include regulatory compliance, constructability, and operability. Each of these constraints causes hard points in the design which the ship designer must accommodate. Some constraints can be softened or removed through research and development of materials and processes, while others such as international maritime rules of practice may be difficult to change. This particular constraint depends partially on the time frame of development of the ship design and the existing stage of applicable rule development.

Regulatory.

The primary source of guidance is the International Maritime Organization's International Gas Carrier (the IMO IGC) Code. These rules are the result of many years of development and negotiation between many countries and as such are not easily changed. While they are subject to limited flexibility of interpretation, the application of this Code to a CNG carrier does require some evolution.

In addition to the IGC Code, the ship should be designed to applicable classification rules. Approval of the ship design by a classification society enables the ship owner to obtain hull insurance and in today's environment assures the stakeholders (producers, consumers, and governments) of an acceptable level of safety in engineering, design and fabrication.

The IGC Code was written for liquefied gas (LNG) carriers and not gaseous gas carriers. The time frame for economical development of a CNG carrier does not allow for wholesale reinvention of the IGC Code. The CNG ship design must then be developed within an equivalent level of safety as defined by the IGC Code. In 2002, the IMO formalized the process for introduction of new technology through publication of its Guidelines for Formal Safety Assessment. The procedures allow proponents and certification agencies (such as class societies) to generate a body of evidence such that regulatory bodies will have a basis for allowing the ship to operate in their respective waters.

EnerSea's Maritime Work Program has included a wide range of safety studies to assess the safety of its VOTRANS™ concept, as well as the specific new CNG ship design and operating plans. Studies and workshops have specifically considered containment system integrity issues and hazard identification/management. One study, including an arduous 3-day workshop, has completed a clearly positive Comparative Risk Assessment between complete gas production/delivery systems for CNG and LNG options.

Regulatory compliance matters have been discussed with U.S. and Canadian authorities regarding application of the existing IGC Code and class rules and the means to define the required equivalent level of safety, particularly within the existing framework of the IGC Code. The existing Code requirements are being adopted to the greatest extent possible. For aspects where the CNG carrier is clearly different, other codes and practices such as API are referenced. With the recent updating of the Deepwater Ports Act to allow for the importation of CNG, the U. S. Coast Guard is now committed to clarifying the pathways for acceptance of the new CNG ships into U. S. waters.

Through this effort, guidelines have been developed for CNG gas carriers which begin to define the path required for successful development of a gas carrier which can be approved and accepted by class and regulatory bodies alike. International ship classification societies are developing guidelines to assist the CNG ship designer. In January 2003, DNV published Part 5 Chapter 15 of their Special Service Rules providing guidance for "Compressed Natural Gas Carriers".

Having completed the initial complement of hazard identification and operability studies, the overarching consensus of the reviewers is that an equivalent level of safety is not only achievable but has in fact been accomplished by EnerSea in their 75,000 m^3 VOTRANS™ systems design.

Fabrication (Ship Production Considerations).

The successful design of a ship must take into consideration fabrication constraints such as lightship draft, length, beam, internal access, lifting of components for installation, and assembly time in the building facility among others.

Today's ships are built in modules so that multiple modules may be fabricated simultaneously. These modules are then assembled in a graving dock or other facility to complete the ship. This reduces the overall fabrication time as well as the length of time the ship production facility is tied up with one project.

The weight and physical dimensions of the modules are limited in most cases by the shipyard's facilities. In some cases, special fabrication facilities may be developed however this requires a long term investment and usually entails construction of multiple ships.

In the case of the cargo tank modules, the maximum weight and height were constrained. The length of the individual tanks was set partially due to fabrication of the tanks in accordance with existing pipe manufacturing techniques as well as lifting clearance at selected shipyards around the world. The tanks were then bundled into modules within the weight limits of these same facilities. The collection of these modules into the ship design then drove the ship bulkhead spacing as well as structural arrangements.

The modules will be transported by an oceangoing barge from a manufacturer to a shipyard to avoid the restraints by ground transportation such as overpasses, load limit on roads, other traffic, etc. At the shipyard, the modules can be transported by heavy lift transporter from the barge to the pre-erection area alongside the dry dock, and stored until installation onboard. All 100 modules will be installed onboard in the dry dock with a heavy lift gantry crane which has a maximum capacity of 900 m tons (see Figure 5).

Operability Requirements

The overall ship dimensions were driven by a need to not only build the ship but to maintain and repair it over its entire service life. Maximum available draft at repair facilities around the world constrained the draft in the repair condition (basically lightship). The maximum lightship draft was set at 7.5m based on a worldwide survey of all major shipyards. The effect of this was to drive the overall length and beam with an associated reasonable block coefficient to arrive at the required repair displacement within the allowable draft at multiple repair facilities worldwide.

Ship speed and hence installed power were driven by many factors including gas production rate, distance to market, economical ship's speed and ship fleet size.

The power required for propulsion set the minimum size of the power plant. However, after the initial cargo system design efforts, it became apparent that a large quantity of power would be required for cargo handling. This set the stage for an all electric ship rather than a low speed diesel with a separate electric power generation system.

The choice of prime mover and type of fuel was set after discussions with "K"-Line and other ship operators regarding availability of ship's engineers trained in the operation of gas turbines versus heavy fuel oil diesels. Dual fuel diesels (gas and heavy fuel oil) were considered but due to the CNG cargo system's inherent capabilities, gas boil-off will not occur. Thus, to maximize delivery of the gas, only heavy fuel oil prime movers were considered.

A high degree of cargo system automation has been incorporated into the design to minimize the size of the crew. Limited additional crew training will be required to ensure safe operation of the cargo loading and offloading systems. Most of these systems are extensions of existing marine systems though maybe somewhat larger, such as the cargo cooling system.

DESIGN OF THE VOTRANS™ CNG SHIP

EnerSea Transport's VOTRANS™ ship design team has designed a 75,000 m^3 compressed natural gas (CNG) carrier. The gas cargo capacity of this ship design varies between 19-23x10^6scm (680-800mmscf), depending on the gas composition. The General Arrangements are depicted in Figure 6.

The design utilizes vertically oriented tanks with all manifold connections at the top of the tanks. No gas piping connections are located below the main deck, consistent with guidelines in IGC code. The cargo containment consists of 100 tank modules approximately 40m tall, each comprised of twenty-four 42 inch diameter pipe tanks.

The cargo section is subdivided into twelve compartments providing two-compartment damage stability in accordance with applicable rules. Wing tanks are located along the side of the ship, over the full length of the cargo block, in accordance with the IGC Code (but relatively wider as compared to traditional LNG ship design practice).

The vessel is powered by four electric main generators burning heavy fuel oil, driving twin electric propulsion motors and propellers providing the vessel with a minimum average transit speed of 18 knots. Excellent maneuvering capability with high propulsion redundancy is anticipated due to the twin rudder and propellers augmented by the twin bow thrusters. This configuration enables efficient power sharing with the cargo loading and unloading requirements while at zero speed.

The vessel has been designed to ABS Class Rules for the ships structure and marine systems while the cargo containment system has been designed using API, ABS, and IGC rules where applicable. The cargo loading and unloading systems have been designed using API and ABS rules as applicable.

The cargo piping systems will require a large number of valves such that a high degree of automation has been included in the design. HAZID studies provided guidance on managing gas pressures throughout the systems. For example the piping system has been designed for the maximum working pressure throughout rather than segregating by high and low pressures as the intended service might otherwise dictate.

EnerSea Transport in conjunction with its development operating partner "K"-Line, elected to place the accommodations and bridge aft. This was due in large part by the location of the power generation and propulsion machinery aft and the cargo handling machinery forward. The design achieves the maximum separation of the accommodations and the cargo handling machinery. Due to this aft location, the height of the bridge was set high to comply with the forward line of sight requirement in the IMO Rules. The actual bridge deck height is comparable with today's large container ships and the large MOSS-type LNG tankers.

The cargo handling system is located forward of the cargo block. Internal submerged turret loading/unloading has been incorporated into the design and hence this location keeps all cargo handling well away from the accommodations block.

Longitudinal strength was driven by the necessity to comply with the ABS rules for ocean going vessels as well as the cargo loading and unloading requirements. Minimal deflection of the cargo tank tops was desired to reduce the impact on the cargo piping connections especially at the top of the cargo tanks. The main deck is very open, similar in concept to today's large hatchless container vessels. However, the holds are enclosed by large, aluminum boxes that are self-supporting structures, designed to appropriate wind and greenwater criteria when secured to the hatch coamings.

A transverse framing system on 3 meters spacing was adopted to reduce the participation of the cargo tank support structure in global bending and to minimize relative movement of the cargo tanks. The midship section resembles the container vessel except that in this case the CNG carrier has longitudinal bulkheads just off either side of centerline (see Figure 7). The design incorporates a double bottom height of 2.2 meters which exceeds the IGC requirements for separation of cargo tanks from the hull boundaries. The gas tank cylinders are supported on skirts well above the inner bottom.

The longitudinally stiffened shell plating and longitudinal bulkheads carry the global loads due to waves and stillwater bending while the transverse frames (in conjunction with the longitudinal bulkheads) provide support for the cargo tanks. Three transverse frames support a transverse row of cargo tank modules. These modules and their associated piping are essentially independent of the next row of tanks. In this way the ship's flexure and its impact on the cargo tank/piping is minimized. The transverse frames were sized to meet extreme acceleration and deflection requirements during loading and unloading as well as transit conditions.

The interior of the cargo spaces will be insulated to assist in maintaining a subzero cargo temperature. The desired insulating characteristics have been achieved through the placement of thin polyurethane foam (PUF) panels to cover all interior surfaces of the cargo holds, including the top of the inner bottom. The tank modules sit upon a denser layer of foam material that can support their weight. Sufficient space has been incorporated in the design to allow for inspection of all cargo tank modules and ship's structure after completion of the ship.

Torsional rigidity has been achieved through the adoption of the 4.25 meter wide wing tank spaces with a 7.5 meter wide main deck space along centerline. Transverse box type deck girders, approximately 1.9 meters wide, are incorporated with transverse bulkheads to complete the primary hull structure. This is similar to current practice in container ship design.

IMPACT OF THE NEW GAS SHIP TECHNOLOGY

In terms of offshore field development, CNG transport can be seen as an immediate and preferred alternative to gas re-injection unless re-injection into a producing reservoir is necessary for pressure maintenance. Generally, that is not the case and gas re-injection often imposes a burdensome cost that has appeared to be the only alternative to flaring when gas volumes can not justify or be tied into an LNG or GTL project.

Frequently, companies are being forced to re-inject into an available formation for "conservation" purposes and possible future recovery. Unfortunately, gas re-injection for "conservation" purposes tends to waste a substantial amount of the originally produced gas as it must be separated, cleaned, and re-compressed for injection – only to be re-produced, re-processed, and re-compressed again for export when a pipeline becomes available. Re-directing associated gas to CNG export can provide a means to begin to monetize reserves in a more timely, flexible way.

If a field cannot justify a project on its own, a "regional pipeline" solution likely depends upon establishing an economic case by aggregating a number of fields from a development area that is likely to involve a diverse array of negotiating partners. These constraints make it difficult to know when an individual field will ever be able to export its associated gas. Whereas CNG gas export can begin within 2-3 years after an operator commits to this export solution, especially when the basis for project sanction is a well-evolved ship design with a shipyard ready to build.

Establishing a "regional operation" of VOTRANS™ gas transportation service provides opportunities for the "economies of scale" that would be targeted in a "regional pipeline" project, but operators are much less geographically constrained. For example, a regional strategy in the Gulf of Mexico would allow a specific operator to rationalize fleet requirements over a number of properties spread out all along that ultra-deep water frontier without being dependent on a complex chain of multi-operator agreements.

Newfoundland's Jeanne d'Arc basin provides another specific region where CNG marine transport is already being recognized as the primary pathway to future development of what may be a considerable gas province. Currently, geographical and sub-arctic metocean conditions make it impractical to consider a pipeline export project based on the limited reserves base (<5tcf) currently identified. However, Premier Grimes publicly announced last year that the province now expects CNG marine transport to open the way for commercialization of their natural gas resources and announced an important initiative to create a world-wide Centre of Excellence for Marine CNG.

Based on the cost of its new ship design and simple offshore import/export terminals, EnerSea has been able to determine that its VOTRANS™ technology can provide the most commercial means for the gas stranded offshore Newfoundland to reach markets in the gas hungry northeastern US. Combining effective tariff charges that have been projected around expected potential production rates with reasonable value being granted to the gas producers, it is possible to demonstrate that Newfoundland's gas can be transported directly to northeastern or mid-Atlantic markets at prices competitive with any source currently targeting the region.

Another way that VOTRANS™ opens up new opportunity for offshore gas development involves the production of what are considered dry, biogenic gas reserves offshore. The deepwater turbiditic Mensa field in the ultra-deep Gulf of Mexico is an example of just such an attractive resource. It has now been proven that lean, dry biogenic gas from an ultra-deepwater reservoir can be produced from a limited number of highly productive wells, through a manifolding system and 100km of dedicated flowlines back up to infrastructure on the slope under motive power provided solely by reservoir pressure. Highly pressured gas in similar remote reservoirs can be produced directly into a VOTRANS™ ship that can connect to and operate a subsea manifold through a specially designed flow/control riser (see Figure 8). The dry gas being produced from the biogenic reservoir will have enough pressure to flow directly into the ship's storage tanks at a desirably targeted temperature without external refrigeration being applied.

A fleet of such Gas Production/Storage/Export (GPSO) shuttles can readily be built upon EnerSea's current ship design to provide an extremely low cost solution for remote gas reservoir development. The GPSO shuttle concept is similar to the single well oil production ship (SWOPS) concept developed and applied by BP in the North Sea over a decade ago. However, due to the ability to target a very specific class of clean gas reservoirs, EnerSea Transport's GPSO concept is much simpler and more robust. Even though it may be desirable to provide a fleet to maintain continuous production, such gas reservoirs are much more compatible with an interruptible production scenario than the oil reservoirs that would have been targeted by a SWOPS development scheme. The world is projected to contain a great number of gas reservoirs with characteristics suitable for this attractive development solution.

CONCLUSIONS

It is obvious that the world is looking for economical and energy-efficient means for moving the vast amounts of "stranded" natural gas resources to markets seeking clean, new energy supplies. The world is beginning to recognize that marine transport of CNG will be one of the important solutions, especially because of its ability to conserve so much of the valuable natural gas resource. EnerSea Transport is extremely pleased to see that so many of the leading energy players are acknowledging the value of a specific innovative technology that is capable of realizing the breakthrough.

EnerSea Transport's Maritime Work Program has generated an immediately applicable ship design that will meet the evolving standards and scrutiny of maritime organizations and governments the world over. A wide range of studies have determined that there are an encouraging number of robustly economic opportunities for utilization of this design to serve many markets. Specific projects are now under serious engineering and commercial assessment based on the results of this cornerstone design that will demonstrate how VOTRANS™ is the key to "de-stranding" reserves that might otherwise have been left behind.

Since the completion of the baseline design (with 75,000m3 internal tank volume), HHI has generated ship designs for both smaller and larger cargo capacities, capable of carrying as little as 15×10^6scm (525mmscf) or up to approximately 28×10^6scm (1bcf). These new designs greatly expand the range of market conditions that can now be served by EnerSea's VOTRANS™ technology.

ACKNOWLEDGEMENTS

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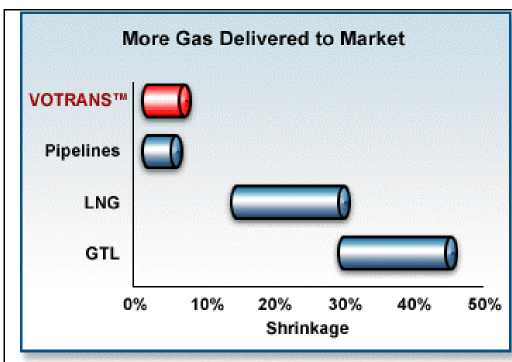


Figure 1. "Shrinkage" indicates % gas lost in processing, transport & storage

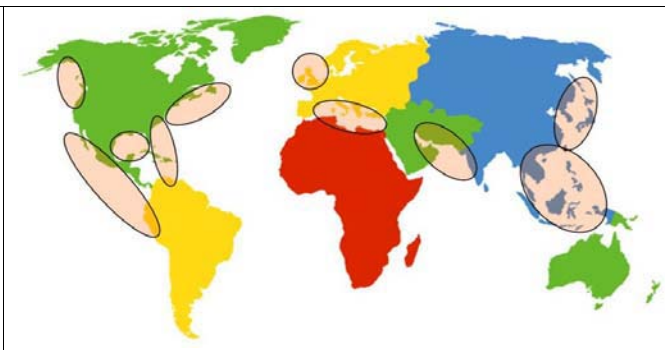
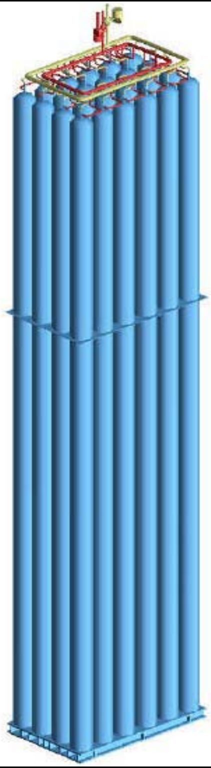
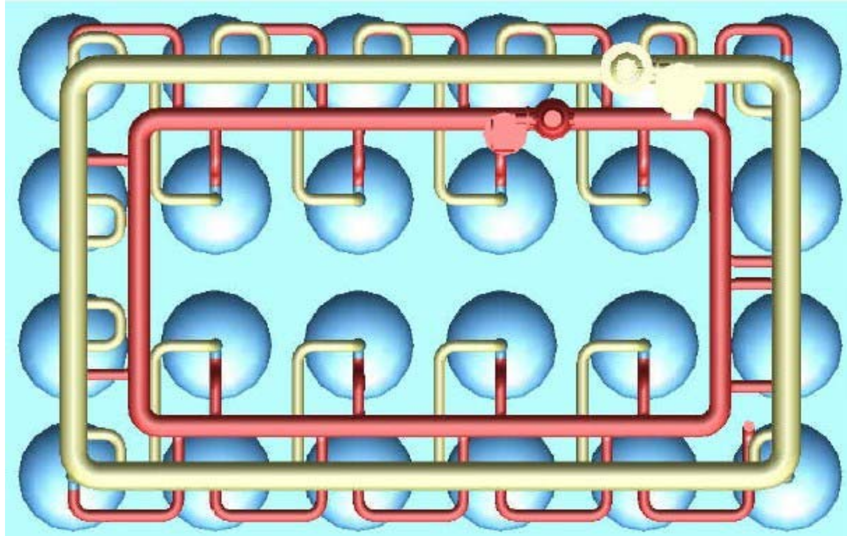


Figure 2. A World of Opportunities for CNG Marine Transport





Views on a CNG tank module
for the
VOTRANS™ CNG Carrier Ship

Figure 3.

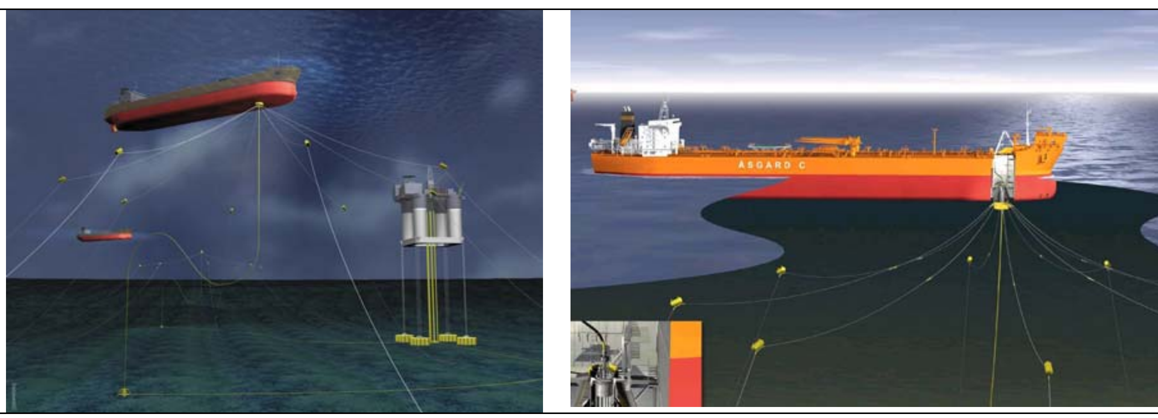
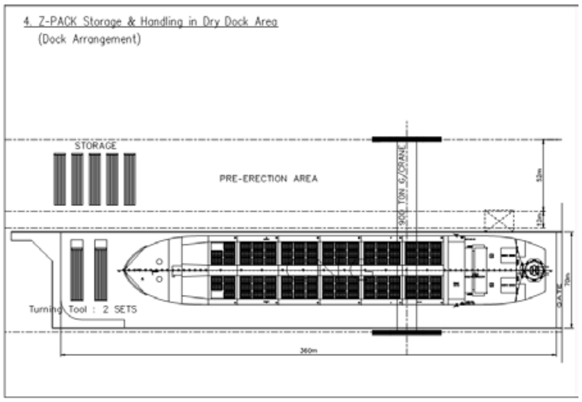


Figure 4. Heidrun shuttling & APL buoy



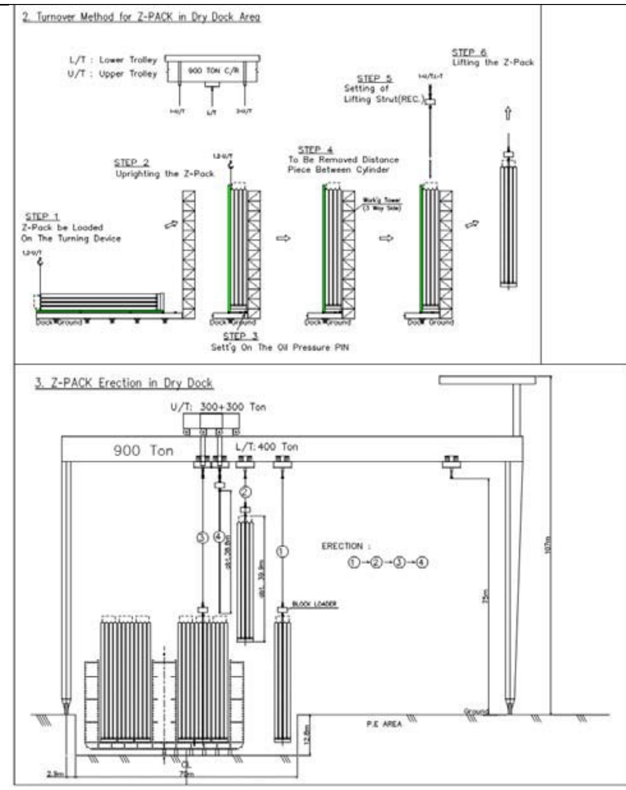


Figure 5.
CNG Tank Module Layout and Installation Operations
at HHI

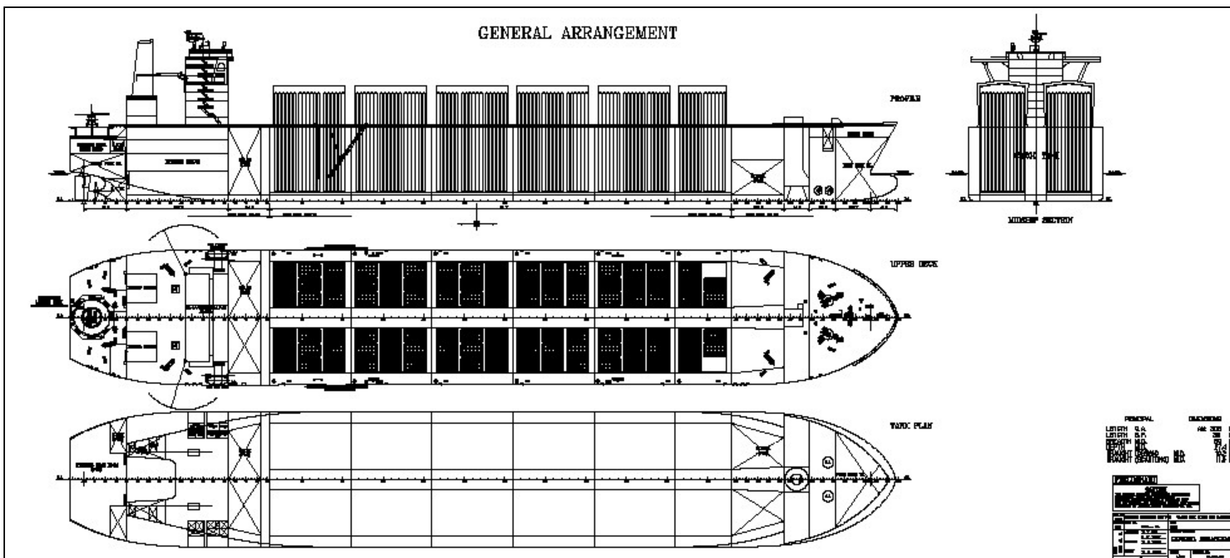


Figure 6. VOTRANS™ Ship General Arrangement

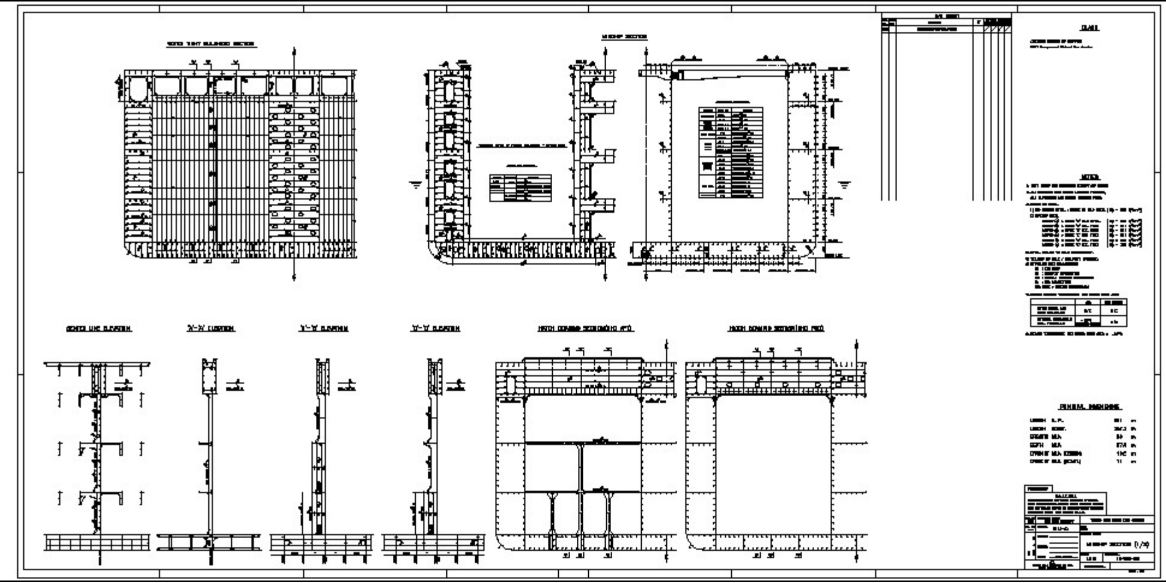


Figure 7. VOTRANS™ Ship Structural Midship Section

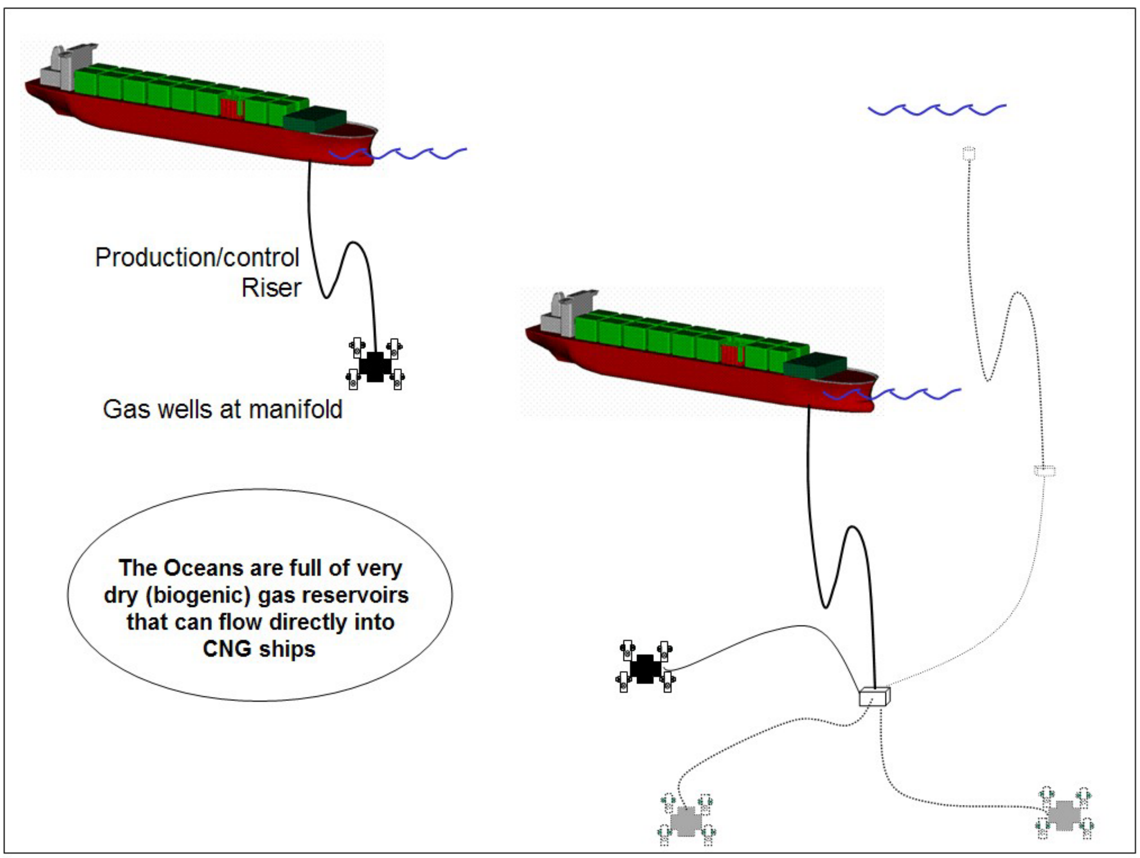


Figure 8. Gas Reservoir Energy can be used to directly charge storage containers on GPSO shuttles