A FEASIBILITY MODEL FOR MARINE ENGINES USING ALTERNATIVE FUELS WITH THE EMPHASIS ON COST/EARNING AND EMISSION FIGURES

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ABSTRACT

With diminishing fossil fuel supply, it is not surprising that price of crude oil will continue to escalate. This fact has caused a renewed interest in the search for sustainable and renewable energy sources to reduce our reliance on fossil fuels. The maritime industry has been actively looking alternative fuel for vessels and recent developments are focused mainly on using Liquefied Natural Gas (LNG) for propulsion. LNG is no doubt a good substitute for marine diesel oil in terms of greenhouse gas emission and price but this energy, derived from fossil sources, is also limited in supply. Biofuel has found many successful applications but in the marine industry, it is used only for recreational vessel. This paper investigates the advantage of using *biofuel* in terms of *greenhouse gases emission* and the main reason ship owners are reluctant to use *biofuel* as the primary for their vessels by comparing the *life cycle cost* of a marine engine using marine diesel, 2 types of *biofuel* and LNG.

Keywords: marine engines, alternative fuels, cost/earning and emission figures

NOMENCLATURE

LCC – Life Cycle Cost
MDO – Marine Diesel Oil
B20 – Fuel mixture of 20% biofuel and 80% diesel
B100 – 100% biofuel
LNG – Liquefied Natural Gas
CO – Carbon Monoxide
CO2 – Carbon Dioxide
NOx – Oxide of Nitrogen
SOx – Oxide of Sulphur
HC – Hydrocarbon
M/E – Main Engine
SFOC – Specific Fuel Oil Consumption
DFC – Daily Fuel Consumption
LDCF - Lubrication and Diesel Oil Correction Factor
ACOFc – Annual Cost of Fuel (current)
ACOFe – Annual Cost of Fuel (escalated)
ACOFd – Annual Cost of Fuel (discounted)
NPV – Net Present Value

1. INTRODUCTION

The scarcity of conventional fossil fuels, growing emissions of combustion-generated pollutants and their increasing costs will make bio-fuel more attractive. Petroleum based fuels are limited reserves concentrated in certain regions of the world and these sources are on the verge of reaching their peak production. Fossil fuel resources are depleting day by day. The scarcity of known petroleum reserves will draw greater attention to the benefits of renewable and sustainable energy sources. This project compares the life cycle cost of a slow speed engine using MDO, B20, B100 and LNG over a 25-year period including the cost of engine, projected cost of engine overhaul and cost of fuel. Since there are no large bore engines in the market that runs on bio-fuel, calculations are done based on discussion with experts and representative of marine engine maker.

1.1 PROBLEM

For centuries, mankind has relied on fossil fuel for almost everything such as heating, manufacturing, transportation, power, etc. When Henry Ford invented automobile, his intention was for his invention to run on peanut oil. In 1900, at the World Exhibition in Paris, five years after Rudolph Diesel patented his engine, it was demonstrated running on groundnut oil. This goes to show that the subject of bio-fuel is not new. Early inventors had foreseen the problems with fossil fuel and taken steps to cut Man’s reliance on this limited energy source.

Fossil fuel was the first choice for energy due to its low price; ease of refining, high energy density and the fact that fuel from vegetable oils can never replace the world’s current fossil fuel consumption has prevented biodiesel from being regarded as a realistic alternative fuel. But use of fossil fuel comes at a price.

Drilling and extraction causes irreparable damage to habitats and marine environment; burning of fossil fuel generates greenhouse gases, causes acid rain and oil spills resulting in direct pollution.

With the world’s oil reserve standing at less than 100 years (BP, 24th August 2010) and increasing cost of crude oil, one would have thought that an alternate fuel which is sustainable and renewable be produced and widely use already. Unfortunately, that is not the case.

The figure above, published by British Petroleum (BP), is based on current production rate but world energy is set to increase due to population growth, economic growth and higher standard of living. Governments in some countries might argue that 100 years is a pessimistic estimate and oil supply will definitely last longer than that due to more efficient use of oil. This argument does not change the fact that fossil energy source is limited.

A study conducted by BP show that approximately 60% of oil usage is for transportation purposes. In view of this, more and more countries are substituting part of their transportation fuel source with bio-fuel. Car manufacturers are also producing more hybrid vehicles that are able to run on alternative fuel.

Shipping might be the most environmentally friendly mode of transport with total emissions at only 3% (Greenship Technology, 2010). The fuel ships use is residual oil from refineries therefore the cost is relatively low. However, the fact that this fuel is derived from fossil fuel subjects it to price hikes as availability decreases.

Shipowners are now looking at ways to maintain their profit margin while coping with the continual rise of crude oil prices. One solution is to install engines of high efficiency rating and capable of using alternative fuel. Currently, the best substitute for MDO is biofuel. While biofuel has found many successful applications, it is used only for recreational vessels in the maritime industry. Therefore, a case study of a bulk carrier was done to determine how biofuel measure up against conventional diesel as primary fuel for merchant vessels.

2. WHAT IS BIOFUEL

Bio-fuel is also known as agro-fuel, alternative fuel or non-conventional fuel. Alternative fuels can be defined as any fuel that is not derived from conventional sources like petroleum, coal and natural gas. Main purpose of fuel is to store energy that can be used sometime later. Almost all forms of fuel are chemical fuels having energy in the form of chemical energy, with its end use being to release the energy captured at any time of use.

Bio-fuel is mainly derived from biomass or bio-waste and can be used for any purposes. The most important feature of biomass is that they are renewable sources of energy unlike other natural resources like coal, petroleum and nuclear fuel. Theoretically, bio-fuel can be easily produced from any carbon source; making photosynthetic plants the most commonly used material for production. Two methods are currently in use to produce bio-fuel. In the first method, sugar crops or starch is fermented to produce ethanol. In the second method, oil from natural oil producing plants such as jatropha and algae are extracted and heated to reduce their viscosity. This oil can be used directly as fuel in diesel engines.

Current usage of bio-fuel is mainly in the transportation sector. Vehicles require fuel that provide high power and is dense for easy storage. The fuel should preferably be in liquid form for easy pumping and handling.

Vegetable oil, an example of bio-fuel and energy content close to that of diesel, has been used in diesel engines with indirect injection systems after water and particulates are separated from it. When bio-fuel is mixed with conventional diesel, it is called biodiesel and this fuel is compatible for most diesel engines.

Oxygen content of biodiesel improves the combustion process and decreases its oxidation potential. Structural oxygen content of a fuel improves its combustion efficiency due to an increase in the homogeneity of oxygen with the fuel during combustion. Combustion efficiency of biodiesel is higher that that of petroleum diesel.

Biodiesel contains 11% oxygen by weight and no sulphur. The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel.

Biodiesel is a popular bio-fuel in Europe due to its similarity in composition to mineral diesel. When this two type of fuels is mixed, the mixture can be used in any diesel engine. In several nations, it is observed that engines converted to run on 100% biodiesel are under the same warranty as conventional diesel engines. A large number of vehicle manufacturer even recommend the use of 15% biodiesel with mineral diesel.

Biodiesel can be used in diesel engines either as a standalone or blended with petroleum diesel. Much of the world uses a system known as the “B” factor to state the amount of biodiesel in any fuel mix. For example, fuel containing 20% biodiesel is labeled B20. Pure biodiesel is referred to as B100.

3. METHODOLOGY

The engine selected is RT-flex58T-B (7 cylinders), a slow speed engine manufactured by Wartsila found typically onboard bulk carriers and tankers with a specific fuel oil consumption of 169 g/kWh and maximum engine power of 15820 kW.

With the information in engine data sheet, annual cost of fuel could be calculated. In order to do that, it was important to know the average load on the engine, number of days vessel would be at sea, price of fuel, number of main engine, lubrication and diesel oil correction factor.

When those information were obtained, the calculations were as follows:

(Engine maximum power) x (SFOC) x (Percentage maximum speed) x 24 x 10^{-8} = DFC in tons

(DFC) x (Number of days at sea) x (Price of fuel) x (Number of main engine) x (LDCF) = ACOFc

Escalated values for a particular year were calculated based on the formula:

$$A \times (1 + B)^C \quad (1)$$

Where A = current value, B = escalation rate and C = age of vessel/engine.
Discounted values for a particular year were calculated based on the formula:

$$A \div (1 + D)^C \quad (2)$$

Where D = discount rate.

Current value (A) can be assumed to be the same for all years for calculation of both escalated and discounted values. Escalation and discount rate assumed to be 3% and 8% respectively for all years.

4. EMISSION

Greenhouse gases emission has always been a major area of interest when discussing benefits of alternative energy. A 1998 biodiesel life cycle study, jointly sponsored by US Department of Energy and US Department of Agriculture, concluded biodiesel reduces net CO_2 emissions by 78% compared to petroleum diesel due to biodiesel's closed carbon cycle. Lloyd's Register took part in "Marine Exhaust Emissions Research Programme" initiated by the US Environmental Protection Agency and emissions were tested on 11 slow speed engines installed on 9 vessels. The following emission factors in kg pollutant per ton of fuel were calculated as follows:

NOx = 84 kg/ton fuel
CO = 9 kg/ton fuel
HC = 2.5 kg/ton fuel
CO_2 = 3165 kg/ton fuel
SO_2 = (21.0 x S)
Where S = sulphur content of fuel (% weight)

In a separate test, Ms. Torril Grimstad Osberg of DNV, project manager for Triality tanker, said, "LNG… would reduce CO_2 by around 34% while particulates and SOx would be reduced by 94%, NOx by 82% and volatile organic compounds (VOC) by 100%".

Assuming the values above were obtained based on engines operating at 100% load, emissions of different alternative fuel at various engine loads were calculated (Refer to Table 1).

4.1 CO_2 EMISSION

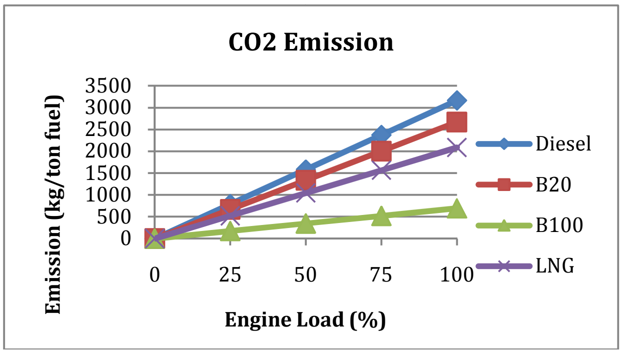

Figure 1: CO2 Emission of Different Fuels

From Figure 1, it is observed that amount of CO_2 emitted when using B20 seems not very encouraging. This might be due to the fact that B20 contains only 20% biodiesel while the other 80% is petroleum diesel. LNG does not reduce CO_2 emission very much either. Emission is significantly less when B100 is used in place of diesel. This reduction is due to biodiesel's closed carbon cycle.

4.2 CO AND HC EMISSION

Referring to Figure 2 and 3, it can be seen clearly that use of biodiesel decreases CO and HC emissions. Reduction in both gases when B20 is used is insignificant due to B20 being predominantly petroleum diesel. Increasing the percentage of biodiesel in the fuel mixture will increase the amount of CO and HC emitted into the environment. If neat biodiesel is used instead, the reduction is almost 50%. CO and HC emission data for LNG was not available so no comparison was done.

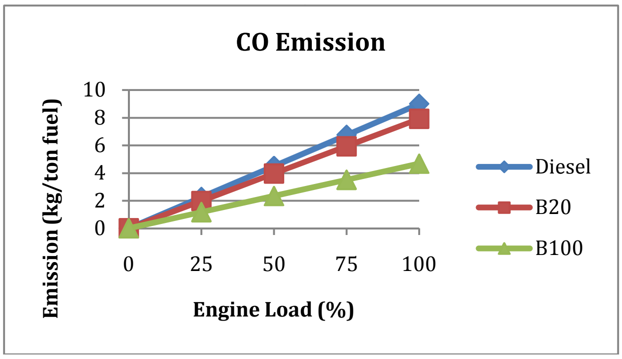

Figure 2: CO Emission of Different Fuels

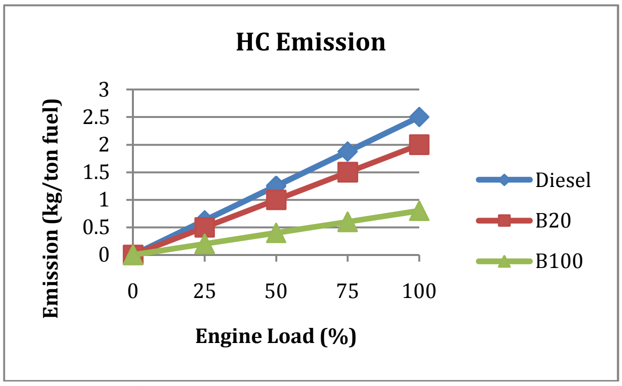

Figure 3: HC Emission of Different Fuels

4.3 SOx EMISSION

Although SOx emission from diesel is only slightly more than 1 kg/ton of fuel, switching to B100 would solve the problem of acid rain caused by SOx since there is no sulphur present in biodiesel. LNG fuel fare very well as its SOx emission is also very low, less than 10% of the amount diesel is emitting, despite being also derived from fossil fuel source (Figure 4).

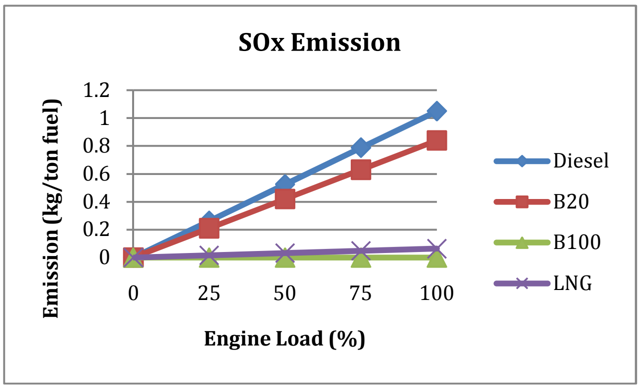

Figure 4: SOx Emission of Different Fuels

4.4 NOx EMISSION

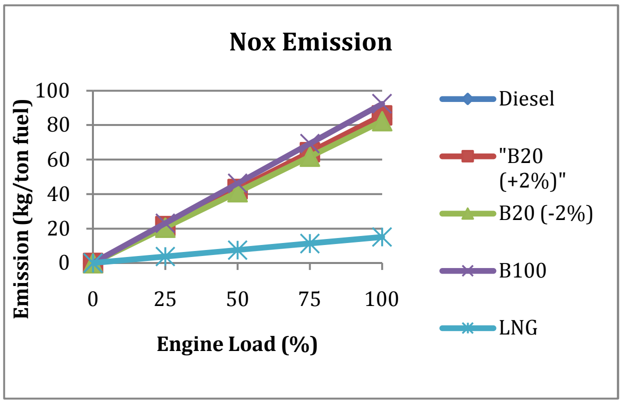

Figure 5: NOx Emission of Different Fuels

It can be seen from Figure 5 that B100 emits more NOx that diesel. This is not surprising since biodiesel is a more oxygenated fuel than diesel and more oxygen will react with nitrogen gas during combustion to produce NOx. Solutions to this problem are already available in the form of Selective Catalytic Reduction (SCR), which is capable of reducing NOx emission by up to 80% and converting the gas into harmless nitrogen and water vapour. NOx emission for B20 either increase or decrease by about 2% compared to diesel depending on temperature of combustion in the engine's combustion chamber.

5. CASE STUDY OF BULK CARRIER

Bulk Carrier (70,000 DWT), with lifespan of 25 years, will carry food grain from Port of Novorossiysk, Russia to Cape Town, South Africa and feed grain on return (Igor Zarembo, 2010), at a speed of 15 knots (75% max speed). Each voyage requires 36 days and 16 hours (www.searates.com) and port stay at each port is assumed to be 7 days. Total number of voyages each year is 7 therefore total number of days vessel is 'at work' each year is 355 days (257 days at sea, 98 days in port). During year of special survey, 6 voyages were taken and total number of days vessel 'at work' is 304 days (220 days at sea, 84 days in port).

5.1 (a) Cost of diesel

Engine maximum power: 15820 kW
SFOC: 169 g/kWh
% maximum speed: 75%
DFC: 15820 x 169 x 75 x 24 x 10^{-8} = <u>48.1 ton</u>

Price of fuel: USD 673.5 (Bunkerworld, 15/04/2011)
Days at sea: 257
Number of main engine: 1
LDCF: assumed to be 1.1

ACOFc: 673.5 x 48.1 x 257 x 1 x 1.1= 9,162,819
ACOFe: 9,162,819 x $(1+0.03)^{1}$ = 9,437,703
ACOFd: 9,437,703 / $(1+0.08)^{1}$ = 8,738,614

NPV of fuel: <u>8,738,614</u>

The above calculation is done when the vessel is at age 1. The same is done for every year vessel is in service up to age 25. Total NPV of fuel cost over lifespan is approximately <u>USD 128,025,439</u>.

5.1 (b) Cost of b20

Engine maximum power: 15820 kW
*SFOC: 172.38 g/kWh
% maximum speed: 75%
DFC: 15820 x 172.38 x 75 x 24 x 10^{-8} = <u>49.1 ton</u>

**Price of fuel: USD 673.5
Days at sea: 257
Number of main engine: 1
LDCF: assumed to be 1.1

ACOFc: 673.5 x 49.1 x 257 x 1 x 1.1 = 9,346,075
ACOFe: 9,346,075 x $(1+0.03)^1$ = 9,626,457
ACOFd: 9,626,457 / $(1+0.08)^1$ = 8,913,386

NPV of fuel: 8,913,386

The above calculation is done when the vessel is at age 1. The same is done for every year vessel is in service up to age 25. Total NPV of fuel cost over lifespan is approximately USD 130,585,948.

**SFOC assumed to increase by 2% due to lower heating content of biofuel*
***Price stays the same, as fuel is predominantly diesel.*

5.1 (c) Cost of b100

Engine maximum power: 15820 kW
*SFOC: 185.9 g/kWh
% maximum speed: 75%
DFC: 15820 x 185.9 x 75 x 24 x 10^{-8} = 52.9 ton

Price of fuel: USD 128.61
Days at sea: 257
Number of main engine: 1
LDCF: assumed to be 1.1

ACOFc: 128.61 x 52.9 x 257 x 1 x 1.1 = 1,924,630
ACOFe: 1,924,630 x $(1+0.03)^1$ = 1,982,369
ACOFd: 1,982,369 / $(1+0.08)^1$ = 1,835,527

NPV of fuel: 1,835,527

The above calculation is done when the vessel is at age 1. The same is done for every year vessel is in service up to age 25. Total NPV of fuel cost over lifespan is approximately USD 26,891,461.

**SFOC assumed to increase by 10% due to lower heating content of biofuel*

5.1 (d) Cost of lng

According to US Energy Information Administration (EIA), price of 1 million British Thermal Unit (MMBtu) of LNG rose to 4.55 USD for the week ending 13th April 2011.

1 trillion Btu = 1,000,000 million Btu
cost 4,550,000 USD

1 trillion Btu = 20,000 million tons LNG
= 25,000 million tons oil equivalent

Since 1 ton = 0.90718 tonne

25,000 million ton LNG will be equivalent to 22,679,618,500 tonne costing 4,550,000 USD

HFO has a calorific value (CV) of 38.9 MJ/litre. Since selected engine has a specific fuel oil consumption (SFOC) of 169 g/kWh, 169 grams of HFO will produce 6574100 J/kWh.

1 Btu = 1055 Joules

6574100 Joules = 6231.4 Btu

Therefore, assuming SFOC of selected engine remains the same when switched to using LNG as primary fuel, fuel consumption would be equivalent to 6231.4 Btu/kWh.

Engine maximum power: 15820 kW
SFOC: 6231.37 Btu
% maximum speed: 75%
DFC: 15820 x 6231.37 x 75 x 24 x 10^{-8}
= 1774 MMBtu

Price of fuel: USD 4.55
Days at sea: 257
Number of main engine: 1
LDCF: assumed to be 1.1

ACOFc: 4.55 x 1774 x 257 x 1 x 1.1 = 2,282,443
ACOFe: 2,282,443 x $(1 + 0.03)^1$ = 2,350,917
ACOFd: 2,350,917 / $(1 + 0.08)^1$ = 2,176,775

NPV of fuel: USD 2,176,775
The above calculation is done when the vessel is at age 1. The same is done for every year vessel is in service up to age 25. Total net present value of cost of fuel over 25 years came up to approximately USD 31,890,932

5.2 LIFE CYCLE COST

All marine vessels need go through an annual survey and a special survey every 5 years. Shipowners usually overhaul the engine of their vessels during year of special survey so as not to take unnecessary time off in the previous 4 years and 'interrupt' inflow of earnings. Engine needs to be overhaul to maintain its efficiency, fuel consumption, minimize risk of explosion and reset to minimum factory specifications.

According to representative from marine engine manufacturer, overhaul of engine normally requires:

a) 16-20 hours per cylinder
b) 6-8 person for the overhaul
c) Approximately 10 days
d) $75 per hour per person on a weekday
e) $85 per hour per person for overtime
f) $95 per hour per person on weekends

It was therefore assumed:

a) 7 person working on engine
b) Engine has 7 cylinders
c) 18 hours to overhaul a cylinder
d) Total required hours = 18 x 7 = 126 hours
e) 10 days to overhaul engine

f) Total weekday working hours including 4 hours overtime per day = 14 x 8 =112 hours
g) Total required working hours on weekends = 126 – 112 = 14 hours

Using the same assumed escalation and discount rates, a life cycle spending on engine, engine modification, engine overhaul and fuel was calculated. Cost of engine was assumed to be 1.5 million USD regardless of fuel used. Modification for engine using B100 comes in the form of an oil-water separator and this machinery was assumed to cost 35,000 USD. Table 2 shows a typical cost breakdown for engine overhaul for the selected engine while table 3 showed the NPV of life cycle cost of engine overhaul for diesel, B20 and LNG engines. Engines running on B100 would require more frequent oil change and maintenance therefore it was assumed that engine overhaul was done every 3 years for engine running on B100 (Table 4). Comparison of LCC for engines running on different types of fuel is shown in Table 5.

6. EARNINGS

Charter rate of Panamax vessel as at 8th March 2011 increased to USD 16,435/day (www.fairplay.co.uk). Assuming the rate stays the same throughout, income for 1st year (355 days) from chartering will add up to USD 5,834,425. NPV of income for the whole life cycle is equivalent to USD 81,524,301 based on the following assumptions:

a) Bulk carrier sail at 75% of maximum power all the time.
b) Charter rate stays the same throughout life cycle of vessel.
c) Charter rate stays the same regardless of primary fuel used.
d) Market rate of carbon credit stays the same throughout vessel life.
e) Escalation rate stays at 3%.
f) Discount rate stays at 8%.
g) Amount of CO_2 emitted is constant throughout life cycle of engine
h) Fuel consumption stays the same despite age of engine.
i) Fuel consumption stays the same regardless of primary fuel used.
j) Vessel in use for all of 25 years.

Additional earning comes from sale of carbon credit at prevailing market rate of Euro 14.5/ton (http://noir.bloomberg.com) or USD 20.11/ton based on 2nd March 2011 exchange rate (www.xe.com).

The carbon credit system was ratified in conjunction with the Kyoto Protocol to stop the increase of carbon dioxide emissions. Countries or groups have an emission quota based on their nature of business or activities. A credit is awarded to these countries or groups for every ton of greenhouse gas reduced below their emission quota. Carbon credit can be traded in the international market at their current market price. For example, an environmentalist group plants enough trees to reduce emission by 1 ton, that group is awarded a credit. A shipping company has an emission quota of 110 tons for one of its ship but that ship expecting to produce 111 tons; the shipping company can purchase the carbon credit from the environmental group.

The carbon credit system looks to reduce emissions by having countries honour their emission quotas and be offered incentives for being below the quota.

From previously found information, ship operating at 75% full power approximately 115 ton of CO2 a day (MDO). If fuel is switched to B20, B100 and LNG, CO2 emission is reduced to 99 tons, 28 tons and 14 tons respectively. NPV of income from carbon credit sale equates to USD 1,201,889 for B20, USD 6,535,271 for B100 and USD 7,586,924 for LNG. Table 6 shows the profit and loss comparison for a 70,000 DWT bulk carrier using different fuel throughout its lifespan. Apparently, based on the parameters considered, using either LNG or B100 provide shipowners with profits between 55-59 million USD.

7. CONCLUSIONS

This paper aims to investigate if it was possible for low speed engines to run on biofuel to cut reliance on fossil fuel and reduce greenhouse gases emission. Results obtained show that use of biofuel in slow speed marine engine is indeed possible with the addition of an oil-water separator due to biofuel's affinity with water.

A case study of a 70,000-dwt Bulk Carrier transporting food grain from Port of Novorossiysk, Russia to Cape Town, South Africa and transport feed grain from Cape Town, South Africa to Port of Novorossiysk, Russia was done to make the study as realistic as possible.

Cost of engine was assumed to be $1.5 million, escalation and discount rate were assumed to be 3% and 8% respectively and cost of engine overhaul was assumed to be the same regardless of fuel used. Engine using B20 and B100 had its SFOC increased by 2% and 10% respectively due to lower heat content of biofuel. LNG engine was assumed to consume the same amount of fuel as diesel engine.

Diesel, B20 and LNG engines were assumed to undergo overhaul every 5 years to coincide with special survey and minimize time taken off hire. For B100 engine, it undergoes overhaul every 3 years due to the need for more frequent oil change and maintenance.

It was observed that LNG, despite being the more popular choice of alternative fuel, was only 4 times cheaper than marine diesel while B100 was 5 times cheaper. Considering just the cost of fuel, engine, overhaul and earnings from sale of carbon credit and vessel charter, only B100 and LNG would provide any form of profit for owners, with B100 providing almost $4 million more than LNG based on calculated net present value. Earnings from vessel charter were about $82 million regardless of types of fuel used.

Earnings from carbon credit sale was dependent on amount of carbon reduced compared to diesel when different fuel was used. Emission factors in kg pollutant per ton of fuel measured by Lloyds Register as part of Analysis of Commercial Marine Vessel Emission and Fuel Consumption Data were used for greenhouse gases emission comparison and the figures were assume to be based on 100% power.

In conclusion, results obtained show that using biofuel in place of diesel for slow speed engines is possible. However, issues such as quantity of biofuel produced prevent the switch from conventional fuel to sustainable alternative fuel. From table 6, it can be seen that using B100 as primary fuel would provide shipowners with a profit of almost 60 million USD. This is possible only because of a sudden increase in cost of crude oil while price of biofuel decreases compared to being usually 12-15% more expensive than diesel. This price fluctuation shows the stability of price of biofuel, especially when trading price of crude oil in the market is very volatile. Although care was taken to ensure values used for calculations were relevant, market fluctuations prevent these values to be updated and accurate.

In terms of emission, despite certain data being unavailable, it is obvious that use of alternative fuel greatly reduce amount of greenhouse gases emitted into the environment, especially when the alternative fuel contains high concentration of biofuel.

With certain issues of biofuel yet to be resolved, LNG seems to be the current best alternative for conventional fuel. However, with LNG being also limited in supply, price increase is inevitable and it will not be long before price of LNG becomes too high for shipowners to bear.

8. RECOMMENDATIONS

More would have to be done to encourage the use of biofuel in the maritime industry, especially in the commercial sector. A few recommendations would be:

1. Increase biofuel production to ensure sufficient supply and stablilise price of the fuel.

2. Increase cultivation of hardy non-food crops and gradual switch to such crops for biofuel production to convince general public that quantity of food crops is sufficient and food prices would not increase.

3. Government to offer more incentives for biofuel production startup or hold a stake in biofuel production plant, policies to increase biofuel percentage in biodiesel blend, offers incentives for people to use biofuel.

4. Engine makers could extend their product warranty for engines running on biofuel provided the fuel is sourced from reputable producer.

Furthermore, use of biofuel benefits the environment. Carbon emission could be reduced due to biofuel's closed carbon cycle. This means that carbon emitted during biofuel production and combustion would be absorbed during the cultivation of crops meant for fuel production.

Acid rain caused by reaction of water vapour and sulphurous oxides from engine exhaust could be eliminated due to absence of sulphur in biofuel. Increase in nitrous oxides in exhaust could be mitigated by efficient scrubber systems currently available in the market.

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Table 1: Emission of Greenhouse Gases of Different Fuels of a Slow Speed Engine (EPA, 2000 and National Biodiesel Board, 2011)

Fuel Type		Diesel	B20		B100	LNG
Emission	Load (%)	Kg/ton fuel	Kg/ton fuel		Kg/ton fuel	Kg/ton fuel
			+2%	-2%		
NOx	100	84	85.68	82.32	92.4	15.12
	75	63	64.26	61.74	69.3	11.34
	50	42	42.84	41.16	46.2	7.56
	25	21	21.42	20.58	23.1	3.78
	0	0	0	0	0	0
HC	100	2.5	2		0.8	-
	75	1.875	1.5		0.6	-
	50	1.25	1		0.4	-
	25	0.625	0.5		0.2	-
	0	0	0		0	-
SOx	100	1.05	0.84		0	0.063
	75	0.7875	0.63		0	0.047
	50	0.525	0.42		0	0.032
	25	0.2625	0.21		0	0.016
	0	0	0		0	0
CO	100	9	7.92		4.68	-
	75	6.75	5.94		3.51	-
	50	4.5	3.96		2.34	-
	25	2.25	1.98		1.17	-
	0	0	0		0	-
CO2	100	3165	2671.26		696.3	2088.9
	75	2373.75	2003.445		522.225	1566.675
	50	1582.5	1335.63		348.15	1044.45
	25	791.25	667.815		174.075	522.225
	0	0	0		0	0

Results for B20 estimated from B100

Data not available

Fuel chosen is RME/F-25 diesel fuel with sulphur content at maximum 5% mass

Table 2: Cost of Service Breakdown

Engine			**Assume:**		
Lifespan	25	years	**Weekday working hours**	10	hours/day/pax
No. of cylinders	7	Cylinders	**Weekday overtime**	4	hours/day/pax
Overhaul	4	(once every 5 years up till 20th year)	**Weekend working hours**	8	hours/day/pax
Overhaul			**Total required hours**	126	
Manpower	7	pax (normally 6-8)	**Total weekdays working hours**	80	
Days required	10	approximate	**Total weekdays overtime**	32	
1 cylinder unit	18	hours (normally 16-20)	**Required weekend hours**	14	
Rate			**Cost of overhaul**	70350	
Manpower	75	per hour per pax	**Cost of overhaul + 5%**	73867.5	
	85	per hour per pax (overtime)	**Nearest thousand**	74000	
	95	per hour per pax(weekend)			

Table 3: NPV of Cost of Service for Diesel, B20 and LNG Engine
Exchange rate as at 17/04/2011 from www.xe.com

Cost of engine overhaul at year:	Escalate at 0.03	Discount at 0.08	
5	85,786.28	58,384.70	
10	99,449.81	46,064.51	
15	115,289.59	36,344.09	
20	133,652.23	28,674.85	
Total cost for large bore engine and engine + B20 =		**169,468.14**	**SGD**
(Cost for overhaul of LNG engine assume the same)		**136,327.04**	**USD**

Table 4: NPV of Cost of Service for B100 Engine
Exchange rate as at 17/04/2011 from www.xe.com

Assuming engine is overhauled once every 3 years when used with B100			
		Escalate at 0.03	Discount at 0.08
Cost of engine overhaul at year:	3	80,861.80	64,190.70
	6	88,359.87	55,681.71
	9	96,553.22	48,300.65
	12	105,506.31	41,898.01
	15	115,289.59	36,344.09
	18	125,980.05	31,526.38
	21	137,661.80	27,347.31
	24	150,426.76	23,722.20
Total cost of engine running on B100 =	**329,011.04**	**SGD**	
	264,669.81	**USD**	

Table 5: Total cost of Engine

	Diesel Engine	**Engine + B20**	**Engine + B100**	**Engine + LNG**
			$	
Price	1,500,000	1,500,000	1,500,000	1,500,000
Cost of Modification	0	0	35,000	0
Cost of Overhaul	136,327	136,327	264,670	136,327
Total cost of fuel	128,025,439	130,585,948	26,891,461	31,890,932
Total (USD)	**129,661,766**	**132,222,275**	**28,691,131**	**33,527,259**

Table 6: Profit/Loss comparison of different fuels

Fuel Type	**Diesel**	**B20**	**B100**	**LNG**
Power Load (%)	75	75	75	75
Cost of Fuel (USD)	128,025,439	130,585,948	26,891,461	31,890,932
Cost of service (USD)	136,327.04	136,327.04	264,669.81	136,327.04
Cost of engine (USD)	1,500,000	1,500,000	1,500,000	1,500,000
Cost of modification (USD)	0	0	35,000	0
Earnings from carbon credit sale (USD)	0	1,201,889	6,535,271	7,586,924
Income (USD)	81,524,300.97	81,524,300.97	81,524,300.97	81,524,300.97
Profit/Loss	**-48,137,465.2**	**-49,496,085.1**	**59,638,441**	**55,583,965.4**

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