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LNG Fueled Offshore Support Vessels in the Americas

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Abstract

This paper details the strong incentives to use gas as a marine propulsion fuel. The gas fuel ship is a very attractive option considering the environmental and economic drivers even though the gas fuel support systems initially cost more and are a challenge to arrange within the ship. The scope of the paper covers the pros and cons of the use of:

- LNG fuel for marine applications,
- Diesel scrubber technology versus utilising natural gas
- Classification and regulatory hurdles
- Some offshore support vessel arrangement considerations.

There has been a significant amount of interest and discussion in recent months in the US regarding the application and benefits of using natural gas as a source of fuel for marine vessels. There are many examples of vessels (LNG carriers, passenger, patrol, ferries, etc.) currently in operation using natural gas in Europe; however, it has been slow to progress in North America as a fuel for operating vessels.

International class societies have been overseeing the design and operation of natural gas fuelled vessels for over a decade now; however, most class societies have only recently created or put into force gas propulsion guidelines and rules. Luckily, most of the guidelines and rules are similar in nature because they have been developed from roadmap International Maritime Organization guidelines. Although the American Bureau of Shipping has draft rules that follow the intent of the international rules, the US Coast Guard has additional domestic interpretations of the international rules that are considered more stringent. In order to suit the particular regulations in the US, the configuration of the vessel plays a large part in the ability to fit an LNG propulsion system without sacrificing cargo capacity, especially for offshore supply vessels.

The capital investment for gas fuelled propulsion and the associated gas distribution equipment is large but the return on investment is achieved in a relatively short amount of time if the costs of the gas fuel are compared with ultra-low sulphur diesel and the cost of urea for the selective catalytic reactor (SCR), and the SCR itself. A conservative annual estimate for the savings in fuel costs are 2 to 2.5 million USD when compared to conventional diesel fuel. Long term maintenance costs for the gas engines is also purported to be less and still more cost effective to maintain compared to an SCR system.

Introduction

In April 2011, Harvey Gulf Marine (vessel operator) and STX Marine (vessel designer) formed the idea of a gas fuelled vessel as the solution for developing an offshore supply vessel with the best possible emission profile to meet EPA and IMO regulations in the Gulf of Mexico and Alaska. Even with the consideration of standard diesel engines with SCRs, it was determined that the most effective technological solution, that met all requirements, was the use of natural gas as a fuel. When the idea for the gas powered OSV was being discussed, the number of classification societies with gas fuel rules were limited. The American Bureau of Shipping (ABS) and the United States Coast Guard (USCG) stepped in and conducted numerous meetings with the vessel operator and ship designer to apply recently published rules and resolve technical issues for the first US flagged offshore support vessel to be powered by gas fuel. Due to the novel nature of having gas fuel onboard commercial vessels in the US, the USCG differed in some aspects from international codes and conventions. The USCG’s most significant concern was the location of the LNG storage tank. Currently, the USCG does not permit the LNG tank to be located in or below accommodations. Another concern was the protection of the LNG tank from mechanical damage. These concerns were mitigated by the IMO tank location requirements discussed later in this paper. The last hurdle was the USCG interpretation of the International Electrotechnical Commission (IEC) 60092-502 hazardous zone requirements. The USCG interpreted the vessel as carrying flammable liquefied gas as cargo and required a higher standard for the LNG storage system. The USCG initially determined that a compartment containing a Type-“C” LNG tank would also be classified as a hazardous space. The hazardous space designation requires high volume forced air ventilation and explosion proof equipment. The additional hazardous zone around the tank was eventually relaxed due to the double walled tank and distribution system design, and the inability to access the cold box from the tank space.

Vessel Description

The latest LNG powered platform supply vessel (PSV) is based on the successful SV310 design by STX Marine Inc. The 302 foot long SV310 is a modern design with the diesel electric power plant located on the main deck level rather than in the hull. The initial impetus to move the power plant above the main deck was to meet the voluntary IMO MARPOL Clean Design class notation, which gives additional protection to the environment. The Clean Design notation covers measures for accident prevention and for consequence limitation, such as a fuel tank arrangement with a double hull. The double hull provides additional protection of liquid cargo and fuel oil tanks in case of collision or grounding. The addition of the double hull necessitates an increase in the volumetric efficiency to carry an equivalent cargo capacity without increasing the length of the hull. By moving the propulsion equipment from the hull and placing it above the main deck, freeing up valuable cargo space, while maintaining a shorter length an increase in the volumetric efficiency from 11 to 17% was achieved.. Although platform supply vessels have traditionally been powered with diesel engines connected to gear boxes and auxiliary generators powering the house and auxiliary loads, the industry is gradually moving towards diesel electric power plants which allow greater flexibility in locating the generator sets. As supply vessels add additional capabilities to meet broader charter requirements (such as external firefighting systems, specialized cargo systems, dynamic positioning, towing winches, etc.), the need to match the intermittent loads efficiently is best met with integrated diesel electric power plants. Around 40% of the world’s PSVs are currently being delivered with diesel electric propulsion plants, with future trends increasing to 60%. A further advantage realized by the above deck propulsion engine location is the enhanced accessibility of the power plant for maintenance or replacement. Other benefits of the additional below-deck volume are the provision of sufficient dedicated ballast capacity to ensure the propellers are immersed at the light service condition following cargo offloading. This provides an increased allowable weather and safety window for dynamic positioning (DP), station keeping and stability.

The STX SV310 design features main electrical and engine rooms that are segregated port and starboard. This segregation makes the allocation of power supply between two redundant propulsion DP systems very straightforward, naturally achieving DP-2 class notation and also making the step to DP-3 easy if it is required. The principle additional requirement over DP-2 is further protection against fire and flooding by complete physical segregation of all propulsion systems and controls onboard.

The main propulsion is electric motor driven z-drives or electric L-drives to minimize space requirements. Transverse thrusters for the DP station keeping are fixed pitch variable speed electrically driven to provide low fuel consumption and lower noise in the accommodations compared to fixed speed variable pitch designs. Because of the proximity of the engine room to the accommodations, noise treatments are critical. Resilient elastomeric mounts are provided for the generator sets and the engine room deckhead and bulkheads are insulated with 4 inch acoustic insulation. Accommodations above the engine room have distributed floating floors to further mitigate noise transmission, damping ceiling tiles, and acoustically effective joiner panels. Because the bow thrusters are a source of pure structure borne noise below the accommodations, the potable water tanks are arranged above and beside the thruster compartment to provide additional vibration dampening.

Total installed power on the STX SV310 is approximately 7,500 kW for the integrated propulsion plant to achieve a transit speed of 12 to 13 knots. Conventionally, this is either achieved with four high or medium speed diesel engines distributed into the two segregated machinery spaces. The SV310 gas fuelled version for Harvey Gulf is powered by three Wartsila 6-cylinder 34DF dual fuel engines with a diesel powered harbour generator. The reason for the larger 34DF engines is explained later in the market drivers section of this paper.

LNG Propulsion Equipment Arrangement

The LNG storage, distribution, and gas fuel engines add complexity to the vessel design and the peculiarities must be fully understood during the design process to prevent any unanticipated issues.

The classification societies (such as ABS, DNV, Lloyds Register, and others) have created rules to guide the design of gas fuel ships. The classification rules are similar because they have been developed from applicable MARPOL regulations: SOLAS, IMO Interim Guidelines on Safety for Natural Gas-Fueled Engine Installations in Ships (IMO Res. MSC.285(86)), IMO International Code for Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code) (draft), and the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). Additional requirements by the flag administration, the US Coast Guard (USCG), also exist. The primary requirements for any gas fuelled ship are the following:

- fuel containment systems (tank types),
- fuel storage location,
- safety zone concept,
- hazardous zone definitions,
- fuel gas supply and distribution,
- bunker station, and
- gas fuelled engines.

Although the USCG presently has no published gas fuelled ship requirements, they accept the use of IMO guidelines with additional requirements. The vessel may enter the Coast Guard’s Alternative Compliance Program (ACP), however, gas fuelled ships are treated as special and are closely monitored by USCG.

The key safety objectives of the regulations relate to gas containment and the mitigation of risks from fire, explosion, and leaked cryogenic fluid resulting in a loss of structural integrity. For ease of installation and risk control, the STX SV310 will have a type-C LNG storage tank. The type-C tank is a cylindrical pressurized tank and is constructed with primary and secondary containment. The cryogenic liquid fuel is contained within an inner tank and a secondary barrier surrounds the inner containment with insulation in between. The secondary barrier is integral to a cold box or tank room. The cold box contains the master shut off valve, LNG to gas fuel supply evaporator, and tank pressure evaporator that controls the pressure within the tank. Should there be a failure of the inner tank, the leaks will be contained within the secondary barrier and leaked to the cold box which is then vented to the atmosphere. If access is restricted to the cold box, then the area surrounding the type-C double walled LNG tank can be treated as non-hazardous.

In order to minimize risks to the tank in a vessel collision, regulations require the tank to be located within the lesser of ship’s breadth divided by 15 (B/15) and 2m from the bottom plating and the lesser of breadth divided by 5 (B/5) and 11.5m from the ship’s side. The STX SV310 vessel design functions well with these requirements when arranging the LNG tank. Because the machinery space is not located in the hull, the cargo tanks can be rearranged to minimize the loss of cargo and utilities space due to the LNG tank. The LNG tank capacity was based on the requirement of full engine MCR endurance for 24 hours a day for seven days. Total LNG geometric volume is 290m^3 with a maximum carrying capacity of 130 tonnes of LNG.

, The vaporised and heated gas is distributed to the engines from the cold box through a double walled piping system; see Figure 1 below. The double walled pipe has an annular space pressurized with ventilated air with the inner pipe containing the fuel gas supply. Instrumentation is installed in the annular space ventilation that will cause an immediate emergency shut down if gas or loss of ventilation is detected. Between the cold box and engines are a set of double block-and-bleed gas shut off valves that include manual/automatic shut-off valves, inerting connections, filters, pressure control valves, and pressure/temperature gauges with transmitters. Depending on the supply, these valves are referred to as gas valve units (GVU) or safety shut off valves. The gas valve units are contained within an enclosure as well, allowing continuous double walled containment up to the engine cylinders. Because of the gas and ventilation monitoring and the extra degree of separation of the gas distribution system, the spaces outside of the double walled system are treated as non-hazardous and can be conventionally arranged with common marine equipment. The ventilation and venting from the gas system and ventilated annular space are exhausted in locations with special hazardous zone designations on the open deck of the vessel. One of the biggest challenges is the location of the gas vent outlet on the vessel. PSVs with active working decks aft for cargo pose a particular risk to mechanical damage to the vent mast and must be thoughtfully located on the vessel to minimize the risk.

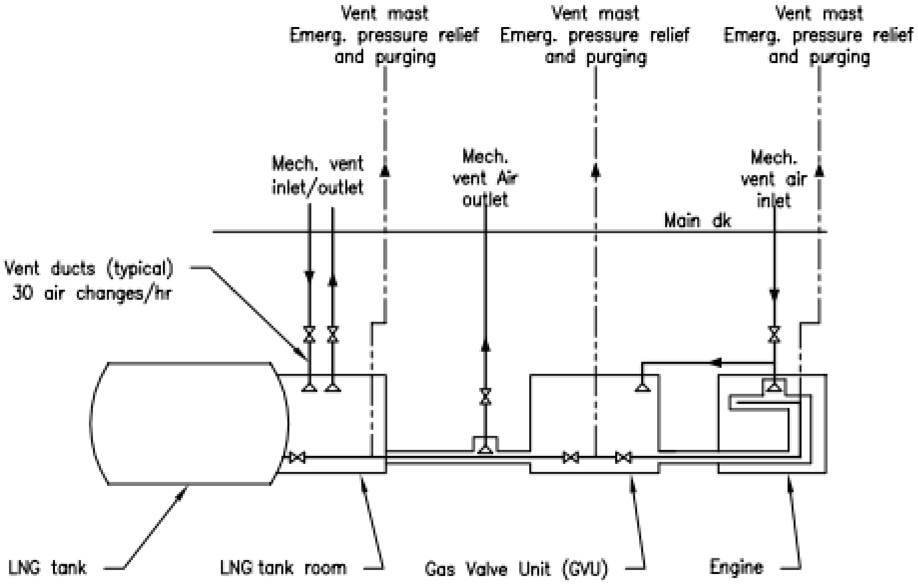

Figure 1: Schematic of LNG Double Walled Piping Concept

Another challenge in the arrangement of the LNG system onboard a vessel is the bunkering system. . The bunkering piping and valves are complex and take up a large area, however, the system must be arranged close to the shell but not be within 800mm. The bunkering station itself has additional requirements that include:

- structural and fire protection,
- sufficient ventilation,
- remote and local emergency shut down valve,
- draining, purging, and inerting provisions, and
- stainless steel drip tray led overboard.

Even with the double walled piping, the machinery spaces with the gas fuelled engines will need to prevent the accumulation of gas in the space. The engine room ventilation must be fed with 100% redundant fans and damper isolated each other in the system. The space may need to be fitted with circulations fans above and below the floor plates to ensure no pockets or dead spaces are created where gas can accumulate. The exhaust system from the gas engines must also be fitted with explosion protection routed to safe locations on the vessel’s exterior.

Available Technology

The marine gas engine market is currently only a fraction of the size of the diesel engine market due to barriers that are specific to vessels using LNG/CNG as a primary source of fuel. As the market drivers become stronger in favour of LNG/CNG, specifically with the introduction of the North American Emission Control Areas (ECAs), it is expected that a significant portion of the market will shift from diesel to gas. There are two main categories of gas engines available on the market today: the dual fuel engines manufactured by Wartsila and MAN; and the lean-burn gas engines manufactured by Rolls-Royce and Mitsubishi.

The dual fuel engines, when compared to pure gas engines, provide more redundancy but at the cost of lower efficiency. However, the ability to switch from gas to diesel seamlessly offers many advantages. If a fault is detected in the gas system and forces the gas supplies to be shut off then the dual fuel engines are able to continue normal operation without any loss in power. The pure gas engines get around this problem by installing multiple tanks, redundant fuel supplies, and segregated engine rooms or with standby diesel engines in separate spaces – at the cost of greater complexity and volume absorption for the propulsion system.

Pure gas engines are purported to have a quicker response to changes in power demands and are able to accelerate and shed load faster than comparable dual fuel engines. This is especially important when matching direct coupled fixed pitch propeller systems through a gearbox to the engine. Fixed pitch propellers require variable input speed to vary thrust. The higher load responsiveness becomes less significant on diesel electric ships with modern power management systems. The power management system is capable of bringing generator engines online to feed the power grid automatically and will limit how fast the generators are connected for overload protection. Furthermore, the dual fuel engines are also capable of large load changes by switching to diesel; however, the transition back to gas fuel will take approximately 2 minutes.

For a dynamically positioned vessel, such as the STX SV310, dual fuel engines offer an extra level of fuel redundancy because of the seamless and automatic transfer to diesel fuel if a fault or failure is detected in the gas supply system. Class will still require multiple day/service tank diesel fuel supplies for a DP ship which means that the engines will transfer to diesel and will continue to operate with a redundant fuel supply if the gas supply fails for any means.

Market Drivers for Natural Gas

There are a number of market drivers in the development of marine propulsion but the primary drivers are regulatory and economics. Further benefits include: purported lower maintenance, charterers preference, green image brand profiling, and others.

Regulatory Drivers

Since the 1990s, there has been particular focus on limiting sulphur oxide (SOx) emissions from ships. This can be achieved three ways: using LNG as a fuel, limiting the sulphur content of the fuel or by secondary means in which the exhaust gas generated is scrubbed or washed to reduce the SOx emitted to the atmosphere. Additionally, particulate matter emissions from combustion are related to the sulphur content of the fuel used and are equally reduced where primary or secondary SOx controls are applied. The principal SOx control regime is MARPOL Annex VI which requires fuel oil maximum sulphur content to be reduced incrementally from up to 4.5% currently to 0.1% inside an ECA in 2015 and 0.5% outside the ECA (pending fuel availability) in 2020[1].

An alternative to bunkering expensive low sulfur fuel oils is to use exhaust scrubbers to achieve equivalent emission performance. Typically these will be exhaust gas cleaning systems which use sea water or dosed fresh water to scrub SOx emissions from the exhaust gas stream. However, a concern with such arrangements is the quality of the wash water discharged – particularly with regard to hydrocarbon material. These systems are not yet in widespread use as they can be very large and heavy, and are generally considered still to be at the development stage.

MARPOL Annex VI has also introduced controls on nitrogen oxide (NOx) emissions from marine diesel engines over 130kW, principally those installed on ships built on or after January 1st, 2000. Tier I and Tier II control levels are achieved by means of in-engine controls. However, ships built on or after Jan.1st, 2016, operating within Emission Control Areas established to limit NOx emissions (ECA-NOx) will be required to operate at Tier III levels. To achieve Tier III levels ships will generally require the adoption of either selective catalytic reduction (SCR) treatment units or exhaust gas recirculation arrangements. Part of the chemical process to reduce NOx in the SCR is to mist urea into the exhaust to convert the NOx to nitrogen and water vapor. To ensure that the NOx requirement is met while transiting an ECA, urea must be expended onboard for the complete duration. The approximate amount of 40% concentrate urea is 7% the total fuel amount consumed.

The Tier III controls could be a further drive to using natural gas as there are challenges operating SCR and scrubbing system even with sulphur controlled fuels. Natural gas, with negligible sulphur content and considerably lower NOx emissions, will readily meet the emission limits that exist today and the higher standards in the future. Therefore, the use of natural gas as a fuel has the attraction that the shipowner/operator can be assured of complete compliance with any foreseeable SOx emission limits over the life of the ship.

An added benefit of using gas as a fuel is the reduction of CO_2 emissions - which is considered a greenhouse gas. Pure gas engines are capable of up to 35% reduction while dual fuel engines reduce CO_2 emissions up to 25%. It should be noted that methane slip (the incomplete combustion of natural gas releasing methane through the exhaust) will reduce greenhouse gases or negate them completely. Methane released in the atmosphere is 20 times more powerful than CO_2 as a greenhouse gas. Engine manufacturers are aware of these challenges and development is taking place to minimize methane slip sources.[2]

American Regulatory Drivers

Air pollution control requirements for the outer continental shelf (OCS) and pollution sources (such as oil and gas exploration, production, and support vessels) were established in the EPA Clean Air Act Amendment of 1990. As of January 10, 2011, the EPA has finalized the update of the OCS air regulations. Section 328(a) of the Act requires that EPA establish requirements, the same as onshore requirements, to control air pollution from OCS sources located within 25 miles of states' seaward boundaries. If the major air pollutants are over 250 tonnes per year, ships/rigs must apply for an EPA Air Quality Permit in order to prove that the ships/rigs are using the best available control technology (BACT) to control pollution emissions in OCS zones. These regulations apply to all OCS sources except those located west of 87.5 degrees longitude in the Gulf of Mexico. Anything east falls under the jurisdiction of the US Department of the Interior. Most importantly, this may include support vessels within 25 miles of the rigs. The BACT requirement stipulates that the rigs do everything technologically possible to meet current and upcoming EPA emission restrictions.

The BACT is an emissions limitation which is based on the maximum degree of control that can be achieved. It is a case-by-case decision that considers energy, environmental, and economic impacts. BACT can be add-on control equipment or modification of the production processes or methods. This includes fuel cleaning or treatment and innovative fuel combustion techniques. BACT may be a design, equipment, work practice, or operational standard if imposition of an emissions standard is infeasible. BACT applies only to the rig but may be applied to the support vessel if the vessel is considered attached via mooring or hoses during on/off loading operations.

Air pollutants that most rigs generate include NO_x, CO, particulate matter, $SO_{x,}$ VOCs and other greenhouse gasses (GHGs). The majority of the pollution is considered emanating from the diesel engines on the rig and the support fleet; although, some of the emissions will also be released from cementing and pumping of heavy muds into the wells. Once the major sources are identified, such as NO_x, the permit seeker will conduct the BACT analysis in order to seek technologies to reduce the major source. In current cases, the rig operators will ensure that the drill ships are equipped with low NO_x diesel engines meeting EPA Tier II requirements. In the future, the EPA will continue to restrict emissions limits as the higher tier emissions standards coming into effect.

Crew, supply, and support vessels need to estimate the emissions when within 25 miles from the OCS source for the purposes of air quality monitoring. If the source is exceeding or nearly exceeding National Ambient Air Quality Standards (NAAQS), the source will request lower emissions support vessels.

The US Environmental Protection Agency (EPA) also has its own stricter set of engine exhaust emission regulations. On January 1st, 2004 the EPA mandated a staged reduction in particulate matter and NOx which are more stringent than IMO requirements. These standards are applied to all marine engines in the US ranging from small category 1 and 2 engines, less than 30 litres cylinder displacement, and large, category 3, marine diesel engines with displacements greater than 30 litres. If an engine is a category 3 marine diesel, then the EPA limits are equivalent to respective IMO tier II – and III standards. This is important because if the engine is a dual fuel gas engine and less than 30 litres displacement then the engine will require an exhaust SCR with particulate filters to meet EPA tier limits when burning diesel. However, if the dual fuel engine is greater in displacement, it will only have to meet the IMO limits on NOx which are achieved with an SCR in diesel mode.

Economic Drivers

Although virtually all fuel oils bunkered by ships world-wide are either residual fuel oil or distillates, the shipping industry is not inherently tied to the use of these fuels. Any potential alternative fuel will need to be assessed on the basis of its availability, overall cost per unit of energy, and any other factors. In the case of natural gas, there is no doubt to its availability given world known reserves but rather its availability to shipping as a bunker fuel. It is anticipated that early projects will involve partnerships in which supplier and consumer commit to invest capital to have the fuel available where facilities may not exist. The first marine LNG propulsion projects are in areas where supply can be made from existing LNG facilities, especially in locations based on the wider use of the existing infrastructure (such as an existing LNG truck network supplying local commercial or industrial activities). In the case of the STX SV310 LNG powered PSVs for Harvey Gulf, they will use LNG trucked by Clean energy from Willis, Texas to Port Fourchon, Louisiana.

The cost of current marine fuels is in the range of 930 to 1,040 dollars per tonne for distillates (42 to 43 MJ/t) and 610 to 680 dollar per tonne for residual fuel oils (39.5 to 40.5 MJ/t). With the upcoming sulphur controls, the distillate costs are expected to rise considerably (residual fuels are not expected to meet future sulphur limits). Presently, the global marine demand is approximately 0.2 Mt/day for distillate fuel and 0.8Mt/day of residual fuel. However, if the need for residual fuel is replaced with distillate, there will be major world impacts to the degree that fuel may not be available to all areas and cause an upsurge in price. Transforming current residual fuels into distillates will depend on exhaust gas cleaning systems.

Compared to residual and distillates, the current cost for LNG is comparable or cheaper. In Europe the cost from the truck to the ship is approximately 450 dollars per tonne while in North America the current cost is much less (depending on transportation costs). The current average cost to ship, from two different suppliers[3], from Port Fourchon LA is Henry Hub price plus an additional $2 per million btu for liquification and another $7 per million btu for transportation. The Henry Hub price for natural gas is currently at record low which illustrates the favourable economic driver in using gas as a marine fuel. It is too early to tell what the trend will be for LNG cost as a marine fuel but, with the aforementioned extensive fuel reserves taken into account, the cost is expected to remain stable in the future and will remain well below the costs of diesel.

The use of residual and distillate fuel is so commonplace that the costs are unrecognisable as part of the new build cost of a ship. In the case of a natural gas fuelled ship, the cost for integration will be significantly higher. The capital cost difference is approximately 10 to 15% greater when considering the loss of cargo space as well as construction and equipment costs.[4] The equipment costs for the complete LNG propulsion system itself will normally be about 30 to 40% higher than diesel machinery. The current costs of some pure gas or dual fuel engines can be as much as 50% higher than comparable diesel engines (at least in the medium speed category). The costs included when comparing equipment capital costs were the LNG storage tank, the bunkering system, engines, and safety related components including the double walled piping and control system, as well as the associate risk analysis.

Economic Case Study

Two hypothetical vessels are compared with the same dimensions, propulsion type, and equipment in today's market. They differ by the propulsion engines and equipment to support either diesel fuel or natural gas/diesel dual fuel only. Both engine types meet EPA Tier 2 emissions requirements therefore they will not require any after treatment technology nor urea consumption. The diesel fuel ship has a deadweight capability of approximately 5,100 tonnes while the dual fuel vessel weighs less by approximately 12 to 17%. This is derived from a tank of approximately 300 tonnes displacing a volume of potential cargo fuel. The 300 tonnes is multiplied by 3 because of volumetric efficiency resulting in a loss of 900 tonnes of cargo fuel oil. However, some of this loss is recouped because the majority of the diesel oil used for fuel can now be used for cargo.

The operating profile is a typical Gulf of Mexico supply mission: one day for transit to the rig, a day and a half for loitering and offloading, and another day for return transit back to port. The vessels would be making 40 trips per year yielding a annual use of 3,360 hours. The transit to and from the rig is estimated to utilize 5,200kw and the loitering/offloading phase utilizing 3,800kW of integrated electrical power from the engine alternators. The diesel version of the vessel utilizes four high speed generator sets at 1,900 kW each; the duel fuel vessel utilizes 3 larger medium speed engines at 2,510 kW each. The difference in the engine selection from the high speed engines to the larger cylinder bore medium speed engines is due to the EPA category 3 distinction discussed earlier. Due to the integrated electrical power plant, all of the generators are considered loaded equally in each operating profile scenario. As Table 1 shows, due to the power difference, there are more high speed engines operating in the loitering mode.

Table 1: Integrated Electrical Power Plant Engine Loading

Operating Mode	Diesel vessel power loading	Number of diesel engines operating	Dual fuel vessel power loading	Number of duel fuel engines operating
Transit to rig	81%	4	82%	3
Loitering/offloading	79%	3	90%	2
Transit to port	81%	4	82%	3

The capital cost expenditure from the conventional diesel system to the dual fuel ship is double when the additional cost for the dual fuel engines, gas valve units, and LNG tank are factored in. See Table 2 below.

Table 2: Conventional diesel versus dual fuel capital cost comparison

	Diesel Vessel	Dual Fuel Vessel
Capital Cost	$1,920,000 USD	$5,585,000 USD

For each operating and power loading the specific fuel consumption was assessed or in the case of the duel fuel, the specific energy consumption. Utilizing a diesel fuel density of 870 kg/m³, an LNG energy content of 18,656 Btu/kg, and the LNG density of 460 kg/m³, the annual fuel consumption in tonnes and estimated costs was estimated and is shown in Table 3. The cost for diesel was estimated at US $1058.6/tonne while the LNG cost was US $231.9/tonne.

Table 3: Annual fuel consumption and costs

		Diesel vessel	Duel fuel vessel
Annual diesel fuel consumption (tonnes)	Transit to rig	1295	25
	Loitering/offloading	1420	20
	Transit to port	1295	25
Annual LNG fuel consumption (tonnes)	Transit to rig	-	985
	Loitering/offloading	-	1065
	Transit to port	-	985
	Fuel costs per year	$4,245,000 USD	$778,000 USD

The use of duel fuel in the vessel results in an annual cost savings 5.5 times better than the conventional diesel powered vessel.

Conclusions

Given the regulatory emission drivers and the economics, it is no surprise that commercial vessels are strongly considering gas as a fuel. When considering the relative nascent technology, regulations, and the difficulties of vessel design with natural gas as a propulsion fuel, the drivers are persuasive enough to overcome any additional challenges. Conventional diesel engine manufacturers will struggle to meet higher tier emissions restrictions, especially the EPA regulations, with scrubbers and SCR. They are feasible technologies but come at the cost of higher maintenance and consumables. Utilizing gas as a fuel ensures that emissions are met without any additional exhaust after treatment technology.

The decision to use gas or dual fuel engines as the propulsion plant options depends on many factors but is essentially based on the ability to accommodate the differences apparent in the two options. Redundant fuel sources for the pure gas engine are a necessity but better emissions and efficiency are the result. Dual fuel engines have compromises that must be recognised and accounted for in the design but are generally more conducive for inclusion into conventional vessels. Either the pure gas or dual fuel propulsion option will likely sacrifice cargo to arrange gas equipment. The STX SV310 design allows the installation of the gas power plant with relative ease and does not reduce the cargo carrying capability drastically. The arrangement of the gas propulsion system must be carefully considered with respect to the applicable rules and flag requirements. The gas distribution system, ventilation, and venting are obvious considerations but contain a myriad of subtleties.

Gas fuel ensures a means of energy stability due to adequate global reserves; however, the future trends for price and availability remains uncertain. Although IMO has set limits on sulphur in distillate, it is not clear whether there has been enough investment in refining to meet marine demand. Furthermore, even if marine demands are met, the additional cost of the greater refined fuel will continue to ensure that gas will continue as an attractive fuel option for many years.

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