

Concept Design of a Bulk Carrier Retrofit with LNG Fuel

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Synopsis

This report showed a case study of a mini-cape size bulk carrier of being retrofitted for Liquefied Natural Gas (LNG) fuel and the selection of its new fuel tanks to meet the stringent emissions requirement. The vessel was equipped with a dual fuel ready (DFR) engine before the retrofit. Engine manufacturer will supply and replace engine parts for LNG fueled operations with no significant modification of the engine structure required. The detailed engineering design considerations were studied with cost reduction and minimum downtime set as ultimate objectives. Top-down and bottom-up approaches for cost estimation are used in this analysis. The analysis was determined by life cycle cost and management costs. The cost analysis showed the payback period of an LNG fueled ship retrofit is 4.5 years against a 0.5% compliant fueled vessel. The payback period is considered reasonable and it shows retrofitting vessels for LNG fuel as an attractive option in meeting new regulation for ship-owners. If the shipyard standardizes the tank construction including outfitting, the specified cost may even go lower. A further reduction is also anticipated with repeating orders of similar vessels.

Keywords — LNG; Conversion; Engineering Design; Innovation; Dual Fuel;

1. Introduction

LNG is one of several options to meet more stringent environmental regulation in shipping. LNG fuelled engines will help protect shipping companies from demanding regulations, local emissions criteria, etc. LNG emits no sulphur oxides (SOx) and practically no particulate matters (PM). Compared to existing residual fuel oil (RFO), LNG also emits almost 90% less NOx. Similarly, LNG's greenhouse gas (GHG) emission is equally rewarding. Applying the best possible technologies to reduce methane leakage, a possible GHG reduction of 20-25% compared to conventional fuel oils is achievable. There are other alternatives such as low sulphur fuel oil or RFO with scrubbers. LNG fuelled vessel is a technically proven solution to exhaust emissions in shipping. As such, there is a commercial opportunity both for new buildings and retrofitting projects. One of the key challenges in adoption of LNG to retrofit the vessel for such purpose is the

high Capex. This report is a continuation of a project led by Tam et al which aims to address this problem and propose an engineering design for rapid retrofitting a typical bulk carrier. The concepts have to be innovative, yet, practical and easily implemented with the current facilities available in a typical production shipyard.

2. Design Considerations

2.1 Trade Route and Ship Type

Currently there is an apparent lack of LNG bunkering infrastructure, which yet has to be developed rapidly. As such, the planning of trade route is critical for a reliable and safe mission.

2.1.1 Trade Route

It is reported that significant volatility of the Baltic Dry Index in the recent months due to the ongoing trade tension and increasingly bearish demand in commodity, it may affect the growth of seaborne trade as provided by Hellenic Shipping News. However, the long term outlook of the global dry bulk market shows a steady trend of sea trades from Australia to China. There are some ports where the LNG fuelled bulk carriers can have bunkering. The main ports are four: Port Dampier in Western Australia (in operation), Singapore (in operation), Labuan in East Malaysia (planned and decided on this island), Hong Kong-Macau Special Administrative Region (in operation in Zhuhai Gaolan) and Zhoushan as planned and decided in this archipelago off the coasts of Ningbo and Shanghai in China as suggested by Sea LNG and Ports.com.

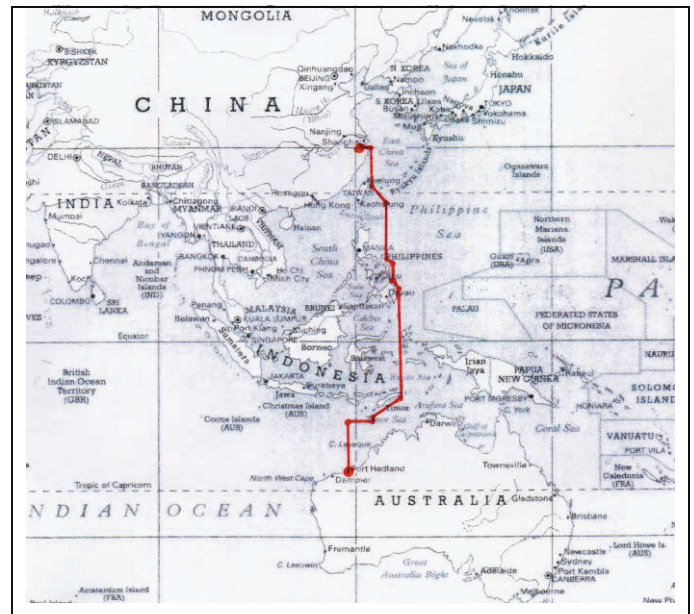


Figure 1: Trade route planned (Credit: Lloyd's Maritime Atlas)

2.1.2 Ship type

In the dry bulk cargo market, the critical aspect is the low-cost transport. The bulk carrier fleet has over 11,000 ships worldwide for combined cargo capacity of approximately 800 million DWT. A bulk carrier is being adopted in this feasibility study as it shows the least challenge for retrofit and it is the most scalable. Almost all bulk carriers are fitted with steel hatch covers opened by rolling to the end where they are tipped automatically into a vertical position without interfering cargo handling. This deck arrangement provides easy design options to retrofit new LNG fuel tank system. The system can be easily fitted out on board even if the bulk carrier is already designed, built and in operations.

A mini-cape bulk carrier is typically installed with a slow-speed two-stroke Diesel engine, two or three auxiliary AC generators driven by Diesel engines, a boiler and an emergency generator also driven by a Diesel engine. The vessel is commonly equipped with two ballast pumps and the ballast water is carried in topside tanks, double bottom, hopper side tanks and floodable hold for use in heavy weather. The principal particulars of a typical bulk carrier mini-cape were obtained from a shipyard report and shown in Table 1 suggested by China Shipping.

Length Over All	255.00 m
Length Between Perpendicular	250.00 m
Breath Moulded	43.00 m
Depth Moulded	20.20 m
Design Draft	13.00 m
Scantling Draft	14.60 m
Deadweight at scantling draft	120,000 tonnes
Service Speed	14.0 Kn
The range of navigation (15% S.M.)	22,000 nm
Cargo Holds (100%)	135,000 m ³
HFO tank	2,500 m ³
MGO tank	400 m ³

Table 1 Principal particular of a typical mini-cape

2.1.3 Engine type

The major machinery onboard the 120,000 DWT bulk carrier before retrofit is listed in Table 2. It is assumed that the vessel will use natural gas as a primary fuel for all engines and boiler onboard after the retrofit. The operations with a single fuel will simplify bunker operations. There is also huge cost saving from using more expensive compliant fuel oil. Liquid fuel will be only used during start up, low load and emergency conditions.

Major Machinery:	Tank Capacity:
Main Engine: 1 x 13,600 kW	LSDO: 190 m ³
Aux. Engine: 3 x 800 kW	DO: 240 m ³
Boiler: 1,800 kg/h @ 7bar	HFO: 4120m ³

Table 2 Existing Major Machinery and Tank Capacity before conversion

2.2. Engine and Ship Modification

2.2.1 Main engine selection

Based on the engine speed of 83rpm, main engine output of 13,600kW is needed to power the vessel. It is assumed that ship owner had taken the long-term view during the newbuilding stage and had ordered engines that are ready for dual fuel operations, i.e. the engine structure will be reused with only some parts replaced for dual fuel operations. All major engine manufacturers offer this dual fuel ready option as a retrofit package.

2.2.2 Auxiliary Engine and Boiler

Based on the power requirement, a 6-cylinder engine was chosen to provide 876kW as an auxiliary engine. The boiler will run on gas for a full load. Based on the steam production of 1800kg/h, a small steam boiler coupled with the dual fuel burners which will be retrofitted to run on gas as well.

2.2.3 Pilot fuel supply

Pilot fuel is injected into the cylinder to ignite the gas charge and is designed for operation on MGO. A pilot fuel pump supply fuel oil to the engine from the service tank via a fuel cooler and filter. A pilot fuel pump raises pressure to the required level and delivers it into a double-walled common rail pipe which is connected to fuel injection valves.

2.3 Tank Sizing

2.3.1 Sizing of a LNG fuel tank

In sizing LNG fuel tank size, the specific fuel consumption (SFC) of gas is required, and this is obtained from the engine guides obtained from Wartsila and WinGD. SFC will vary with engine load, SFC corresponding to continuous service rating (CSR) at which the main engine will be operating most of the time. The following formula is applied to obtain the LNG tank capacity base on main engine running at CSR and two of the three generators operating at 800kW, the fuel gas consumption for the endurance of 14 days:

$$C = (n_{ME} \cdot P_{ME} \cdot SFC \cdot 24 + n_{AE} \cdot P_{AE} \cdot SFC \cdot 24) / LHV$$

Where

C is the Daily Fuel Gas Consumption

n_{ME} is the number of the main engines

P_{ME} is the power of the main engine

n_{AE} is the number of auxiliary engines

P_{AE} is the power of auxiliary engines

LHV is the lower heating value of LNG at 50 MJ/kg

Assuming a design margin of 25%, hence, the total LNG tank capacity is estimated at 1500 m³.

2.3.2 Sizing of a fuel oil tank

Light diesel oil is required for the pilot fuel system for the LNG fueled engines. The consumption rate of pilot fuel oil can also be found from the engine guides. Assuming a bunker frequency of 3 months, the total pilot fuel consumption is about 42 m³ and the existing LSFO tank of 190m³ will be more than sufficient to cater for this.

2.4 Regulatory Compliance

The ship deck and the inner tank top side requires strengthening to accommodate new LNG fuel tank, vaporizer, reliquefaction unit and bunkering station. A preliminary structural assessment and a detailed structural engineering analysis has to be carried out by naval architects. Additional safety features for fire protection and explosion is required. New surface coating and corrosion protection extending the service life of vessel are incorporated.

The engineering design of this LNG fuel powered bulk carrier follows the rules and regulations in SOLAS 2014 and SOLAS 2015, the IMO IGF Code 2016, the classification rules as applicable and the guidelines based on best practice and experience on ships in service stated in IMO resolution 2009 and IMO circular 1455. The IACS Interpretations of the IGF Code 2018, the IACS LNG bunkering guidelines 2017, and the SGMF's Gas as a marine fuel safety guidelines 2017 shall be kept in reference. The ISO 20519:2017 International Standards sets requirements for LNG bunkering transfer systems and equipment used to bunker LNG fuelled vessels.

3. Location of New Fuel Tanks

Several locations were investigated for possible new fuel tanks installation for a total volume of 1,500m³ as indicated in Figure 2. Two horizontal LNG tanks installed on deck at aft of the ship was finally determined as the best location, as shown in Figure 3, due to the many advantages it offers. A modular concept of installation can be adopted to minimise outfitting onboard the vessel. This concept is very commonly used for modularising the process and drilling plants of offshore units. The various equipment like bunkering stations,

vaporisers, LNG pumps, piping, electrical distribution boxes and control panels can all be fitted in the workshop prior to the arrival of the bulk carrier in the yard. Installation onboard is also optimised as the whole unit is lifted as one unit onto the aft of the bulk carrier and interfacing with the ship's systems is simplified and the connection should be designed to be "plug and play".

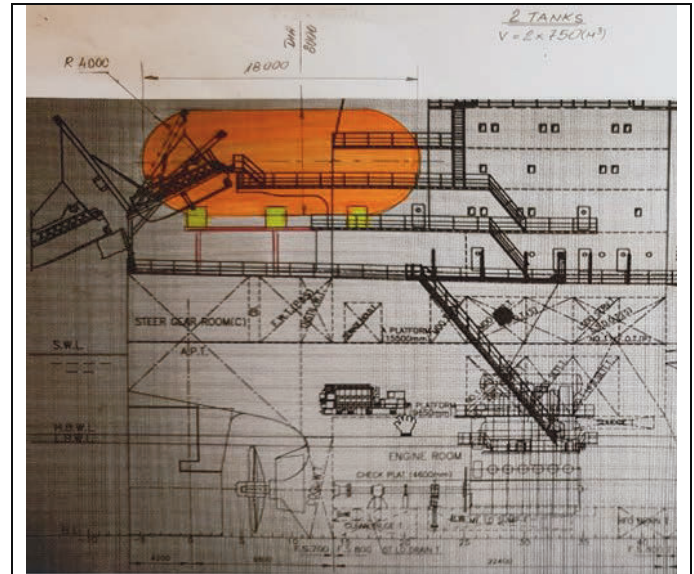


Figure 2: Two LNG fuel tanks installed horizontally with a total capacity of 1,500m³

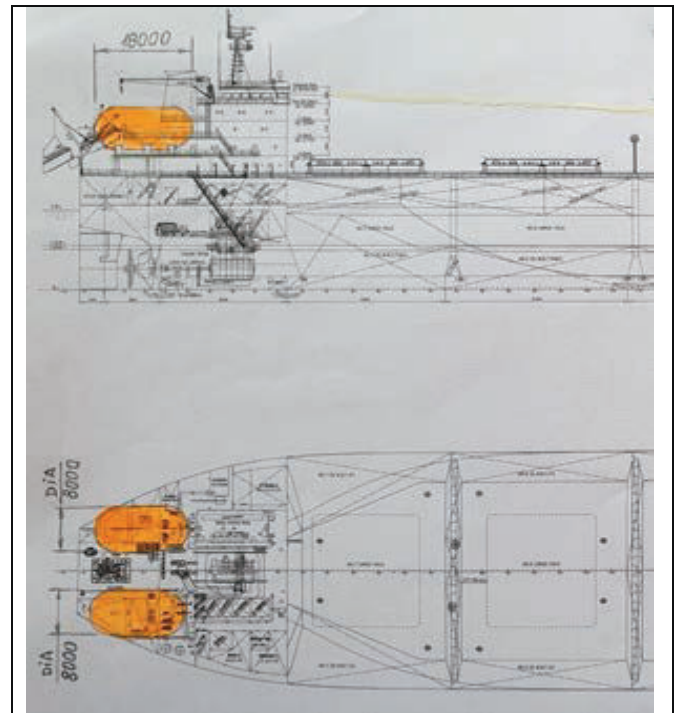


Figure 3: Two LNG fuel tanks proposed to be installed at aft of bulk carrier for LNG retrofit

Pros	Cons
Low No of tanks for simplicity of design in the foundation	Not C.O.T.S. tanks.
Near to engine room to run piping.	The larger tank needs more strengthening of deck and foundation, deck extension.
Low surface area for heat transfer for b/off.	Higher CapEx for tanks for non-standard tanks initially.
Simplified bunkering operation due to 2 x tanks.	Stability margin effects.
Safer as an exposed deck.	

Table 2 Pros and cons of LNG fuel tank location

3.1 Stability check

The stability of bulk carrier after retrofit is checked through the following steps. It has to show enough margin in GM is maintained after the retrofit.

The summary of LSW for retrofitted to LNG bulk carrier vessel is:

$$LSW = 16475 \text{ t}$$

$$VCG = 13.68 \text{ m (from BL)}$$

where:

LSW = Lightship weight

VCG = Vertical centre of gravity

- a) The summary for HFO in tank before retrofiting:

$$W_{HFO} = 2075 \text{ t}$$

$$VCG_{HFO} = 1.20 \text{ m (from BL)}$$

where:

W_{HFO} = Weight of HFO

VCG_{HFO} = Vertical centre of gravity of HFO

- b) Weight of the LNG tanks:

$$W_{LNG}^{2TK} = 531 \text{ t}$$

$$W_{2TK}^{2TK} = 265.5 \text{ t}$$

where:

W_{LNG}^{2TK} = Weight of the LNG in the two LNG tanks

W_{2TK}^{TARE} = Weight of the two LNG tanks

- c) The summary Weight of LNG in two tanks and VCG:

$$W_{2TK}^{GROSS} = W_{LNG}^{2TK} + W_{2TK}^{TARE} = 797 \text{ t}$$

$$VCG_{LNG}^{TK} = 27.5 \text{ m from BL}$$

where:

W_{2TK}^{GROSS} = Gross weight of LNG and tanks

VCG_{LNG}^{TK} = Vertical centre of gravity of LNG and tanks

- d) Following the Stability examples and calculations, KM, VCG and GM are:

$$KM_{max} = 14.59 \text{ m}$$

$$VCG_{total} = 11.84 \text{ m (from BL)}$$

$$FSC_{2TANKS} = 0.05 \text{ m}$$

$$GM_{min} = KM_{max} - VCG_{total} = 2.7 \text{ m}$$

where:

KM_{MAX} = Maximum KM

VCG_{TOTAL} = Total vertical centre of gravity

FSC_{2TANKS} = Free surface

GM_{MIN} = Minimum metacentric height (Margin for increasing of VCG)

After LNG retrofiting the stability of vessel shall be with $GM_{MIN} = 2.70\text{m}$. As per same document, expected VCG of DWT^{GROSS} (120 000t) shall be ~12m which is less than $KM_{MAX}=14.59\text{m}$.

Water Ballast VCG_{WB} shall be below 10.10m which is less than $KM_{MAX}=14.59\text{m}$. That respectively shall increase calculated GM_{MIN} .

For comparison calculated $GM_{MIN} = 2.70\text{m}$, the most critical case is with $GM_{(fluid)} = 2.97\text{m}$ which is very consistent with our calculated GM_{MIN} . Hence, the stability of vessel after LNG retrofiting shall be with enough good margin. An internal report from Chengxi Shipyard was referred for stability information.

4. Cost Analysis & Project Scheduling

It is necessary to estimate retrofit cost so that an objective comparison can be made taking into account the capital expenditure at the onset and fuel savings in subsequent years to derive payback period for capital investment. It will be done from two approaches: top-down approach taking in account the macro-considerations like newbuilding rate and investment cost of competing technologies; as well as a bottom-up approach by accounting the material, fabrication, installation costs and mark-ups.

4.1 Top down approach

A key factor for the success of liquid to gas conversion for LNG fueled ships is finding sufficient space for storing liquid and gas fuel on board the vessel. It is considered less expensive and complicated to place the tanks above deck. From the technical information of a typical bulk carrier GA drawings, the installation of LNG tanks on the open deck was investigated. One of the priorities in the engineering design was prevention of cargo volume loss and payload. The primary consideration in deriving the cost level for LNG system retrofit for a bulk carrier will be the newbuilding price of a new LNG-fuelled bulk carrier. New building price of a capesize bulker of 180,000 dwt will cost \$47.5 million while a Kamsarmax of 82,000 dwt will cost \$27 million in May 2018. When interpolated for the 120,000 dwt bulker, the newbuilding cost is expected to be \$37 million. If the bulker is specified as being LNG fuelled, the cost is estimated to be \$45 million.

4.2 Bottom up approach

Major equipment costs cover mainly costs related to retrofiting engines and boiler to dual fuel configuration. Equipment for LNG system is also included like LNG tanks, valves, pump, vaporiser and GVU. Cost for engine and boiler retrofit is estimated based on past experience and interaction with engine makers. The main cost driver for LNG system is the fuel tanks and this is estimated by calculating the material weight of the selected four LNG tanks and multiplying by the material cost of

9% Ni steel of \$1500/ton and a makers' mark-up factor. Supporting systems like inert gas, gas detection, fire-fighting systems will need to be installed on the bulk carrier as these are new systems. The basic costs of each system are based on experience and a mark-up factor is applied. For common marine systems, a factor of 1.5 is used while for cryogenic systems, a factor of 2.0 is used to reflect the premium these makers can charge due to its novelty and lesser competition. Certain existing systems like ventilation, electrical and control systems will also need to be upgraded. The same approach is applied to these systems as well.

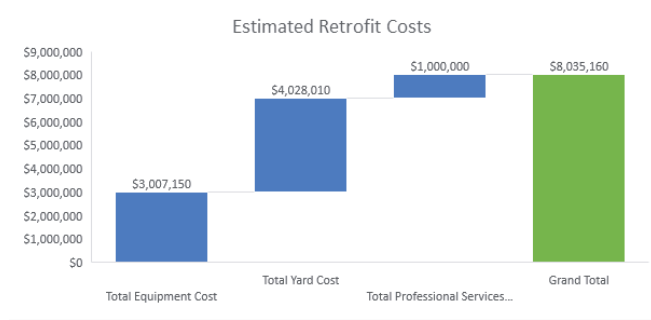


Figure 4 Estimated Retrofit Cost Breakdown

Using the top-down approach based on newbuilding prices, comparison with competing technologies and historical retrofit contract values, a top limit of USD 10 million had been established to make the retrofit an attractive option in this study. Using the bottom-up approach by breaking down the retrofit costs into equipment costs, yard costs and professional services, a total retrofit cost of USD 8 million is derived. It is comparable to the cost limited by a top-down approach. It is advisable to cater a safety margin of about one million USD to act as a buffer against uncertainties and inaccuracies in cost then there is a good match between the two approaches.

4.3 Project Scheduling

Several factors will govern the successful project scheduling for the retrofit. Firstly, the duration of a vessel in yard time has to be minimized wherever possible to reduce losses in charter revenues. The exact location of the yard for the retrofit work is also critical. The availability and requirements of other stakeholders such as autonomy of tanks, shore-based fuel bunkering systems, safety, classifications and flag states are important. In general, the entire retrofit project will be developed and planned during the sales phase. The use of a modular concept for installing of the LNG fuel system will save precious downtime and cost for this project. It is shown in Figure 5 that the project will take about 62 weeks from planning to completion with dry docking of seven weeks' time estimated. The project scheduling was prepared with spreadsheet.

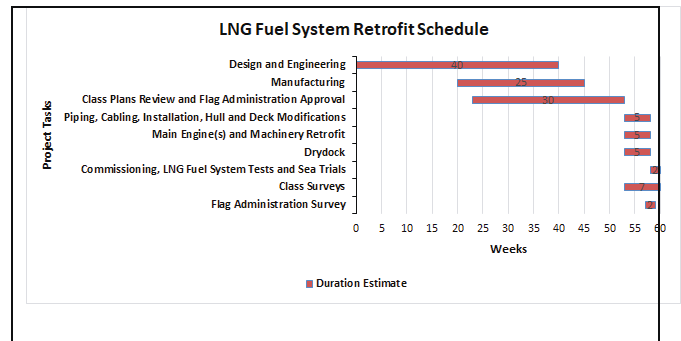


Figure 5 Retrofit schedule of the bulk carrier

5. Conclusion

The report demonstrated an application of modular installation concept was proposed to the most cost effective for the retrofit of a bulk carrier with LNG fuel and a reduction in project downtime with reasonable project cost.

An optimized deck arrangement for the modular LNG gas supply, filling and safety systems increase the cargo capacity and efficiency of the vessel. Based on the main engine output of 13,600kW and an assumed engine speed of 83rpm, a commercially available dual fuel engine was selected as the power plant for this study. It is assumed that ship owners had taken the long-term view during the newbuilding stage and Dual Fuel Ready (DFR) engines are being installed.

Various enticements and inspirations, including laws and regulations, to reduce shipping's exhaust emissions are being implemented. In the long run, the shipping sector with more LNG fuelled vessels helped by retrofit with short downtime will achieve a cost saving of 50% in comparison with low sulphur MDO.

One of the most challenging works to retrofit a vessel with LNG fuelled engine is the type of fuel tanks and their location. An innovative design was proposed with the pros and cons studied. Finally, the option of two tanks on the aft deck has been chosen as this arrangement makes all necessary piping connection to a minimum length.

All design, engineering works including production drawings proposed are prepared to allow most construction work done in shops so that yard cost is kept low. Where possible, the complete unit/assembly will be transferred into a modular construction for ease of installation, commissioning.

Using the top-down approach in cost analysis based on newbuilding prices, comparison with competing technologies and historical retrofit contract values, a price tag of USD 10 million had been established to make the retrofit an attractive option. Using the bottom-up approach by breaking

down the retrofit costs into equipment costs, yard costs and professional services, a total retrofit cost of USD 8 million is derived. It is comparable to the cost limited by the top-down approach. It is advisable to cater a safety margin of about a million USD to act as a buffer against uncertainties and inaccuracies in cost then there is a good match between the two approaches.

Acknowledgments

The team would like to express special thanks of gratitude to the technical partners at Keppel Offshore and Marine (KOM), Sembcorp Marine (SCM), Winterthur Gas & Diesel (WinGD), Wärtsilä, DNV GL and Shell for consulting sessions as well as a number of professionals in the industry who helped to address our research project and enrich the contents with their insights, through informal chats to sharing sessions.

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