ASSESSING THE CARBON DIOXIDE EMISSION REDUCTION POTENTIAL OF A NATURAL GAS CONTAINER CARRIER

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ABSTRACT

At present, natural gas is a plausible part of the solution to reducing CO_2 emissions from shipping due to a reduction in shipboard carbon emissions when it is used. Natural gas has a favourable energy density and price when compared to oil, as well as significant reductions in NO_x, SO_x and PM emissions. The established natural gas and LNG carrier market has also advanced the need for classification society rules for the storage of both liquid and gaseous fuels that have already been readily applied to ships using natural gas as a fuel supply. The main obstacles to the implementation of natural gas are its low storage density, the economic viability of retrofit into existing ships, its safe storage and its supply and availability in ports. This study focuses on examining the viability of natural gas for powering a panamax container carrier with a specific route and hence a specific operating profile in order to evaluate the overall ship impact and the potential CO_2 reductions from modifications to the ship including the selection of fuel, marine power plant and transmission combinations. A panamax container carrier has been investigated because this ship type represents a significant proportion of the market, has unique power requirements and is volume and stability limited. Solutions will examine a trade-off between the amount of shipboard natural gas utilised and the combined cost of fuel and CO_2 emissions, from the retrofitting of existing ships to more significant changes, only viable for a new build.

Keywords: Natural Gas, Container Carrier, Auxiliary, Carbon Dioxide Emissions, Low Carbon Shipping

1. INTRODUCTION

The main aim of this paper is to compare and contrast the characteristics of natural gas use in marine power plants against the existing utilisation of heavy fuel oil and marine diesel oil power plants, both from a carbon dioxide emissions reduction and cost perspective.

Additionally this study will assess the accuracy and limitations of the ship and marine power plant modelling methods that have been employed and evaluate the impact and importance of proposed and existing regulatory measures on a panamax container carrier.

The majority of the ship impact study focuses on converting the auxiliary engines to run on natural gas on a panamax size container carrier. In an industry which is very cautious about changes, especially when it involves a new technology, converting auxiliary power seems the first logical step. There is one instance of this; Reederei Stefan Patjens is to retrofit LNG on board a 4 year old 5,000 TEU container vessel (DNV, 2010). This would be the first use of LNG as fuel on board a container ship and in global trades, currently LNG is used mainly on coastal ferries (Einang & Haavik, 2000). Two of its auxiliary engines and its auxiliary boiler will be modified so they can be fuelled by LNG and the cargo space next to the engine room will be converted into a gas technology room and LNG will be supplied using only containers on deck (DNV, 2010).

There is a lot of scope for reducing CO_2 emissions on container carriers by improving the efficiency of auxiliary power generation by managing or reducing loading and/or by using alternative fuels to fuel oil.

To put the potential for CO_2 emissions savings from auxiliary power into context the installed auxiliary power in a container carrier can provide, roughly, around 80% of the propulsion requirement of a equivalent sized bulk carrier (Clarksons, 2010) (more specifically, significant ships 2007 shows this ratio to be as much as 88% (comparing Ital Mattina 8400kW generating capacity to the 9561kW engine power of Orange Trident Bulk Carrier) (RINA, 2007)).

1.1 NATURAL GAS CHEMICAL COMPOSITION AND CHARACTERISTICS

Natural Gas is a mixture of different hydrocarbon gases known in scientific names i.e. methane, ethane, propane and butane. Methane in most cases counts for more than the 90% of natural gas constitutions (~95%) while the rest consists of ethane, propane and butane (Union Gas Limited, 2011). The use of natural gas is considered as the most advantageous rather than any other type of fossil fuel. In methane the ratio of number of carbon-hydrogen bonds to the number of the carbon atom is 4 more than any other type of fuel. This means that for the same amount of energy extracted by combustion, less fuel is required. Moreover, less fuel corresponds to reduced CO_2 emissions.

2. ALTERNATIVE FUELS TO NATURAL GAS

Several simulations were carried out to evaluate the CO_2, NO_x, and SO_x, emissions and electric power production from exhaust gases for a given loading (vessel speed). This included combinations of various fuels (residual, distillates and natural gas), thermal engines and machinery arrangements. Figure 1 shows different machinery arrangements.

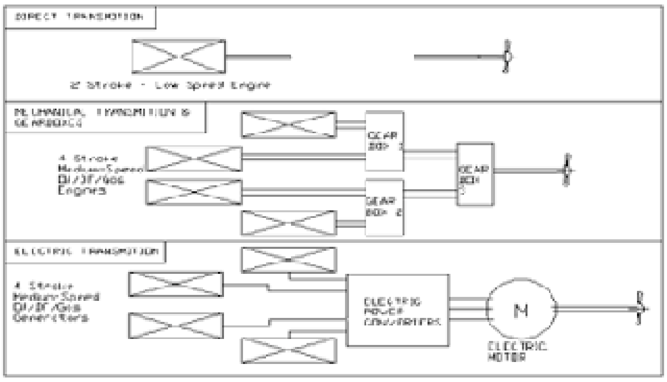

Figure 1: The different machinery topologies that were examined.

The examined simulation results at 100% maximum continuous engine rating (MCR) are presented in figure 2. In figure 2, each line represents each one of the machinery types while the horizontal axis expresses the type of fuel starting from residuals (left) to distillates and natural gas (right). Moreover, in table 1 and table 2 for 75% (approximately 90% of the vessel speed) and 100% MCR, respectively, the results are sorted from the most green to the most pollutant. At 75% and 100% MCR, the use of natural gas characterises the less pollutant combination.

Note that these simulations have not considered the additional weight of natural gas storage tanks or of gearboxes required for 4 stroke arrangements.

The use of natural gas is the less CO_2 polluting solution due to its high ratio of number of bonds to number of carbon atoms as well as its high lower calorific value.

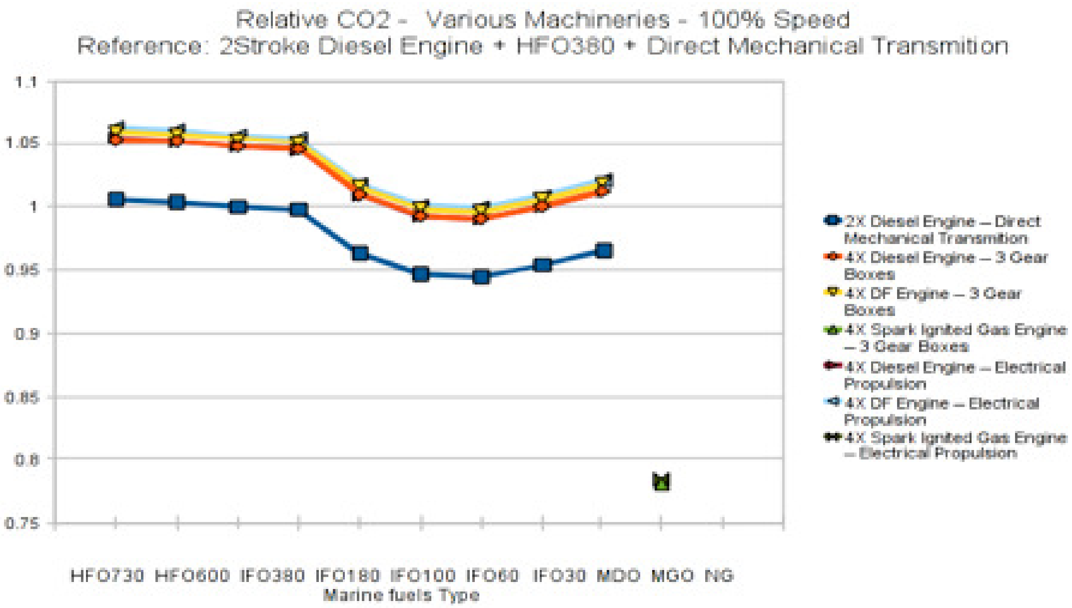

Figure 2: Relative CO_2 emissions reduction of different fuel and machinery arrangements for a panamax container carrier at 100% MCR with Gas engines running in diesel mode.

If the only choice is the use of oil fuel, the better solution is to replace the common IFO380 (Intermediate Fuel Oil 380 (380cSt at 50˚C) with IFO30 (Intermediate Fuel Oil 30 (30cSt at 50˚C)). The results help to answer the tricky choice between residual or distillate fuels for reduced CO_2 emissions. With distillate fuels, less fuel is needed for the same output as they are of higher calorific value but they are of higher purity so more hydrocarbons pass for a given amount of fuel. The other side of the problem is that residual fuels are of lower calorific value and so more fuel is needed but with lower purity. As the most reliable factor for the CO_2 production is the number of carbon molecules which are consumed, it seems that the best combination is an intermediate fuel with the proper combination of lower calorific value and purity.

Table 1: Relative CO_2 emissions reduction of different fuel and machinery arrangements for a panamax container carrier at 75% MCR.

Fuel**	Engine & Transmission*	Relative CO_2 Emissions	Fuel**	Engine & Transmission*	Relative CO_2 Emissions
GasDF	4M	0.851	IFO30	4E	1.014
GasDF	4E	0.862	IFO60	4E	1.017
Gas	4M	0.864	MDO	4M	1.018
Gas	4E	0.872	MDO	4E	1.024
IFO30	2D	0.945	IFO100	4M	1.028
IFO60	2D	0.946	MGO	4M	1.030
MDO	2D	0.954	IFO100	4E	1.034
IFO100	2D	0.963	MGO	4E	1.037
MGO	2D	0.966	IFO180	4M	1.064
IFO180	2D	0.998	IFO380	4M	1.067
IFO380	2D	1.000	HFO600	4E	1.071
IFO600	2D	1.004	IFO180	4E	1.071
HFO730	2D	1.006	HFO730	4M	1.073
IFO30	4M	1.008	IFO380	4M	1.074
IFO60	4M	1.010	HFO600	4E	1.078
			HFO730	4E	1.080

Key to table 1 and 2:

*2D = 2-stroke direct transmission
*4M = 4-stroke mechanical transmission
*4E = 4-stroke electrical transmission
**GasDF = Dual-fuel engines running on gas

(4 stroke arrangements have three gearboxes, see figure 1)

Table 2: Relative CO_2 emissions reduction of different fuel and machinery arrangements for a panamax container carrier at 100% MCR with gas engines running in diesel mode.

Fuel**	Engine & Transmission*	Relative CO_2 Emissions	Fuel**	Engine & Transmission*	Relative CO_2 Emissions
Gas	4M	0.781	IFO100	4E	1.010
Gas	4E	0.784	IFO100	4M	1.010
IFO30	2D	0.945	MGO	4E	1.013
IFO60	2D	0.947	MGO	4M	1.013
MDO	2D	0.954	IFO100DF	4M	1.016
IFO100	2D	0.963	MGODF	4M	1.018
MGO	2D	0.966	IFO100DF	4E	1.019
IFO30	4E	0.991	MGODF	4E	1.021
IFO30	4M	0.991	IFO180	4E	1.046
IFO60	4E	0.993	IFO180	4M	1.046
IFO60	4M	0.993	IFO380	4E	1.049
IFO30DF	4M	0.996	IFO380	4M	1.049
IFO180	2D	0.998	IFO180DF	4M	1.052
IFO60DF	4M	0.999	HFO600	4E	1.053
IFO30DF	4E	0.999	HFO600	4M	1.053
IFO380	2D	1.000	HFO730	4M	1.054
MDO	4E	1.001	IFO380DF	4M	1.054
MDO	4M	1.001	IFO180DF	4E	1.055
IFO60DF	4E	1.001	HFO730	4E	1.055
HFO600	2D	1.004	IFO380DF	4E	1.057
HFO730	2D	1.006	HFO600DF	4M	1.058
IFO30	4M	1.006	HFO730FD	4M	1.060
IFO60	4E	1.009	HFO600DF	4E	1.061
			HFO730DF	4E	1.064

According to the simulations results, a fuel around 30cSt at 50˚C seems to offer the best combination. From figure 3, the possible CO_2 reduction in comparison to IFO380 is about 5%. However, it should be noted that the authors have not examined standardised fuels, but what is commonly met in the fuel market.

According to the manufacturers of all the examined engines (Wärtsilä) (Man B&W), the engines can consume residual fuel with viscosity no more that 700cSt at 50˚C. However, for research purposes only, the use of marine fuel with viscosity 730cSt at 50˚C has been examined.

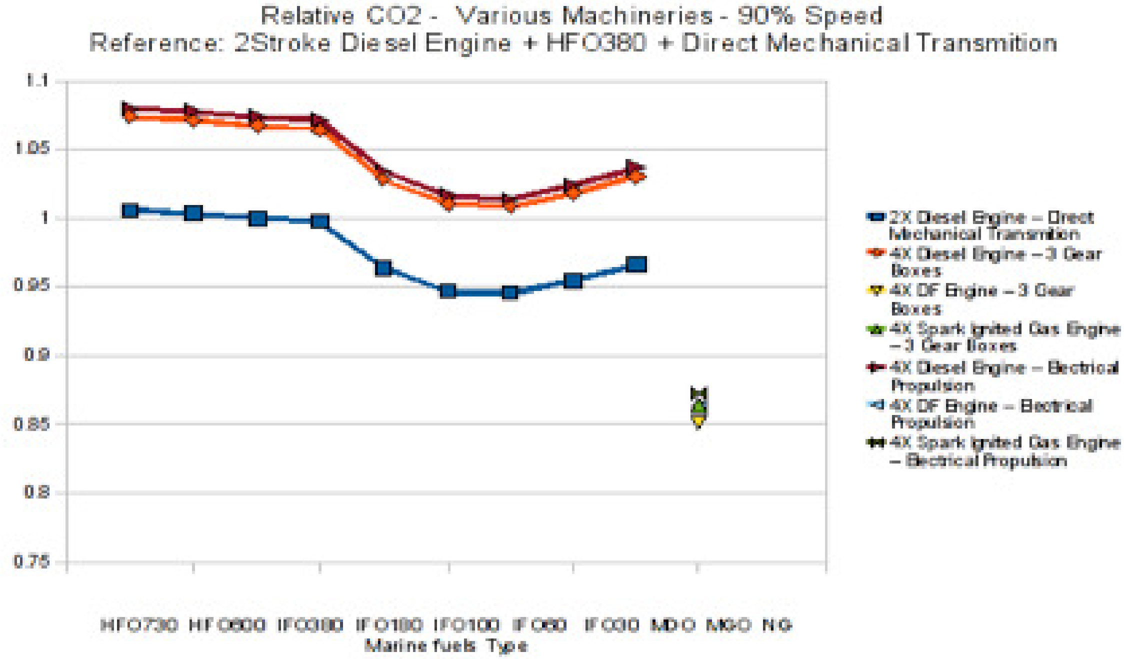

Figure 3: Relative CO2 emissions reduction of different fuel and machinery arrangements for a panamax container carrier at 75% MCR.

Biofuels are expected to be a promising solution for reducing nitrogen oxides (Kalligeros et al., 2003) and sulfur oxides, but due to the huge marine industry demand, they can be used only as blended fuels. Furthermore, due to their high prices, their use is expected to be limited.

Dual-fuel engines can combine the use of oil or gas giving in this way the flexibility to consume fuel of lower sulfur content far away from environmental protection areas and gas inside these areas. Also no significant conversion of the vessel general arrangement is needed as the limited need for gas can be hosted in containerised tanks on deck.

As illustrated in table 1 and table 2 by the difference in CO_2 savings between the 2-stroke and 4-stroke engines a 2-stroke natural gas engine will provide further efficiency savings. 2-stroke natural gas and LPG were not examined here because of limited data. Currently the only example of this is the Quantum 9000 concept design by Det Norske Veritas (DNV) and Man (DNV & Man, 2011).

3. BARRIERS TO IMPLEMENTATION

The main barriers to implementation of LNG as a fuel are:

- Tough regulatory requirements (see section 3.1).
- Storage requirements (related to regulatory requirements) (see section 3.2).
- Lack of bunkering infrastructure.
- “well to propeller” carbon dioxide emissions of LNG are likely to be higher than for heavy fuel oil, especially if renewable sources of energy are not used for liquefaction. In order to understand the full impact of switching to alternative fuels, consideration of the through-life carbon emissions is important. Especially considering that marine transportation routinely uses residual fuel, both a waste product of petroleum refining and a blended product itself (Winebrake et al., 2006).
- Relatively under-used marine power plant technology compared to oil-based marine power plants, increases risk.
- Economic viability of fitting to existing ships.
- Natural gas is a non-renewable resource and will have similar or worse price sensitivity than that of oil (especially if natural gas becomes widely adopted), this makes future profitability uncertain.

3.1 CLASSIFICATION SOCIETY REGULATIONS

DNV and Germanischer Lloyd (GL) regulations for gas fuelled engine installations are very similar and are based upon, or refer to, established rules for gas carriers (DNV, 2011) (GL, 2010).

The regulations ensure that explosions in any space containing gas sources should not cause:

- damage to adjacent spaces.
- flooding.
- damage to work or accommodation areas.
- damage to life-saving equipment.
- chain reactions (e.g. involving cargo or oil).

This is done by ensuring that gas storage, machinery spaces, piping arrangements, bunkering and ventilation are adequately protected from both the leakage of gas and sources of vapour ignition (GL, 2010).

Gas storage pressures higher than 10bar are not normally accepted and have to be individually certified and approved (DNV, 2011) (GL, 2010).

Adequate redundancy should also be made available. In the case of leakage a secondary independent fuel supply should be available and for gas only installations the fuel storage should be divided between two or more tanks of equal size located in separate compartments (GL, 2010).

Gas storage tanks should be placed as close to centreline as possible (minimum of B/5 and 11.5m from the ships side, minimum of B/15 and 2m from the bottom plating) (DNV, 2011) (GL, 2010). Compressed and liquefied gas storage on open deck is allowed providing tanks are placed B/5 from the ships side and have adequate natural ventilation (GL, 2010).

3.2 NATURAL GAS STORAGE

One of the greatest challenges in using natural gas is not only the gas handling and safety management but also its storage.

There are two ways according to which natural gas can be stored. At a very low temperature (-163˚C) and at atmospheric pressure (Moon et al., 2005) as liquefied natural gas (LNG) or at a pressure between 100 to 275 bar as Compressed Natural Gas (CNG), to achieve densities approximately a 1/3 of that of LNG (Young et al., 2007).

CNG may be justified, in terms of gas carriers, to exploit smaller less contiguous gas reserves where the investment in LNG facilities cannot be justified (Young et al., 2007). CNG remains very unlikely to be adopted as a fuel on large ships because of its very high working pressure. Hence, storage of natural gas for propulsion is frequently in liquefied form and achieved by insulated tanks at atmospheric pressure or in insulated vessels with (safe) working pressures below 10bar (IMarEST, 2010).

Table 3 shows an overview of LNG carrier tank types. Some factors, such as bridge visibility, are less relevant for the use of natural gas as a fuel.

The filling heights restriction shown in table 3 is imposed by sloshing and is a problem in membrane type tanks (Moon et al., 2005). Spherical tanks have the advantage that they can discharge cargo under pressure in an emergency and do not require an emergency cargo pump. In LNG carriers membrane tanks are normally preferred because a membrane LNG carrier is capable of loading 8% more cargo than a spherical tank type container carrier with identical principal ship dimensions (Moon et al., 2005).

Table 3: Liquefied natural gas tank types (SNAME, 2010).

Tank Type	Advantages	Disadvantages
Mark III, NO96 and CS1 (Membrane Type Tanks)	Good bridge visibility and flat deck area. Less cool down time. Volumetric efficiency and reduced Suez toll. Large production capacity in Korean Shipyards	Inspection and maintenance access. Partial Load Restrictions. Secondary barrier tightness test (SBTT) required every five years.
Moss Spherical	Inspection and maintenance access. No filling heights restriction. Parallel construction with hull. No emergency pump necessary. Greater distance between cargo tank and hull.	Bridge visibility, deck space and increased windage area. Volumetric Efficiency. Limited licensed builders.
SPB	Good bridge visibility and flat deck area. Inspection and maintenance access. No filling heights restriction. Parallel construction with hull.	Higher production cost. Limited licensed builders.
Type C	Inspection and maintenance access. No filling heights restriction. Can be Mass Produced.	Small parcels.

4. UTILISATION OF LNG FOR AUXILIARY POWER ONBOARD A CONTAINER CARRIER

Cylindrical LNG tanks (IMO Type C tanks) appear to be the most plausible tank types for LNG storage for auxiliary power, as cylindrical tanks are the most efficient shaped pressure vessels (in terms of weight). Should LNG be more widely adopted type C (cylindrical) tanks would also be the least expensive as they can be mass produced, independent of the ship. Having tanks that are not integrated into the hull of the ship reduces the need for specialists skills in the ship yard, tanks can be assembled and tested elsewhere. In this study the Wärtsilä LNGPac (Karlsson & Sonzio, 2010) system was used, which combines type C tanks with a tank room (for auxiliary equipment), it is plausible that this kind of packaged system could be mass produced. TGE Marine (in cooperation with MAN) also use a similar system with type C tanks (Man, 2010).

An article by Wärtsilä gave two possible locations for locating LNG tanks for auxiliary power (Levander & Sipilä, 2008). One was on either side of the main engine and the second was as containerised tanks on deck, as is proposed by DNV (DNV, 2010).

It was decided that tanks in and around the superstructure and engine room may be more difficult to implement because of classification society regulations, particularly those concerning tanks being in the middle of the ship and keeping manned spaces "gas safe and explosion proof", as outlined in section 3.1. The most likely and perhaps pessimistic option (in its impact on cargo) is to utilise the cargo hold in front of the superstructure. This also allows the forward engine room bulkhead to be utilised as a divide between the manned machinery spaces and the main engine and may allow the container carriers already explosion proof hold ventilation system (if fitted) to be utilised to support the ventilation requirements required for carrying LNG (Fig. 4).

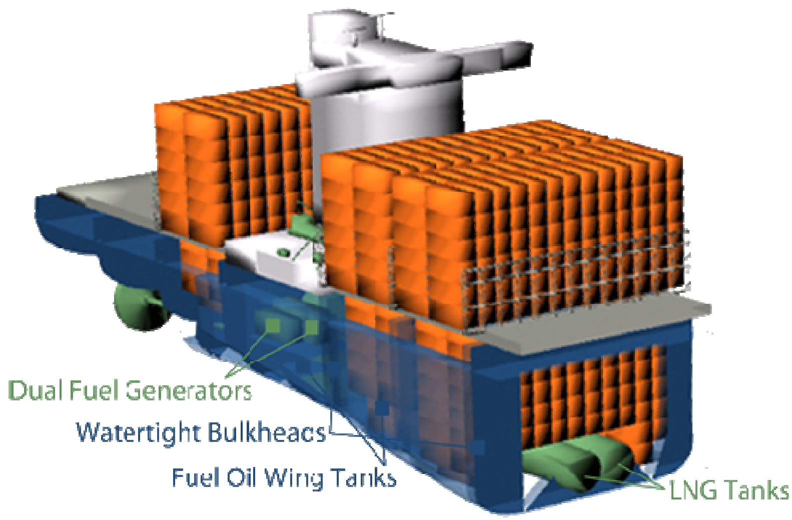

Figure 4: Potential LNG tank arrangement for auxiliary power on a panamax container carrier.

As depicted in Figure 4, the LNG tanks were placed horizontally in the cargo hold rather than vertically, so that 40 foot containers can be stowed above the LNG tanks, vertically placed tanks will only allow 20 foot containers to be stored in the hold. For other ship types vertically placed LNG tanks may be preferred. The existing four diesel engines could be modified to run on natural gas or new dual fuel engines could be installed. The need for two or more separate tanks is also required for redundancy.

4.1 METHODOLOGY

The panamax container carrier was chosen because it has unique stability characteristics and it represents 25% of the container carrier fleet (in terms of number of ships), the largest proportion for any one container carrier size (Clarksons, 2010).

The parametric ship model requires human input to generate designs in order to decide where to place equipment. Ship design methods to ensure that the ship model adheres to all current and upcoming rules and regulations and represents actual ships can be parameterized and automated to a certain extent.

A number of point designs have been investigated and the model has been validated against existing ships and scaling algorithms. Weight data was estimated to a 3-digit level to ensure the model can be scaled correctly to different size ships and design speeds and so that future ships can be designed using data that has been calibrated to existing ships.

The point design panamax container carrier in this study is representative of existing conventional container carrier designs powered by a 2-stroke engine running on fuel oil and designed for a speed of 25 knots at 75% MCR (75% MCR was used because this is the value at which EEDI is calculated (IMO, 2009)). The model has a length of 294m, a 32.2m beam, a 12.2m draught, a 72605 tonne design displacement with a calculated capacity of 4584 TEU containers with 400 reefer containers.

This study focused on retrofitting the auxiliary power generators to use LNG instead of fuel oil. The difference between a retrofit and a new ship design is that in a retrofit any additional weight or lost weight (including weight required for ballast) is assumed to impact on payload and the payload is adjusted to keep the ship at the same trim and draught. No changes are made to the overall structure and size of the ship.

Figure 5 shows the direct changes to the ship when retrofitting a ship to adopt an alternative fuel. The indirect effects are assessed in the whole ship impact and include the change in ballast arrangement required due to the change in the centre of mass of the ship (as discussed above structural changes are limited for retrofits.)

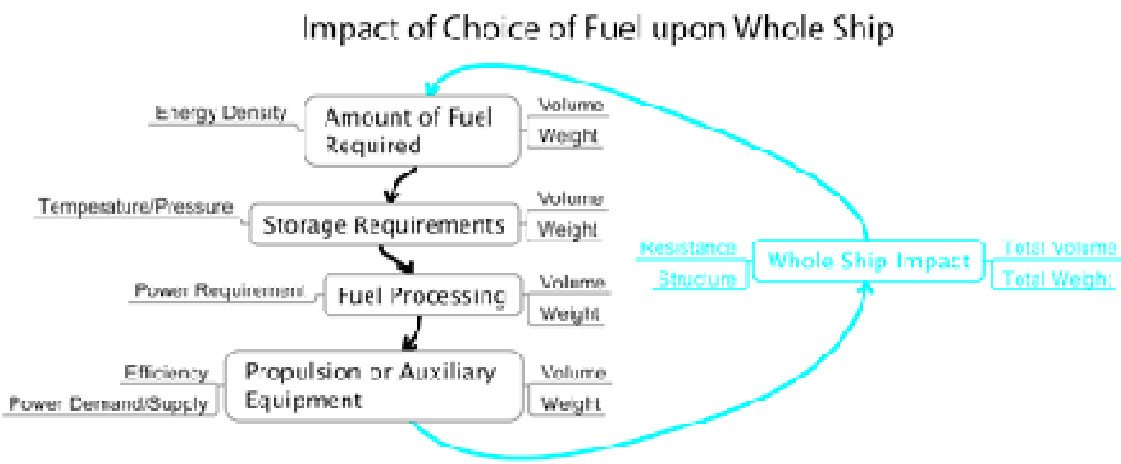

Figure 5: Ship retrofit impact.

The resistance data used in this case in order to find residuary resistance is from model test data corresponding to the hullform (frictional resistance can be calculated directly from the speed, length and wetted surface area of the model using the 1978 ITTC Method). This was validated against Holtrop-Mennen and found to give a difference of about a knot, which shows an acceptable margin of error due to the complex nature of estimating resistance. Also the resistance calculation should be accurate enough to make a decision on which engine size to choose, being accurate beyond this presents no further benefit.

The auxiliary power is the hardest to estimate, the reefer containers were assumed to have a power consumption of 12kW per FEU container then a utilisation factor was used to correct the overall rated power requirement to the actual power supplied considering reefers are not requiring 12kW of power constantly and the items that make up the ships hotel load are not all used at the same time. By comparing the number of reefers and installed power for a number of container carriers a utilisation factor of 0.3 was sufficient (RINA, 2007). Factors, such as this, are important to correct ship modeling estimates to actual ships.

It was assumed that boil-off, which is small, around 0.1% of cargo per day for a LNG carrier (Chang et al., 2008), was also occurring at a rate lower than the fuel usage. As for a container carrier generators will need to be run constantly in order to keep the reefer containers cool.

4.2 SHIP IMPACT AND POTENTIAL CARBON DIOXIDE EMISSION REDUCTION

Using Wärtsilä generating sets and dual fuel generating sets (20, 26, 20DF and 34DF) (Wärtsilä, 2011), changing the generator fuel from diesel to LNG reduced the amount of fuel that was required for a given output power because natural gas is more energy dense than oil-based fuels (as described in section 1.1). In this case, there was a reduction of around 13% in fuel mass in going from diesel to natural gas fuelled power generation (this is based upon manufacturer's specifications).

Taking into account the 302 tonnes of additional mass of the pressurised LNG tanks and a 46 tonne reduction in fuel weight (described above) the overall net effect on the panamax container carrier was a 256 tonne mass increase in power generation related mass. This is a small mass increase compared to the displacement of the ship but an increase in power generation related mass (consisting of generators, tanks, fuel and auxiliaries) of 48% compared to the conventional fuel-oil power generation system. The majority of this mass impacted on cargo, as well as cargo support (weight of hatches, cell guides, etc.).

It was found that as the LNG tanks were less dense than the heavy containers at the bottom of the hold they were replacing 38 additional 'light' containers were added on deck to get the ship to float at its design draught after the retrofit. Additional space around the tanks was also left for ventilation purposes. This arrangement is shown in figure 4. This had a negative impact on stability, reducing upright design condition GM from 0.87 to 0.79. The requirement for the minimum GM is 0.15m (DNV, 1995).

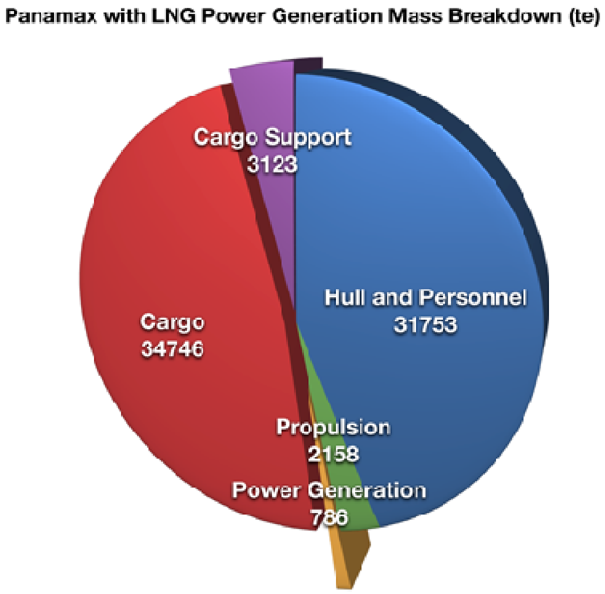

Figure 6: Panamax container carrier with LNG auxiliary power retrofit mass breakdown.

A breakdown of the main weight groups (also used as a method of validation) on the retrofitted ship in its design condition is shown in figure 6.

Container carriers normally use trim ballast to keep a level draft in different loading conditions. Retrofits may have an adverse affect on trim, which may place limits on the extent of the LNG retrofit or may require additional operator guidance.

Reducing emissions from auxiliary systems, which are independent of ship speed, means that in terms of the emissions of the overall ship, the greatest benefits are in port and at low speeds, the overall CO_2 emissions reduction ranges from 5.1% at 15 knots to 0.6% at 25 knots. By considering a operational profile of a container vessel (Cerup-Simonsen et al., 2009), which has been imposed on figure 7. The overall CO_2 emissions reduction and mass of fuel carried was found to be 2.7% and 1.6%, respectively. Figure 7 also illustrates the huge difference in emissions within a few knots at higher speeds.

Emissions per tonne of cargo were calculated in order to account for any change in cargo volume and weight due to the storage of LNG and associated regulations for container carriers and the carriage of natural gas. So assuming the main engine fuel and both auxiliary fuels cost the same per tonne there would be a 1.6% cost-saving. No attempt has been made here to analyse fuel prices, which can be very sensitive and this operational profile is limited and does not consider time in port.

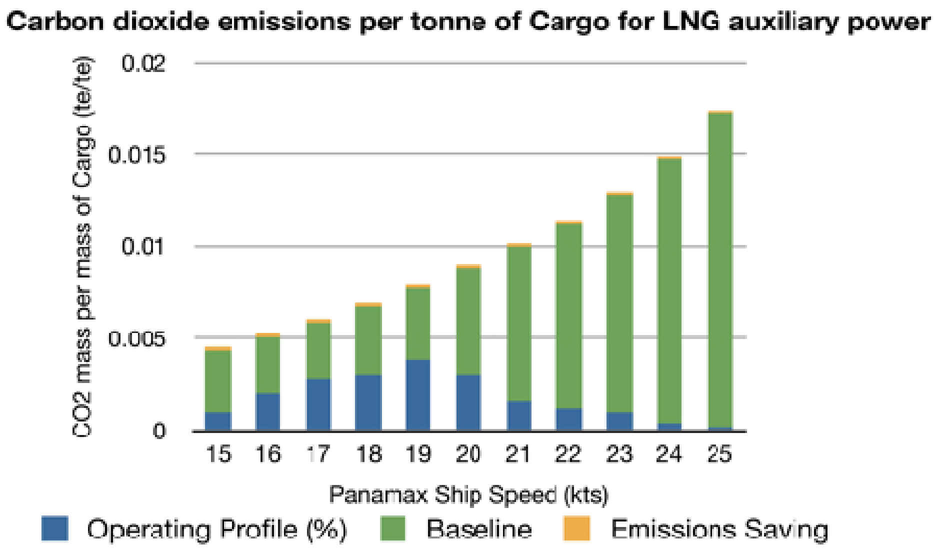

Figure 7: Carbon dioxide emissions for a panamax container carrier with LNG auxiliary power at different operating speeds.

In port (without main engine running) the CO_2 emissions reduction and weight of fuel carried was found to be 23.8% and 11.9%, respectively.

LNG for auxiliary power is particularly useful when reducing emissions in port and low emissions zones at a regional regulatory level and in particularly sensitive sea areas (IMO, 2006) at an international regulatory level. Such regulations primarily concern NO_x and SO_x emissions and particulates rather than CO_2 and GHG emissions, but these emissions are significantly reduced by adopting natural gas. An article by Wärtsilä (Levander & Sipilä, 2008) also claims that running on LNG in port instead of shore power is also less expensive.

4.3 EFFECT OF CONTAINER CARRIER LNG FUELLED AUXILIARY POWER ON EEDI.

When calculating the energy efficiency design index (EEDI) for a container carrier the capacity parameter is taken as 65% of the deadweight (IMO, 2009). This is assumed in order to account for containerships being not full to capacity. This 65% has a big effect on EEDI. Building smaller container carriers may be able to offer more flexibility in order to meet capacity demand compared to larger ships, which may be more likely to travel empty (especially considering demand in different directions on the same route not necessarily being the same), this is not reflected by using a fixed number for all ship sizes. Cargo is also volume limited rather than strictly dependent on weight. Both mass and volume of cargo will effect emissions, although mass has a more direct impact on ship resistance.

In the EEDI calculation auxiliary engine power is calculated based only on main engine power (although there is a mention that when the load is significant it can be calculated from the power of the generators (IMO, 2009)). For container carriers both the auxiliary power and main engine power is large compared to other ship types, a fixed calculation does not take this into account and means that the auxiliary power is dependent upon design speed when this is unlikely to be the case.

EEDI does not encourage the use of alternative fuels for auxiliaries, especially if the auxiliary power is larger than that calculated by the EEDI calculation. The reduction in EEDI by the use of carrying more cargo appears to far outweigh the benefits of changing the auxiliary fuel. It is also less risky than adopting a fairly new technology and the cost savings are more apparent. This may well be representative of real life carbon dioxide savings, but perhaps EEDI should be more biased towards the need to encourage investment in new technologies.

5. CONCLUSIONS

LNG is not the single solution to reducing CO_2 emissions because there are barriers to the implementation of a new technology in an industry where risk is kept low and a heavy amount of regulation is required. The reduction in CO_2 emissions from LNG is significant enough for it to be part of the solution.

Current 2-stroke HFO engines are very efficient and reliable. A testament to this is that a quarter of LNG carriers utilise two stroke diesels even though they have LNG more readily available (Chang et al., 2008) because of their high efficiency, although they only carry LNG one way. Using LNG for auxiliary power and dual fuel engines, although less efficient than gas only engines (Wärtsilä, 2011), are good ways to de-risk the technology from a ship-owners perspective. Although, adoption of LNG only power does reduce the need for fuel treatment facilities it would also not allow you to use fuel oil should LNG not be available.

Most commercial ships have a very large range in the order of 20000nm. It is apparent that this allows ships to purchase fuel where it is cheapest and carry it with them. When a fuel is used that is less energy dense in its storage compared to fuel oil, such as LNG, changes to such design and operating practices would be more beneficial. Containerised natural gas storage as suggested by Wärtsilä (Levander & Sipilä, 2008) may offer a bunkering alternative where by fuel is moved quickly on and off the ship as required, possibly while transiting a canal. However, this method does seem implausible due to safety concerns that will have to be addressed individually by classification societies.

It was calculated that LNG, compared to ISO fuel oil, reduces CO_2 emissions by more than 20% and NO_x emissions by 80%. SO_x and PM emissions are not present from burning natural gas. While CO_2 emissions are the main focus in this paper, there is an incentive for adopting LNG in order to minimise NO_x SO_x and PM emissions, especially near ports, hence LNG auxiliary power seems plausible. This is advantageous to help adopt LNG in order to reduce carbon dioxide emissions. A potential 2.7% carbon dioxide emission reduction and 1.6% fuel saving (by weight) by switching to LNG auxiliary power is a significant enough incentive, depending mainly on the rigorousness of regional emissions legislation.

Ships with high auxiliary loads, low speeds and/or shorter voyages can maximise the potential of minimising fuel consumption and CO_2 emissions from LNG auxiliary power.

EEDI has been created in order to directly reflect the carbon dioxide emissions of a given ship, but EEDI might be more effective if it were biased towards promoting the development of new technologies. In this way EEDI could factor in risk to account for the low risk “wait and see” attitude of the shipping industry.

In the ship impact study for using LNG for auxiliary power the cargo impact was enough to reduce the CO_2 fuel savings in terms of tonnes of cargo by around 2%. The additional weight of the LNGPac LNG tanks was significant enough to increase the weight of the auxiliary systems by almost half the original fuel oil weight.

Further work is required to assess the possible weight and volume impact of storing LNG compared to diesel oil and existing oil tanks on the CO_2 emission savings and the amount of fuel required.

6. FUTURE WORK

The difference between design conditions and operating conditions (Cerup-Simonsen et al., 2009) is another issue which has not been discussed here but will be relevant to future ship designs that could be designed for lower speeds (reducing the need for slow steaming).

As well as the design speed, the ship size, type and topology (arrangement) will also have an impact on the calculated carbon dioxide emissions saving.

It also may be worth investigating the opportunity to combine LNG with other ship systems, such as using it as a cold sink for air conditioning.

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