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A strategic development of alternative fuel initiation and its adaptation in a developing country: a feasibility study on methanol fuelled domestic passenger ships in Indonesia

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A STRATEGIC DEVELOPMENT OF ALTERNATIVE FUEL INITIATION AND ITS ADAPTATION IN A DEVELOPING COUNTRY

A feasibility study of methanol fuelled domestic passenger ships in Indonesia

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Dissertation Declaration

I certify that all the material in this dissertation that is not my work has been identified and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my personal views and are not necessarily endorsed by the University.

(Signature): EKO MAJA PRIYANTO

(Date) : 18 September 2017

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Abstract

Title of Dissertation: **A strategic development of alternative fuel initiation and its adaptation in a developing country: A feasibility study of methanol fuelled domestic passenegr ships in Indonesia**

Degree: MSc

The study aims to provide insight and to explore the future potential of methanol as an alternative marine fuel for domestic passenger ships in Indonesia. An overview of methanol characteristics as fuel and the current status of global methanol-fuelled passenger ships, including the technology availability and regulation development, will be examined. For potential application in Indonesia, an analysis of resources availability, stakeholder readiness, and potential challenges are investigated.

The potential performance of methanol technology is discussed and divided into two perspectives: the shipowner perspective and the government perspective through case studies of two passenger ships owned by PELNI, MV. Labobar and MV. Gunung Dempo. As shipowners tend to look at the industrial-economic aspects, an economic feasibility is performed by developing a combinatorial scenario approach based on the combination of economic measures of merit (NPV and payback period) and technical scenario (main-pilot fuel set up). Some of the variables are included in the calculation, such as ship age, ship productivity, and macro-economy conditions. Regarding government perspectives, the environmental protection and policy compliance are evaluated by examining six emission types (NOx, SOx, CO_2, CH_4, N_2O, and PM). Additionally, since there is a trade-off situation in government subsidies between the government and shipowner interests, the optimization and sensitivity analysis is performed by utilizing a combinatorial scenario model to determine optimum methanol price and external variables influencing the decision to support methanol technology in the Indonesian market.

The study found that Indonesia has some advantage to introduce methanol as marine fuel. However, methanol competitiveness is mainly dependent on ship productivity and the price differences between methanol and MDO. Moreover, policy analysis through the optimization approach could be one of the government approaches to determine the optimum condition in establishing methanol as marine fuel. Additionally, the short, medium, and long term recommendation is given as consideration.

KEYWORDS: Methanol, marine fuel, passenger ship, combinatorial scenario analysis, policy compliance, subsidies, techno-economic calculation

Table of contents

List of tables

List of figures

List of abbreviations

BFIV	=	Booster fuel injection valve
BGI	=	Geological agency of Indonesia
BKI	=	Biro klasifikasi Indonesia
BLG	=	IMO Sub-committee on bulk liquids and gases
BP	=	British Petroleum
CCC	=	Sub-committee on carriage of cargoes and containers
CCTV	=	Closed-circuit television
CH_4	=	Methane
ClassNK	=	Nippon kaiji kyokai
CO_2	=	Carbone dioxide
CPO	=	Crude palm oil
DGST	=	Directorate general of sea transportation
DIKH	=	Directorate of upstream chemical industry
DNV-GL	=	Det norske veritas - Germanischer lloyd
EBTD	=	Earning before taxation and depreciation
ECA	=	Emission control area
EEDI	=	Energy Efficiency Design Index
EEOI	=	the Energy efficiency operational indicator
EMSA	=	European maritime safety agency
ESDM	=	Ministry of energy and mineral resources
EU	=	European Union
GHG	=	Greenhouse gas
HFO	=	Heavy fuel oil
IBC Code	=	International code for the construction and equipment of ships carrying dangerous chemicals in bulk
IFO	=	Intermediate fuel oil
IGF Code	=	International code of safety for ships using gases or other low-flashpoint fuels
IMO	=	International maritime organization
ISO	=	International standards organization

KMI	=	Kaltim methanol industry
LCC	=	Low cost carrier
LFL	=	Low flammable limit
LFO	=	Light fuel oil
LHV	=	Lower heating value
LNG	=	Liquefied natural gas
LPG	=	Liquefied petroleum gas
LR	=	Lloyd register
MARPOL	=	the International convention for the prevention of pollution from ships
MDO	=	Marine diesel oil
MGO	=	Marine gas oil
MMBD	=	Million barrels per day
MoS	=	EU Motorways of the sea
MSC	=	the Maritime safety committee
Mtoe	=	Million tons oil equivalent
N_2O	=	Nitrous oxide
NOx	=	Nitrogen oxides
NPV	=	Net present value
PELNI	=	Pelayaran nasional shipping company
PHE	=	Public health England
PM	=	Particulate matter
POME	=	Palm oil mill effluent
PPC	=	partially premixed combustion
PTO/PTI	=	Power take off/ power take in
RAN-GRK	=	National action plan for reducing greenhouse gas emissions
RISE	=	the Research institute of Sweden
RoPax	=	Roro passenger
SCR	=	Selective catalytic reduction
SEEMP	=	Ship energy efficiency management plan
SFOC	=	Specific fuel oil consumption
SKK Migas	=	Special Task Forces For Upstream Oil and Gas Business Activities Republic of Indonesia

SOLAS	=	the International convention for the safety of life at sea
STCW	=	the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TDC	=	Top dead center
TSCF	=	Trillions of standard cubic feet
UNEP	=	the United Nations environment program
ZVT	=	Zero vision tool

1. Introduction

1.1 Background

The availability of energy in the future has recently come to the world's attention. One of the reasons that the energy issue is becoming a hot topic in all the nations of the world is that global energy demand tends to increase more rapidly than the available resources. Also, increasing energy consumption, especially fossil fuel consumption, leads to negative environmental impacts. Therefore, the United Nations endeavours to facilitate sustainable and clean energy implementation by addressing energy issues in the 7th[1] Goal of its 17 Sustainable Development Goals, with some specific targets[2].

Global energy consumption rose significantly from 8,133.34 million tons oil equivalent (Mtoe) in 1990 to 12,928.39 Mtoe in 2014, where developing countries are to be the main contributors in driving the energy consumption (BP, 2016a). Indonesia, as a developing country, also experienced an energy consumption increase of 3.9% in 2015, or almost double compared to the last 15 years (BP, 2016b). In addition, non-renewable energy sources (oil, coal, and gas) still dominate

[1] 7th Goal of "17 Sustainable Development Goal: Ensure access to affordable, reliable, sustainable and modern energy for all"

[2] One of Sub Target of Goal 7th is "By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology"

the energy supply in Indonesia, representing 75% of the energy consumption (Hasan et al, 2012).

Currently, the Indonesian government is paying more attention to its high dependency on fossil energy, particularly in fuel oil. According to the 2015 annual report revealed by SKK MIGAS[3], between 2003 and 2015, the reserve of oil and gas in Indonesia declined by approximately 91 Mtoe per year (SKK, 2015). In contrast, Indonesia's oil consumption for domestic purposes has increased from 1.2 million barrels per day (MMBD) in 2003 to 1.6 MMBD in 2013. It is projected to continue rise by 5-6% untill 2030. At that time, the domestic production will be unable to meet the domestic demand and Indonesia will have to import up to 75% of its oil supply to fulfill the domestic demand (Budiman, 2014). High dependency combined with unstable oil prices might expose the country to greater energy security risks. Thus, Indonesia may become more vulnerable to future supply or price shocks.

According to data in the Indonesian energy profile of 2015, prepared by the Ministry of Energy and Mineral Resources (ESDM), the transportation sector consumed almost 329.41 Mboe or 32% of total energy consumption (ESDM, 2016). Since Indonesia is an archipelagic country, consisting of over 17,000 islands, domestic marine transportation plays a key role in transporting goods and people across the country. This requires goods and people to be transported approximately 2000 times, using domestic maritime transportation that consumes approximately 7000 barrels of bunker fuel per day (Budiman, 2014). Dependency on fossil fuel in the unstable oil price conditions can lead to disruption in the maritime sector, where the transportation of goods and people across the country will be affected, and economic growth declined.

Interestingly, Singapore, as the closest country to Indonesia, has initiated the implementation of a strategic step of environmental protection in the maritime sector called "The Maritime Singapore Green Initiative Programme". This program could pave the way to the first implementation of an Emission Control Area (ECA) in South East Asia. When the ECA is imposed, it might influence the shipping industry in

[3] Special Task Forces For Upstream Oil and Gas Business Activities Republic of Indonesia

South East Asia, particularly in Indonesia, where almost 97% of the energy used in the transport sector is using fuel oil that much generate air pollution (ESDM, 2012).

Strategic initiatives and measures have also been taken by the Indonesian government to overcome the problem related to sustainable energy and reduced greenhouse gas (GHG) emissions by initiating the "National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GRK)". In order to follow up the strategic plan, stakeholder focus group discussions and studies on the energy issue in the maritime transportation sector have been undertaken. Almost all of the studies have emphasized a shift to liquefied natural gas (LNG) as a ship fuel, but the use of it has not taken up yet. Even though LNG is produced on some big islands in Indonesia, it cannot currently supply the domestic demand. The main cause is the lack of LNG fuelling facilities and infrastructure because establishing the facilities and infrastructures requires a huge investment (Budiman, 2014).

Since the use of LNG in the Indonesian maritime sector is still under discussion, other alternative fuels need to be introduced to reduce dependency on fossil fuel while addressing environmental issues. Methanol is a promising alternative and sustainable fuel for the future shipping industry since it can be produced from various resources: natural gas, biomass, synthesis gas, and coal (Zhen, 2015). If the resource is biomass, methanol is much more GHG friendly than LNG. Additionally, methanol has a similar positive reduction of air pollution (NOx, SOx, and PM) to LNG and can comply with NOx Tier II requirements without any major conversion (Stojcevski, 2014). Also, based on Stena Line experience, a methanol fuel system does not require any cryogenic processes or equipment. Thus, dual fuel methanol conversion from existing ships is easier and cheaper than conversion to LNG (Westling, 2013).

Different ship types might have different approaches to safety and technology application (IMO, 2016e), so it is necessary to determine the ship type that will be this research object. According to the geographical characteristics of Indonesia, ease of observation, and also the economical point of view, one of the best ship types that can be applied as a case study of methanol application is the passenger ship. Passenger ships are well known in developing countries, especially

Indonesia, as one of the best means of transport to connect islands. In addition, ships have liner routes and routine bunkering makes it easy to predict and to monitor their activities. Moreover, an alternative fuel needs to be introduced because passenger ships in Indonesia are heavily dependent on fossil fuel and very sensitive to fluctuations in fuel oil prices. However, as with any new fuel, attention has to be paid to certain potential risk characteristics, such as low-flashpoint and toxicity because passenger ships have stringent requirements in safety regulations related to passenger safety and risks associated with fuel application.

Projects considering methanol as ship fuel has been executed in some European countries and IMO has published reports regarding methanol-fueled ships. Still, the study of methanol as ship fuel is not as massive as LNG as fuel, particularly when it comes to cost-benefit analysis of converting the propulsion system and combined with the evaluation of energy efficiency of the converted system. Moreover, there is no study of methanol application in ships in developing countries, intending to develop strategic adaptation, planning, and implementation of it for sea transportation. A thorough analysis, including economic, environmental, and technological aspects of methanol-fuelled ships compared with resource availability and stakeholder readiness in developing countries is highly needed.

1.2 Objectives

According to the aforementioned background, this study aims to provide overall insight and to explore the future potential of methanol as an alternative marine fuel for domestic passenger ships in Indonesia. Furthermore, the specific goals of the study are to provide relevant information on the following topics:

- To identify the current status of implementation of methanol as marine fuel worldwide including supporting regulation.
- To identify the existing and potential resources of methanol in Indonesia.
- To assess the economic viability of the application of methanol fuel systems onboard passenger ships in Indonesia.
- To examine the challenge in implementation of methanol as fuel on passenger ships regarding supply chain, safety issues based on methanol characteristics, strategic cooperation, and regulation in Indonesia.

- To propose recommendations and insight for the Indonesian government and related stakeholders to consider methanol as a promising marine fuel in domestic passenger ships.

1.3 Scope of study and methodology

This study will only focus on methanol as a substitution for fossil fuels applied to maritime transportation, particularly focusing on passenger ships. The study does not attempt to perform analyses on all methanol applications onboard, for instance, fuel cell technology on board as fuel. The analysis focuses extensively on the application of methanol in the direct internal combustion engine. The study is concentrated on the Indonesian market, and it does not consider other markets.

In this study, the information regarding the current status of methanol-fuelled passenger ships in the world and the potential of methanol resources in Indonesia will be gathered through a secondary data collection and interviews with experts in relevant fields. The resources include annual reports and statistical data from relevant stakeholders, IMO Guidelines and reports, journals, government policy and regulation document, previous project reports, and other approved literature from experts in relevant fields.

In order to understand to what extent, in terms of economy and regulations, the implementation of methanol as passenger ship fuel can be introduced and supported in the Indonesian market, a case study will be conducted on two passenger ships owned by Pelayaran Nasional (PELNI). Interviews and communication will be conducted with PELNI in order to get the primary data. Also, communication will be conducted to the industrial experts that are closely relevant to the specific case study in order to gain relevant information, for instance: Wartsila.

Furthermore, necessary information and data gathered during the comparative study and the interviews, producing the basis for measuring economic and technical viability of a fuel shift and technology investment using techno-economic calculation. The measures of merit will be based on Net Present Value formula, Payback period approach, and combinatorial scenario analysis (NPV and payback period of ship modification versus Price of Methanol versus The percentage of dual fuel).

In addition, optimization analysis using OptQuest-Cristal Ball will be used in order to identify the optimum support from the government to the market in order to introduce methanol as a clean and more sustainable maritime fuel.

1.4 Structure and organization

In order to achieve and accomplish the objectives of this study, this dissertation is organized and divided into the following sections:

Chapter 1 will introduce a background and objectives as to provide a better understanding of the necessity of this study. The scope of the study and the methodologies used are also explained briefly in this chapter.

Chapter 2 will provide a literature review regarding fundamental information of methanol, general development of the methanol market, previous related projects, research, or reports that have been performed, to be used as the basis of modeling and optimizing the case study.

Chapter 3 will present the characteristics and concept of handling methanol as fuel in an internal combustion engine. Moreover, this chapter will present the current status of methanol as a marine fuel in passenger ships, including the overview of technology readiness. The current status of international regulations which support the implementation of methanol as a marine fuel will be reviewed.

Chapter 4 will discuss the potential implementation and challenges of methanol fuelled passenger ships in Indonesia. Firstly, the market condition of Indonesian domestic passenger ships will be explained. Secondly, the potential resources of methanol production in Indonesia will be examined, both from renewable and non-renewable resources. Finally, the potential challenge dealing with the implementation of methanol as a marine fuel in Indonesia will be analyzed in terms of administratives burden, supply chain, and regulation gap.

Chapter 5 will provide a techno-economic and a decision-making analysis through a case study of passenger ships owned by PELNI. This chapter will discuss how and to what extent methanol can be introduced in the Indonesian market. Furthermore, the discussion will be divided into two perspectives: the shipowner perspective and the government perspective. The discussion will also address the outcome of the decision-making analysis whether the technology solution is feasible from an economic point of view and deserve to have support from the government.

Finally, Chapter 6 will present an overall conclusion and compile the recommendations for short, medium, and long term for the Indonesian government and related stakeholders.

2. Literature review

Methanol is commonly referred to as wood alcohol or methyl alcohol with the chemical formula CH_3OH. In the market often abbreviated as MeOH (Olah, Goepert, and Prakash, 2006). Methanol is a simple single-carbon alcohol, colorless, and biodegradable. However, methanol is highly flammable with a flash point around 11°C, and also very toxic (Methanol Institute, 2017).

Methanol can be produced from fossil based resources (non-renewable) to renewable and sustainable resources, for instance wood, biomass, sewage, and also from CO_2 (Bromberg & Cheng, 2010). There are three basic steps commonly used by industry to produce methanol, namely synthetic gas (syngas) production, syngas to methanol conversion, and distillation or purification of effluent. The sources of synthetic gas can be natural gas, coal, biomass, crude oil, or other carbon based sources. Despite this, the industry still prefers natural gas or methane as the feedstock since the production cost, energy consumption, and impurities are lower than the other feedstock (Bozzano & Manenti, 2016)

The evolution of the market and research for methanol as transportation fuel was started during World War I when gasoline shortage happened in Europe (Reed & Lerner, 1973). Afterwards, methanol became attractive during the first oil crisis in the 1970's (Haraldson, 2015). In 1982, ten automotive producers in the United States initiated to produce 16 different models of automobiles to investigate the compatibility of methanol as fuel. The comparison with fully gasoline vehicles was conducted, and the result was comparable since the performance and emission reduction has increased by using methanol. Based on the results of the initial program, the Ford company started to produce methanol fueled vehicles.

Surprisingly, the methanol consumption for US transportation reached 12 million gallons in 1993. Afterwards, in 2005 following 200 million miles of methanol based vehicle operation and 25 years implementation, methanol as fuel was stopped by the US government due to plummeting oil prices causing methanol no longer attractive to the industry and no incentive from the government to continue the methanol program in the transport sector (Bromberg & Cheng, 2010).

The use of methanol in large diesel engines, particularly in ship propulsion engines is relatively novel but has been supported by laboratory research and real operation testing. One of the successful pilot projects was Pilot Methanol. The project was converting the main engine of the passenger ship “Stena Germanica”, owned by Stena Lines, which has a route Gothenburg Sweden – Kiel Germany (Ellis & Tanneberger, 2015).

There are also some laboratory research for methanol study conducted by academia. Svensson et al (2016) analyzed the indication of emission development from methanol combustion in diesel engines operated on the concept of partially premixed combustion (PPC) mode by simulation and modeling, then validated by experiment. The results obtained with the concept of PPC mode, was that when the machine ran with methanol, it would be less likely to form soot, which is the opposite of diesel fuel. However, the value of CO and NOx is still similiar to diesel fuel.

Brynolf, Fridell, and Andersson (2014) have compared several marine fuels in the North European market based on their life cycle performance to assess the effect of the fuel selection on environmental performance. From the assessments results obtained, show that methanol can be an effective transition fuel in reducing air pollution equal to LNG. However, only biomass-based methanol has the potential as a future alternative fuel in reducing global warming while reducing air pollution. The authors have underlined the limitation of environmental performance data related to methanol engine performance due to no validation, thus the emission value was assumed.

Retrofitting ships using environmentally friendly technology is one of the preferred solutions for a ship owner on the basis of economic performance, to comply with current and future environmental regulations (Aronietis, Sys, and

Vanelslander, 2014). Stevens et al (2015) developed a framework that linked policy makers, who impose new environmental regulations with the implementation of sustainable technology in the market, and shipowners' decision whether building new ships or retrofitting the ships. In addition, simulation and modeling has been done by Aronietis et al, (2014) to asses nine emission abatement technologies (LNG main engine, wind propulsion, LNG cold ironing, PTO/PTI, speed reduction, voyage optimization, SCR, scrubber) based on economics (cost, saving, market penetration), emission performance (effectiveness of reducing emissions, reducing externality cost), and energy performance (fuel saving, increasing of energy efficiency). The paper concluded that shipowners should invest in the technology that gives better economical and energy performance. Moreover, speed reduction gets the highest score over all three criteria among other solutions. However, speed reduction is rarely implemented on domestic passenger shipping since liner shipping has certain destinations, tight schedule, and is operated in dense water traffic. However, the paper does not include methanol as a solution in the modeling and simulation.

Grahn et al (2013) investigated future marine fuels based on cost-effectiveness analysis using a linear optimisation model for short sea vessel, ocean vessel and container vessel. Natural gas based fuels, including methanol, can be cost-effective options for fuel oil substitution in the maritime sector. The cost-effective analysis was conducted particularly for methanol and LNG as marine fuel for dual fuel engines. However, the study did not evaluate the effect of pilot fuel usage in the dual fuel engine and the different prices between main fuel and pilot fuel.

Banawan, Gohary, and Sadek (2009) discussed the environmental and economic benefits in retrofitting main engines suitable for alternative fuels in short voyage passenger ships. The NOx and SOx reduction percentage was calculated by varying the percentage of the dual fuel composition. However, the scenario of percentage of dual fuel compositions in the economic calculation is not included in the study.

Ellis and Tanneberger (2015) also conducted economic analysis by comparing some compliance alternatives within the ECA scenario including methanol. The summary stated the competitiveness of methanol depends on the differentiation of methanol price with traditional fuel such as MDO and HFO.

IMO (2016) published a study on methanol as a marine fuel, including its economic feasibility. The scenario that was built is based on the percentage of time spent in ECA and methanol price. Moreover, a comparative analysis between methanol and scrubbers using HFO was performed. However, only the payback period was considered as the parameter of analysis without involving net present value. The comparative analysis was furthermore only conducted from the shipowner’s perspective, while it is highly important to analyze how governments can support the market, not only being imposed by regulation.

3. Overview of methanol as marine fuel in internal combustion engines

3.1 Methanol characteristics as fuel

Methanol as fuel has lower energy density than oil fuel, particularly compared to diesel oil. Based on Table 1, the energy density of methanol is 20.1 MJ/kg while diesel oil has 42.8 MJ/kg. Therefore, in order to be equivalent in terms of energy density with diesel oil, the volume and the storage space of methanol needs to be almost double.

Methanol has a lower cetane number compared to diesel, 5 compared to 45-55. Low cetane number means that the fuel does not self-ignite easily and thus needs ignition aid. However, its high octane number combined with its high flame speed could be an indication of good burning rates. In addition, despite these properties, methanol is categorized as lean combustion condition because its stoichiometric of air-fuel ratio is lower than that of diesel oil. However, the similar proportion of air-diesel fuel ratio still applied as the reference, since methanol also has lower of the lower heating value (LHV) compared with diesel oil (Stojcevski, Jay, and Vicenzi, 2016).

One of the challenges using methanol as fuel is the formaldehyde formation during occasions of incomplete combustion. However, from a MAN experiment, it was confirmed that there is no formaldehyde formation detected from combustion because in the diesel cycle the methanol molecule is combusted in temperatures up to 1300^{o}C inside the combustion chamber, and there is no methane slip in methanol-fuelled diesel engines (MAN, 2104). Moreover, since methanol contains no sulfur, the engine power efficiency can be improved by increasing the use of thermal energy from exhaust gas without generating sulphuric acid, which is highly corrosive.

Table 1. Methanol fuel properties

	Unit	Methanol	LNG	Diesel
Formula		CH_3OH	CH_4 (>90%)	$C_nH_{1,8n}$ (C_8-C_{20})
Carbon composition	(wt %)	37,5	~75	~86
Density	kg/l	0,79	0,44 (LNG)	0,85
Water Solubility	-	Completely	No	No
Boiling Point	ºC	64,6	-162	150-370
Flash Point	ºC	11	-188	min 60
Auto Ignition	ºC	455	540	240
Viscosity	cSt@20ºC	~0,6	n.a	~013,5
Octane	RON/MON	109/89	120/120	-
Cetane number	-	5	-	45-55
LHV	MJ/kg	20,1	45-50	42,8-43,1
Flammability limits	Vol%	7-36	5-15	1-6
Flame speed	cm/s	52	37	37
Heat of Evaporation	kJ/kg	1178	n.a	233
Stoichiometric A/F ratio	-	6,45	17,2	14,7
Adiabatic flame temperature	ºC	1910	1950	2100
Bulk Modulus	Mpa	777	848	1350
Sulphur content	%	0	0	3,5 max

Source: (Stojcevski et al, 2016; Olah et al, 2006)

The impact of zero sulfur content is not only in reducing sulphuric acid but also the methanol does not produce SOx. The only source of SOx comes from small amounts of pilot fuel, either from HFO or distillate fuel. Similiar patterns of emission reduction of the other emitters (soot, NOx, PM, CH_4, CO_2) has been confirmed by engine manufacturers during performance tests (Stojcevski et al, 2016; MAN, 2016).

Wartsila has measured the reduction of NOx and smoke formation during initial tests of the Vasa 4L32LNGD and Sulzer 6LZA40S-MD. Without any major conversion; the engine in methanol-mode could reach low tier II compared to LFO at constant and variable speed (see Figure 1), while the smoke is reduced by 40% from the reference of pure LFO (Stojcevski et al, 2016). In addition, PM and SOx is generated only from the pilot fuel with no formic acid detected in exhaust gases (Haraldson, 2013).

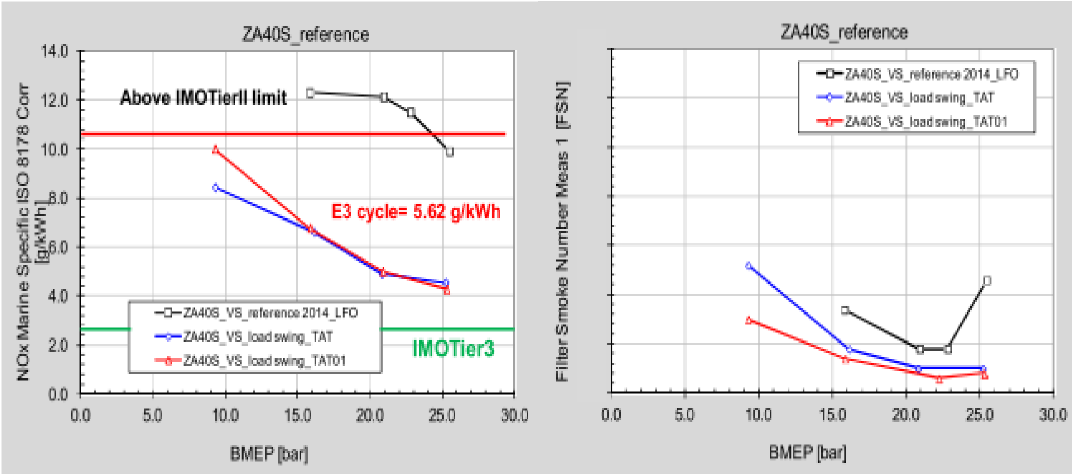


Figure 1. NOx emission and smoke trend (Stojcevski et al, 2016)

3.2 Environmental aspect of methanol

Methanol is a colorless organic liquid in normal atmospheric conditions (1 atm, 72°F), and could generate vapour if any ingress of high temperature imposed to the storage tank. The vapour of methanol released from storage to the atmosphere could react with NOx to produce methyl nitrate. However, the methanol vapour or the compound can be decomposed by photolysis, and it is estimated that around 75-82% will be degraded from the environment after five days. Furthermore, it is also possible that methanol can leak or spill into the sea from a ship. When methanol comes into contact with seawater, it will be completely miscible and dissolve. It happens because methanol has a low coefficient of water-octanol partition and the solution is very stable. In addition, methanol is harmless to most aquatic organisms (Methanol Institute, 2017).

3.3 Safety aspect of methanol

There are three main safety concerns in carrying methanol as fuel onboard a ship, namely flammability, corrosivity, and toxicity (Haraldson, 2015). First, flammability of methanol is closely related to the vapour generation incorporated with the flammability limit. Methanol is a liquid fuel and could release more vapour than diesel oil, depending on the temperature with the flammability ranging between

6-36 vol% (Methanol Institute, 2017). An explosion is possible if the concentration of released vapour was in between the flamability range and a source of ignition was introduced. Moreover, methanol has unique characteristics of its flame where the flame colours are blue transparent and almost invisible, particularly in a bright room or in daylight condition. The Research Institute of Sweden (RISE) has experimented on methanol fire behaviour in the proFLASH project. According to their findings, the visibility of flames becomes reduced by increasing water content. Hence, alcoholproof-contained foam fire extinguisher is more effective and practicable than a traditional extinguisher, since it can restrain vapour formation and dilute the methanol (Evegren, 2017).

Second, methanol is more corrosive and aggressive to some materials compared with diesel oil or natural gas, because methanol is categorized as a solvent and also electrically conductive (Methanol Institute, 2017). Some metals, for instance, aluminum alloy, nitrile, galvanized steel, and other metals which are sensitive to methanol containing water, could not be used in the methanol system (Methanol Institute, 2017). Some resins, fiberglass, and plastics compound are also sensitive to methanol. Hence, selection of material compatibility with methanol should be done carefully, since those materials are often used as gasket and sealing in the engine and supporting system (see Table 2).

Table 2. Compatibility of gasket and sealing material towards methanol

	Nitrile	EPDM	Neoprene	SBR	Silicone	Butyl	Polyacrylate	Hypalon	Viton	Polyurethane	Fluorosilicone	Kalrez
Diesel Oil	1	4	3	4	4	4	1	3	1	3	1	1
Methanol	4	1	1	1	1	1	4	1	4	4	1	1
Methane	1	4	2	4	4	4	1	2	1	3	3	1

(Adapted from http://mykin.com)

1	Satisfactory	3	Doubtful
2	Fair	4	Unsatisfactory

Subsequently, methanol is toxic by inhalation, ingestion, or skin exposure. If methanol vapour is inhaled or exposed to it during a long-term period, it will cause headaches and eye irritation. The minimum ingestion doses of methanol that can cause severe damage, even death, is in the range 300-1000 mg/kg. However, methanol is not considered as a carcinogen or reproductive toxicant to human health (PHE, 2015).

The hazards of methanol to some extent can have serious risks to humans and property. Hence, it is necessary to conduct safety design and assessment, particularly for areas where the possibility of methanol leakage is high, where humans can be exposed, and where there are sources of ignition. One of the safety assessments that can be reference for methanol as marine fuel implementation was performed by EMSA and LR in a study "Safety Assessment Methanol and Ethanol Fuelled Ships" (IMO, 2016a; Ellis & Tanneberger, 2015).

3.4 Current status of methanol-fuelled passenger ship projects

3.4.1 Pilot Methanol project

This project was initiated by the European Union (EU) under EU Motorways of the Sea (MoS) program (Jan 2013-Dec 2015). Sweden, Finland, and Germany were involved in this cooperation project including their industrial stakeholders, for instance Wartsila, Stena AB, and SSPA. The objective of the project was to demonstrate and deploy research and real experiments on methanol as a clean, sustainable, and safe fuel in the future shipping industry. In addition, the project is also seeking an appropriate infrastructure to support safe fuel bunkering in ports (EC, 2015).

In order to achieve the objective, three strategic steps were set. The first step was to conduct research in the laboratory. This step was carried out in order to find and verify the performance of methanol-fuelled marine diesel engines. The second step was testing methanol as a marine fuel in real operation onboard a ship by converting four main engines of Roro Passenger Stena Germanica to be dual fuel (Methanol-MGO) engine. Moreover, this step also examined the development of supporting safety and security regulations and the relevant bunkering station in port.

The last step will deploy the technology development to 24 other ships and other countries in the North Sea and Baltic area (ZVT, 2015).

To support the first and second steps, the EU covered financial support by EUR€ 11,251,000 from the total project cost of around EUR€ 22,502,000. Following the action plan, Sweden also initiated a submission to IMO regarding the requirements of alternative fuels that have a low flashpoint as the basis of IGF Code amendment. However, the third step is still waiting for the monitoring results of the Stena Germanica operation (ZVT, 2015).

3.4.2 Methaship

Methaship is a national research project funded by the German government with the duration from September 2014 to March 2018 (Sahnen, 2017). The project aims to assess the feasibility of methanol as marine fuel in new passenger ships (cruise ship and RoPax), including development of methanol-fuelled passenger ship design and study of infrastructure readiness to support methanol implementation (IMO, 2016b). This project consortium consists of 3 companies; Meyer Werft, Flensburger Schiffbau Gesellschaft, and Lloyd Register. Further, they have support from the industrial sector, such as engine manufacturers (MAN and Caterpillar) and chemical company, Helm AG (LR, 2015). Eventhough the project is an ongoing progress, Germany has submitted some documents to the IMO related to the amendment of guidelines for low-flashpoint fuels based on the finding in the Methaship study.

3.5 Methanol system design and technology

3.5.1 Methanol fuel system

A methanol fuel system consists of five main parts: bunkering, storage, methanol supply, methanol-fuelled engine, and an inert gas system (see Figure 2). Each part has some components that will bestable under all expected operating conditions. Also a single failure on one of the fuel system will not lead to a high risk to the ship and crew onboard the ship (LR, 2016).

In terms of technology maturity of individual components, almost all components in the methanol system are ready in the market except for the marine diesel engine or consumer as shown in Table 3 (IMO, 2016e). The maritime industry has a long experience with methanol as cargo, and the provisions have been stipulated in the IBC Code. Therefore, the bunkering technology is already mature. On the other hand, methanol application in a marine combustion engine is relatively new. Hence, only few engine manufacturers have developed this technology, for instance Wartsila and MAN B&W.

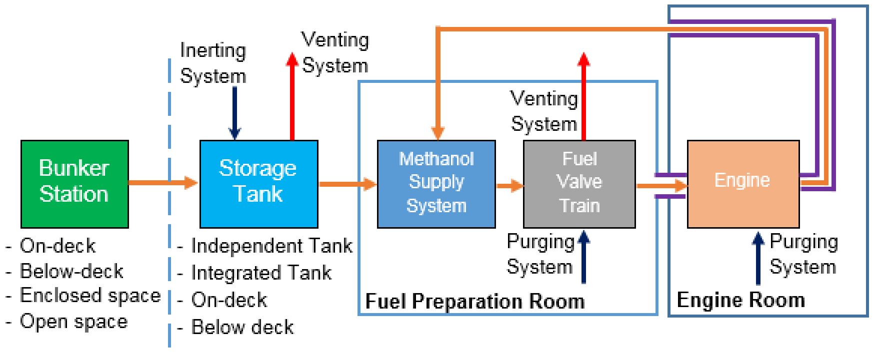


Figure 2. Methanol system arrangement (Adapted from MAN, 2014; Aabo, 2015)

Table 3. Technology System Maturity for Methanol as Marine Fuel

Methanol System	Technology Readiness	Remarks
Fuel Bunkering System	Mature	-
Fuel Storage System	Mature	Fire detection-IR CCTV may provided, since methanol flame is not visible at certaint condition
Fuel Supply System	Mature	-
Methanol-fuelled engine	Relatively New	- Methanol Fuel Injection system - Low-Flamable Limit engine monitorig system - Methanol purging system
Inert Gas System	Mature	- Methanol inerting and purging configuration after main engine

(Adapted from table 5-1 to 5-5, IMO, 2016e)

In particular, methanol has an advantage over LNG because it does not need any means of cryogenic processing or special storage tanks as methanol can be stored in an existing fuel tank or even in the ballast tank with some treatment, such as tank coating with zinc silicate paint and storage purging. Storage purging with nitrogen in the storage is needed to avoid the vapour being contaminated with salty air, which can increase the conductivity and corrosivity. Moreover, nitrogen will keep the vapour of methanol inside the tank below LFL to avoid explosion inside the tank. Additionally, due to the low-flashpoint characteristic, some additional safety equipment needs to be provided, if necessary such as infrared-CCTV (IMO, 2016e).

3.5.2 Methanol-fuelled marine engine technology

3.5.2.1 Conversion-based perspectives (Wartsila)

Wartsila has conducted initial testing for a methanol-diesel engine concept using the engines Wartsila Vasa 4L32LNGD and Sulzer 6ZA40S-MD (Haraldson, 2015). The methanol concept applied to the initial testing is pilot fuel aided diesel combustion. The fuel timing was adjusted so that methanol will be injected close to TDC and ignited with a small portion of diesel as pilot fuel (Stojcevski, 2014). Both of the engine tests showed the same trend of efficiency and performance with the diesel engine when running in dual fuel mode with no reduction output or load (Haraldson, 2013).

In addition, Sulzer 6ZA40S, as used in the initial testing, is the same engine type installed in Stena Germanica, and it becomes the reference of the conversion project. According to Laakso (2017), there should not be any other constraint for retrofitting or converting except the cost, depending on the engines that should be retrofitted. Meanwhile, Haraldson (2015) mentioned the scope of conversion solutions as follows:

- Modify existing fuel pump by exchanging fuel plunger and adjusting fuel timing
- Modify cylinder heads by making an inlet channel for methanol supply to the injector. Also, as exhaust gases from methanol combustion contain less lubricating particulates; hence, the exhaust valve needs to be modified to reduce excessive wear
- Install methanol common rail systems, including a high-pressure methanol pump

- Exchange a fuel injector that is compatible with methanol-diesel fuel application, including sealing and control oil system (see Figure 3)
- Upgrade the engine control system
- The double-walled concept including purging system should be designed to reduce the potential risk of methanol leakage and contact with another part of the fuel injector.

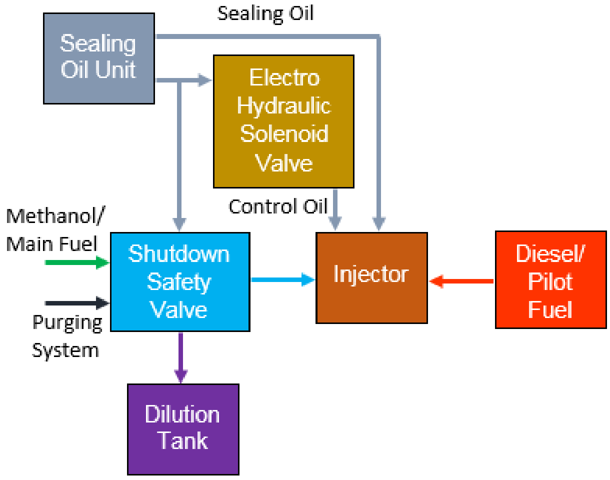


Figure 3. Methanol injection system (Adapted from Stojcevski et al, 2016)

Since methanol as marine fuel technology is relatively new, there are possible future developments to improve its performance, such as variable injection timing of dual fuel, independent pilot fuel injector apart from main fuel injector, methanol-water blended fuel, and single methanol fuel (Stojcevski, 2016).

3.5.2.2 New engine-based perspectives (MAN B&W)

MAN B&W has developed the ME-LGI concept mainly for a two-stroke engine as their portfolio business. The concept can be applied in new engines as well as in retrofitted existing MAN engines (MAN, 2016). The safety concept and operational principles applied in ME-LGI is analogous to the well-proven ME-GI (gas injection-based engine) concept (MAN, 2014).

Based on the MAN ME-LGI concept (MAN, 2014), methanol is regulated from the methanol supply system to the engine room through the fuel valve train system which consists of a master fuel valve incorporated with double block bleed valves and a nitrogen purging system. In addition to the double walled-ventilated methanol piping passing through the engine room, all methanol components supporting the engine are of double-walled design and any leakage occurred will be collected in a dedicated double barrier collector. From the leakage collector, liquid methanol will be converted into vapour and continuously monitored by a specific sensor. Whenever the vapour content is higher than specified limits, the engine will switch-over into oil fuel. In addition, in order to inert and clean the engine piping and equipment, a purge return system is installed. The inert gas from the purge return system will push back the liquid methanol to the fuel service tank (see Figure 2).

The Booster Fuel Injection Valve (BFIV) is equipped to increase fuel injection pressure in the combustion chamber. The essential systems in BFIV are integrated cooling-lubricating systems. The system will control the temperature below 60^{o}C and at the same time lubricating the inner part of BFIV. Moreover, the oil sealing system is developed to prevent methanol-hydraulic oil contamination. However, if the systems recognized methanol contaminates oil system, then the engine will change-over to the solely diesel engine.

3.6 The status of regulations of methanol as marine fuel

3.6.1 IMO

3.6.1.1 SOLAS

Methanol can be categorized as a low-flashpoint fuel under the definition stipulated in SOLAS chapter II-1 Part A-2.30 :

"Low-flashpoint fuel means gaseous or liquid fuel having a flashpoint lower than otherwise permitted under regulation II-2/4.2.1.1"

Having been amended by Resolution MSC 392(95) (IMO, 2015a), SOLAS Chapter II-1 Part G Reg. 56.1-3 and 57, provides the pathway to make the IGF Code the technical regulation mandatory for new ships or existing ships intending to convert to using low-flashpoint fuel after 1 January 2017. Moreover, the discussion for establishing the new part in the IGF Code which contains the provisions of low-flash point fuels other than methane-based fuel is an ongoing progress. Hence, SOLAS Chapter II-1 Part F Reg. 55, pertaining to alternatives design and arrangement, can be employed as the basis for analysis, evaluation, and approval of methanol as marine fuel.

3.6.1.2 MARPOL

MARPOL Annex VI, particularly chapters 3 and 4, has set specific targets for recent and future air pollution compliance in the shipping industry as shown in Tables 4 and 5. The stringent future emission thresholds will encourage the shipping industry to use emission abatement technology, including methanol as clean and sustainable marine fuel, to meet the required conditions (IMO, 2016e).

Table 4. The NOx control requirement based MARPOL annex VI regulation 13

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n<130	n=130 - 1999	n≥2000
I	1 January 2000	17.0	$45 \times n^{(-0,2)}$	9.8
II	1 January 2011	14.4	$44 \times n^{(-0,23)}$	7.7
III	1 January 2016*	3.4	$9 \times n^{(-0,2)}$	2.0

*Only in NECA area stipulated in MARPOL Annex VI chapter III Reg.13

Table 5. The SOx - PM control requirement based MARPOL annex VI regulation 14

Outside ECA	Inside ECA
4,5% m/m prior to 1 January 2012	1,5% m/m prior to 1 January 2010
3,5% m/m on and after 1 January 2012	1,0% m/m on and after 1 January 2010
0,5% m/m on and after 1 January 2020	0,1% m/m on and after 1 January 2015

Table 6. The value of Cf from various fuels

Type of fuel	Reference	Carbon content	Cf (t-CO2/t-Fuel)
Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	0.8744	3.206
LFO	ISO 8217 Grades RMA through RMD	0.8594	3.151
HFO	ISO 8217 Grades RME through RMK	0.8493	3.114
LPG	Butane	0.8264	3.030
	Propane	0.8182	3.000
LNG		0.7500	2.750
Ethanol		0.3750	1.913
Methanol		0.5217	1.375

Source: (IMO, 2014)

MARPOL annex VI chapter IV also prescribed the EEDI requirement for newbuilds or major-conversion ships. The requirement of GHG reduction target depends on the type, size, and the date built or converted (IMO, 2016e). In order to calculate EEDI, one of the components involved is the CO_2 emission factor of the fuel. Based on Table 6, methanol has been recognized as a marine fuel, and the carbon content is 50% lower than LNG, MDO, and even HFO. It means that using methanol as marine fuel significantly will reduce CO_2 emission.

3.6.1.3 IGF Code

The IGF Code is the regulation intended to provide safety and technical provisions for ships using dedicated gases or other low-flash point fuels. The code was adopted by Resolution MSC 391(95) and entered into force on 1 January 2017. Regulations pertaining to other low-flashpoint fuels are ongoing developments at the IMO. Hence, the compliance of using methanol as marine fuel will be verified based on alternative design as long as it meets the goals and requirements stipulated in the relevant chapter of the IGF Code (IMO, 2016d).

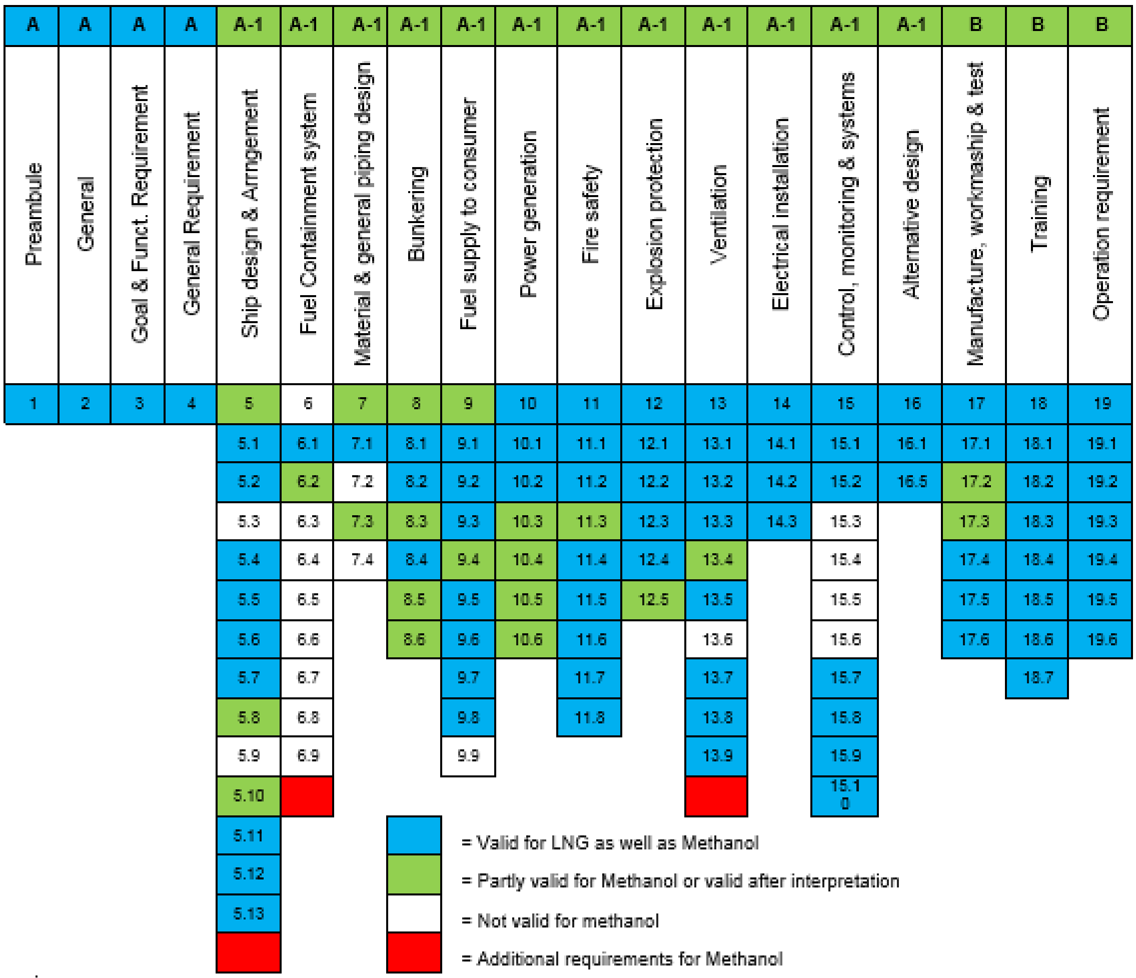
The progress of regulation development of methanol as marine fuel can be seen in Table 7. In addition, IMO has set up the completion target for amendments of the IGF Code and guidelines for low-flash point fuels in 2019, based on the output for the 2018-2019 biennium document (IMO, 2017).

Table 7. The progress of regulation development of methanol as marine fuel

2009	2010	2011	2012	2013	2014	2015	2016
	BLG-14	BLG-15	BLG-16	BLG-17	CCC-1	CCC-2	CCC-3
	Proposal for expansion of IGF scope to involve methanol & ethanol	Agree to include low-flash point fuel into WG discussion	Discussion of properties and hazard of low-flash point fuel	Proposal for requirement of methanol	Discussion to develop interim guidelines of methanol	Draft interim guidelines of methanol	- Discussion of safety assessment of methanol as marine fuel - Report of Methaship project
MSC-86	MSC-87					MSC-95	
Adoption of Interim Guidelines of IGF	Agree on expansion of the IGF scope to include low-flash point fuel					- Adoption of IGF Code - Amendment of SOLAS to make IGF Code mandatory	

Source: (author, 2017)

Parallel with the completion of the IGF Code, the draft of specific requirements for methanol has been made mainly led by Sweden starting from BLG-14. In addition, commencing in BLG-17, a gap analysis of the IGF code – Methanol characteristics comparing methanol characteristics was made in order to understand to what extent the IGF Code can cover methanol as marine fuel (see Figure 4).



(adapted from Freudendahl, 2016; IMO, 2012a; and IMO, 2012b)

Figure 4. Gap analysis draft of the IGF Code and methanol

3.6.1.4 IBC Code

The IBC code is not closely related to the use of methanol as marine fuel since it only regulates dangerous chemicals as cargo in bulk. However, the requirements in the IBC Code are still relevant as a reference to understanding safety measures related to methanol onboard a ship. According to the IBC Code chapter 17 (IMO, 2016c), the category of pollution of methyl alcohol is considered as Y, meaning that the noxious liquid substances are deemed to create a hazard either to marine resources or human health. Hence there is a need to justify quality and quantity limitation of the discharge outboard ships. Moreover, the methanol carrier is considered as a type 3 ship, meaning that it is not necessary to have a double hull to protect it from hull damage and cargo spill. Moreover, the IBC Code should only considers the vapour of methanol as flammable, and the fire protection be alcohol-resistant foam.

3.6.1.5 STCW

In order to ensure that the crew onboard has adequate knowledge, qualification, and skills to handle ships using low-flash point fuels, the IGF Code, Part D chapter 19.2, linked the code to the STCW Convention that has been amended by Resolution MSC 396(95) (IMO, 2016d). MSC-95 has amended the inclusion of the requirement of training and qualification of masters, officers, ratings, and other personnel on ships according to the IGF Code STCW Convention Part A-V/3. In addition, the specification of minimum standard of competence of basic and advanced training has been set-up and the requirement has to be fulfilled by seafarers prior to serving on board ships using low-flashpoint fuel (IMO, 2015b).

3.6.2 Classification societies

Recently two classification societies, LR and DNV-GL, have developed regulations specific to the application of methanol as a marine fuel (Ellis & Tanneberger, 2015). Other classification societies adopted and modified the pattern of the IGF Code as the basis of rule development, for instance: ClassNK and BKI.

The provisional rules for the classification of methanol fuelled ships developed by LR were updated in January 2016 (LR, 2016). The rules consider risk-based studies on the specific equipment or system as part of the submission requirement document. In addition, the specific material type and requirements for a methanol system have been incorporated in order to accommodate the corrosion hazard of methanol. The class notation for the ship that complies with these rules will be “LFPF(GF,ML)”.

The rules developed by DNV-GL for low-flashpoint fuels are incorporated in Part 6: Additional class notations; Chapter 2 Propulsion, power generation, and auxiliary systems; Section 6: Low flashpoint liquid fuelled engines-LFL Fuelled (DNV-GL, 2017). The rules clearly specify the applicability for methanol and ethanol as marine fuel. However, the section does not clearly specify the type and requirements of materials. Also, the rules are not considering risk assessment of the equipment and system as part of the class submission document. On the other hand, the rules have been considering specific ship types in order to address the risks involved when using methanol as marine fuel. The class notation for a ship that complies with the rules will be “LFL fuelled”.

ClassNK amended the rules and guidelines “Part GF Ships Using Low-Flashpoint Fuels” in December 2016 (ClassNK, 2016;BKI, 2015). BKI, as the Indonesian classification society, amended the Guidelines for the use of gas as fuel for ships in October 2015. Both of the regulations mainly regulate methane-based (CNG and LNG) fuels based on the IGF Code. Hence, the compliance of using low-flashpoint fuel, such as methanol, will be verified based on alternative designs as stated in ClassNK rules chapter 1.1.1.3 and BKI guidelines section 2.3.2.

3.7 Discussion

Methanol has been known as an internal combustion engine fuel for many years, particularly in the Otto cycle. The project of methanol applications in diesel engines shows positive results in terms of emission reduction and risk handling based on their characteristics. Currently, methanol is relatively new as marine fuel which contains toxic and explosion hazards, but there is ample room for improvement in its application onboard ships. Considering increased support recently from maritime stakeholders (academia, engine manufacturers, shipyards) in research and development of methanol technology and risk assessment, combined with positive progress in the development of supporting regulation of low-flashpoint fuel by IMO and classification societies, it may improve the clarity and maturity of risk mitigation and safety control technology.

From the gap analysis of the provision in the IGF-methanol guidelines, the requirements of methanol fuels on board the ships are similar to LNG and in some extent even lower since methanol is not considered as cryogenic liquid. In-line with the maturity of risk assessment and technology, it possible that the risk management in the methanol fuel system in marine application will improve and come even closer to common fuel such as MDO. Thus, it will stimulate the reduction of safety control equipment and investment cost in the future.

4. Potential of methanol as passenger ship fuel in Indonesia

4.1 Overview of passenger ship operations in Indonesia

Considering Indonesia as an archipelagic country, it should have a strong and well-managed sea transportation to connect and transport people, trade commodities, or other cargo among islands or areas. The maritime sector should be the driving force of the economic development, and reduce the social inequalities among the islands or areas of Indonesia. However, currently, domestic marine transportation is mainly serving the areas with high economic activity in the west of Indonesia rather than in eastern Indonesia. The inequality of marine transportation services create a disparity of logistic cost and price of goods (Bappenas, 2015; Zaman et al, 2015). Also, according to the Global Competitiveness Report 2016-2017 released by World Economy Forum (Schwab, 2016), Indonesia's connectivity index rating in the marine sector is 75, which is lower compared to neighbour countries, for instance, Malaysia (17), Thailand (65), and Singapore (2).

Therefore, the President of Indonesia initiated the concept of "Tol Laut", or sea highway, as part of a big vision in creating Indonesia as global maritime fulcrum. The idea of the sea highway is to connect routine shipping lanes from eastern to western Indonesia and to minimize logistics costs and to bridge the economic development gap (Bappenas, 2015). One of the Government initiatives was assigning PELNI, as a state-owned company, to provide pioneer shipping services mainly in eastern Indonesia (see Figure 5), through Presidential Regulation No.2 year 2016 and Minister of Transportation Regulation no 6 year 2016.

According to the regulation of the Ministry of Transportation no 35 year 2017, the definition of pioneer shipping transportation is a sea transportation service on the routes established by the Government to serve areas or territories that have not been or are not served by sea transportation before because it has not provided commercial benefits. Hence, based on this policy the government also provides operational subsidies to PELNI due to operating in uncompetitive commercial areas, which is regulated by the Ministry of Transportation. On the other hand, although PELNI receives subsidies, there is still competition with the air transportation, particularly with low cost carriers (LCC) air services (PELNI, 2016). Since the Government policy is developing connectivity in all sectors, air transportation, and its infrastructure are also a part of the Governmental strategic development.

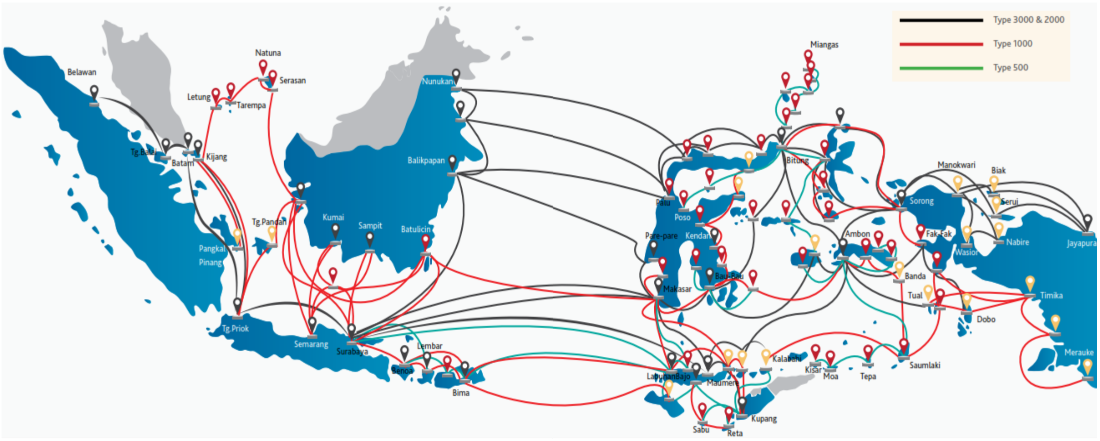


Figure 5. PELNI passenger ship routes 2016 (PELNI, 2016)

Despite the challenges above, there is room for improvement for the benefit of the company welfare. Based on the PELNI annual report 2016, the fuel cost component was the biggest single variable cost, about 54% of the total operational cost of ships in this company. Therefore, improvements by using an alternative fuel such as methanol, with a lower price, less emissions, and an affordable technology investment, is one of the best options that can be considered by the government and the management of the shipping company.

In addition, the application of “green technology”, such as methanol as marine fuel, will provide competitive advantage for the shipping company in competing with other modes of transportation by elevating the "green" brand reputation and attract passengers to use "green transportation". Further, it will reduce the negative environmental impact without compromising the productivity of the passenger ship operation.

4.2 Potential sustainability of methanol as marine fuel in Indonesia

From the supply chain and fuel production perspectives, sustainability of feedstocks gives methanol an advantage among other alternative fuels to be a transitional marine fuel as well as a future sustainable fuel. However, from the literature and energy projections (Sugiyono et al,2016; Prasodjo et al,2016), methanol has not been acknowledged as a promising alternative and future marine fuel in Indonesia.

The ease of methanol production from various feedstocks makes it suitable as a transition or future alternative fuel of marine fuels in Indonesia. Moreover, Indonesia holds many potential feedstocks, both fossil and renewable resources for methanol production.

4.2.1 Fossil resources

4.2.1.1 Coal

Coal can not only be used in steam power generation but also in a potential methanol feedstock. Methanol can be produced from coal through gasification to produce synthesis gas, followed by methanol synthesis and purification. Moreover, the production will consume 1.42-1.59 ton of coal per ton of methanol (Zhen & Wang, 2015). In addition, Indonesia has abundant coal resources and is one of the major coal producers in the world (Hasan et al, 2012). In 2015, the total coal resources in Indonesia were 126.61 billion tons and the total reserves around 32.26 billion tons (BGI, 2015). This abundant resource makes coal-based methanol production a possibility in Indonesia.

4.2.1.2 Natural Gas

Methanol production using natural gas in Indonesia was commercially commenced in 2000 by the Kaltim Methanol Industry (KMI) with a production capacity of 600,000 ton per year. In producing methanol, KMI has been using steam reformer and low-pressure synthesis methanol technology (see Figure 6). Approximately 750-1300 m^3 of natural gas is consumed to produce one ton of methanol, depending on the technology applied (Shen et al, 2012). Furthermore, in order to optimize production efficiency, the methane slip during steam reforming processing is treated by using a partial oxidation method (KMI, 2015).

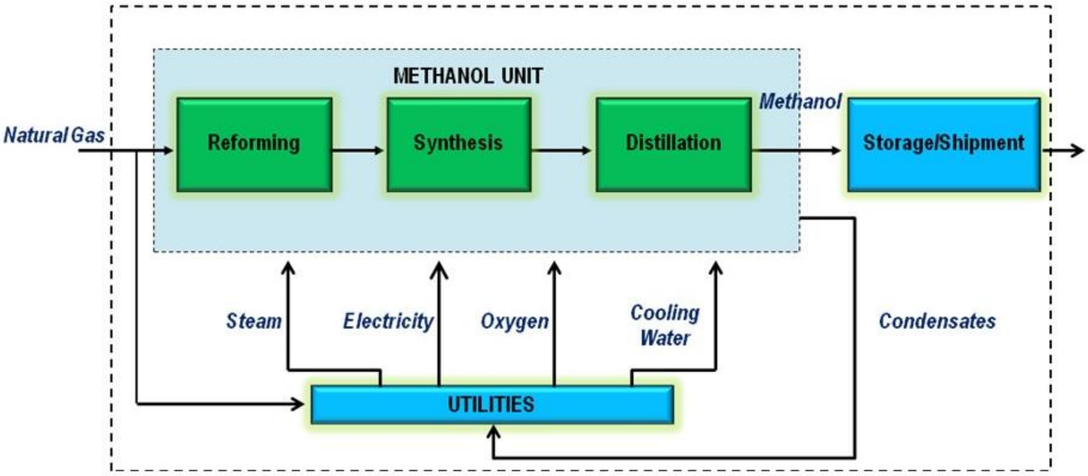


Figure 6. Methanol production process at KMI (KMI, 2015)

Indonesia's total natural gas reserves in 2013 amounted to 150.39 trillions of standard cubic feet (TSCF). The largest reserves are in Natuna with reserves of 50.48 TSCF, followed by West Papua, with a total reserve of 23.90 TSCF (DIKH, 2016). Moreover, Indonesia has other potential natural gas resources from shale gas and coal-based methane (Prasodjo et al, 2016). Even though Indonesia is rich in natural gas resources, the domestic absorption of natural gas is relatively low (Sugiyono et al, 2016). Therefore, by utilizing methanol as a marine fuel certainly has the potential to increase domestic market absorption.

4.2.2 Renewable resources

4.2.2.1 Industrial Waste

Indonesia is one of the biggest crude palm oil (CPO) producers in the world, with around 16 million of CPO produced annually, with 608 palm oil mills in 2011 (Nizami et al, 2017; Winrock, 2015). The CPO industry produces a lot of solid waste (empty fruit bunches, fiber, and shells) and palm oil mill effluent (POME) (Sugiyono et al, 2016). According to Goenadi et al. (as cited in Sugiyono et al, 2016), every ton of palm oil fruit will produce 180 kg of fiber and shell, and 600-700 POME. Decomposition of POME in anaerobic condition may produce biogas containing 50-75% methane to potentially become methanol feedstocks (Winrock, 2015).

Furthermore, the sugar industry can potentially provide methanol feedstocks because of the produced by-products such as molasses, bagasse, and leaves of the cane tops (Sugiyono et al, 2016; Batidzirai et al, 2012). Another potential industry is the pulp and paper industry that produces byproducts of non-condensate gas which can be used as bio-methanol feedstock (Sugiyono et al,2016).

4.2.2.2 Municipal waste

With a population of more than 250 millions, Indonesia has a big problem with municipal waste. One solution could be to transform waste into potential energy. Through the process of sanitary landfill and anaerobic digestion, municipal waste can produce methane as methanol feedstock (Sugiyono et al, 2016). Utilizing biomass to convert into energy is rather small in Indonesia, apart from the technology that is needed to be imported from outside and the culture of citizens sorting out rubbish based on their material is also relatively low.

4.3 Potential challenges in implementation of methanol as marine fuel in Indonesia

4.3.1 National regulations related to methanol as marine fuel

The existing requirements and standards of marine fuels regulated by the Ministry of Energy and Mineral Resources (ESDM), has yet to cover methanol as a domestic marine fuel. Only certain fuels that are commonly used were covered by regulations, for instance the Decree of Directorate General of Oil and Gas No.14496 K/14/DJM/2008 solely regulating the standards and specifications of IFO and MFO, the Regulation of the Ministry of Energy and Mineral Resources No. 32 year 2008, only governing biofuel as alternative fuel.

Moreover, the Directorate General of Sea Transportation (DGST) has not developed the requirements of ships using low-flashpoint fuel yet. On the other hand, BKI, as the only classification society that has received full authority from the Government, has established regulations of methane-fueled vessels based on the

IGF Code. However, the regulations need to be amended, and the provisions of low-flashpoint fuel including methanol need to be added.

According to the IGF Code, "In the meantime, for other low-flashpoint fuels, compliance with the functional requirements of this Code must be demonstrated through alternative design". This means that if the Government does not have any prescriptive rules for other low-flashpoint fuel applications, including methanol, then the ship design has to be approved as an alternative design through risk assessment. BKI, as a classification society, has developed the guidance for risk evaluation for an alternative arrangement, while the Administration does not possess such regulation. Cooperation between both institutions is highly needed for the success of the implementation of methanol as marine fuel in Indonesia.

4.3.2 Training and competency

Despite its potential and advantage as a new alternative fuel technology, the application of methanol as a marine fuel may confer risks to a person onboard. There is also a potential for mishandling by crew due to unfamiliarity or lack of training. It is important to keep in mind that there might be a resistance to new fuel systems by "traditional" seafarers. There is no maritime institute in Indonesia with the necessary facilities providing appropriate training and certification of proficiency based on the IGF Code and the STCW.

To overcome the above challenges, the Administrator needs to establish a compact training module, which consists of a theoretical and a practical program based on the STCW Convention Part A-V/3 of regarding "Mandatory minimum requirement for the training and qualification of master, officers, rating, and other personnel on ships subject to the IGF Code". Moreover, the shipping company must ensure the familiarization of the crew onboard by having annual exercises or drills according to the ISM Code, especially on personnel protection equipment.

4.3.3 Coordination among stakeholders

In 2014, the Indonesian government established the Coordinating Ministry of Maritime Affairs that coordinates and synergizes 4 Ministries (Ministry of Transportation, Ministry of Fisheries, ESDM, and Ministry of Tourism). However, their obligation is merely on coordinating and synergizing related ministries, whilst they have no liability on making a strategic maritime energy roadmap and policy that are associated with all respective ministries and institutions (Menkomar, 2015).

Indeed, establishing an energy policy and introducing methanol as an alternative energy in maritime transport requires coordination among the stakeholders and preferable should not only be handled by the Ministry of Transportation. According to the regulation of the Ministry of Energy and Mineral Resources No.45/2005, regarding the standards and quality and supervision of various fuels that are marketed domestically, the authority to manage and standardize the quality, technical provision, and availability of marine fuels lies on the Ministry of Energy and Mineral Resources. However, the Ministry of Transportation requires the data of fuel availability and quality to comply with MARPOL Annex VI requirement. In addition, the strategy to introduce methanol as fuel into maritime industry also including coordination in ship conversion activity (see Figure 7).

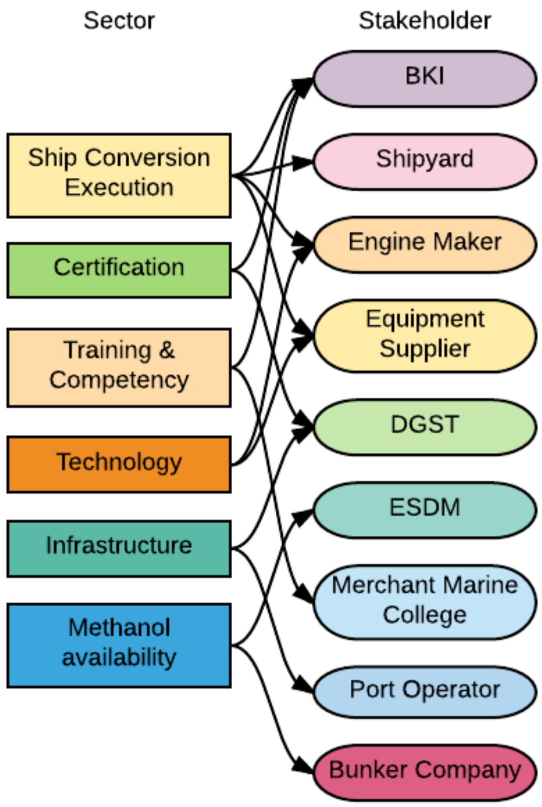


Figure 7. Stakeholders in the conversion activity of methanol-fueled vessels (Author, 2017)

4.3.4 Supply, demand, and logistics

The total supply of methanol in Indonesia in 2014 was around 450,000 tons, and it was mainly produced from KMI (DIKH, 2016). While KMI has the capability to produce methanol up to 600,000 tons, there is an opportunity to increase the production if the market can absorb it. According to the market projection from the Ministry of Industry, in 2020 the total methanol demand in Indonesia will be 2.4 million metric tons annually (DIKH, 2016).

Currently, 80% of the methanol demand in Indonesia is coming from the formaldehyde industry (KMI, 2015). Even though methanol can be an energy resource, there is no market yet. Developing methanol as a marine fuel in Indonesia can improve the market absorption and introduce a new energy market (see Figure 8). Nevertheless, establishing a new market needs enormous efforts and strong cooperation among all of the stakeholder in a different sectors.

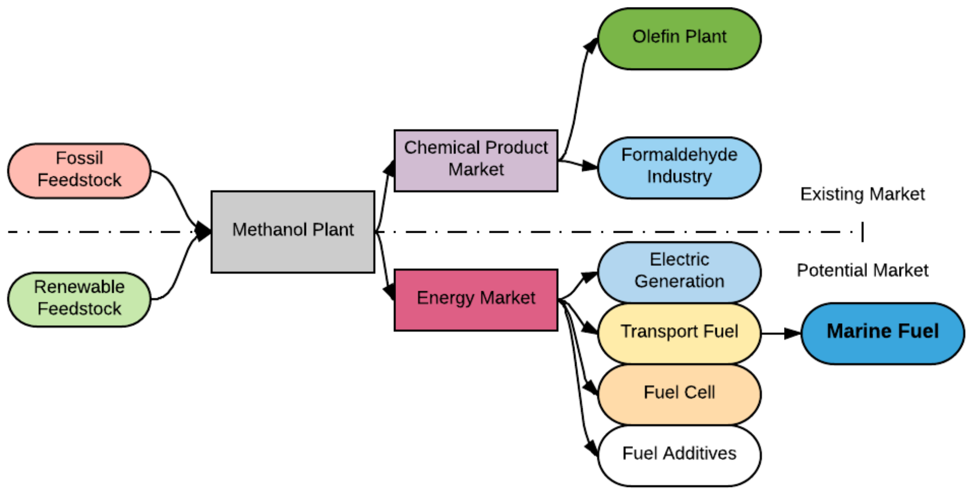


Figure 8. Existing and Potential Market of Methanol in Indonesia (Author, 2017)

On the other hand, as Indonesia is an archipelagic country, the logistic channels need to be established according to the market assessment in targeted islands. There are three options for methanol distribution, namely by small-scale chemical tankers, ISO-tank containers, or by trucks (see Figure 9). Small-scale vessels or ISO-tank containers would be used for delivering methanol in long distances, from the producer or to big consumer islands while trucks would be used for land based transport or between neighboring islands. In addition, to improve the future market, it is necessary to provide a sufficient fleet of methanol tankers to meet the demand.

There is an absence of regulation regarding authorization, standardization, and certification of ship bunker suppliers in Indonesia. Currently, BKI and DGST are working together to establish a scheme to maintain the quality of marine fuels and to promote the availability of domestic fuels based on MARPOL Annex VI Regulation 18 as well. Since the standard and scheme is still an on going process, additional types of other alternatives fuels, such as methanol, can be introduced.

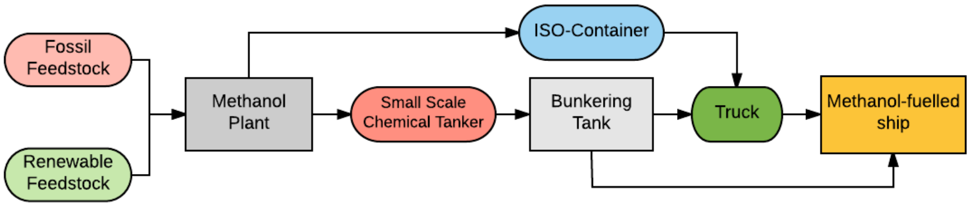


Figure 9. Simple Supply-Chain of methanol as marine fuel (Author, 2017)

4.3.5 Infrastructure

To maintain the supply-chain and the availability of methanol as marine fuel, there is a need for a functioning infrastructure in the designated port (Andersson & Salazar, 2015). Currently, There are existing methanol infrastructures for the supply-chain chemical industry, such as the port of loading belongs to KMI with a capacity of 30,000 DWT and the port of unloading in Siam Maspion Terminal, which can be used as a fuel bunker place.

Methanol has liquid properties under atmospheric pressure; there are similarities with existing marine fuels (HFO, MDO, and MGO) in the infrastructure of bunkering, distribution, and storage. However, since methanol is a low-flashpoint fuel, there are some minor modifications needed to the existing marine fuels infrastructure. However, at the beginning of methanol implementation, it is not necessary to modify or change the infrastructure as bunkering can be done with the "truck to ship" method as seen in Figure 10 (Methanol Institute, 2017).

Figure 10. Methanol bunkering activity at Stena Germanica - Truck to Ship methods (Methanol Institute, 2017)

4.4 Discussion

Indonesia has some advantages to introduce methanol as marine fuel since Indonesia has methanol producers and abundant potential resources. However, since building an energy policy and introducing methanol as an alternative marine fuel involves some ministerial, national institution and academic institutions it is necessary to establish effective communication and a strategic approach planning, as proposed in appendix A. The proposed coordination framework consists of three coordinating ministries with the respectives coordinated ministries and necessary stakeholders (BKI, bunker company, petrochemical industry, also a research and development institution. Hereinafter, coordinating levels are made from feedstocks to the end user.

Moreover, the Indonesian Government has to review and strengthen its energy status and policy, as a legal and political foundation to all stakeholders to support and to find energy solutions in transportation, particularly in marine transportation. It will be more attractive if the government can provide a tax holiday policy for the petrochemical industry which allocates methanol sales for transportation, particularly sea transportation and also for shipowners who convert their vessels into methanol-fueled vessels.

5. Environtmental and techno-economic analysis

Introducing methanol as a marine fuel in the Indonesian market requires investments and clarity in the national strategic energy and transport roadmaps, for instance a government subsidy system. If the provisions to support their application have not been established, it may not be implemented (Buhaug et al, 2009). In order to understand to what extent methanol can be introduced to the market, a techno-economic and policy-making analysis is performed in a case study of two passenger ships owned by Pelayaran Indonesia (PELNI).

The discussion of this chapter is divided into two perspectives: the shipowner perspective and the government perspective. Typically, shipowners look at the industrial-economic aspects and benefits, such as Net Present Value (NPV) and the payback period. On the other hand, the government rather looks at the optimum support to the market, such as subsidies, to comply with regulations and with government programs.

5.1 Shipowner perspective

From the shipowner's perspective, retrofitting existing ships with methanol technology is preferred over building new ships since they are emphasizing the industrial-economic consideration (Aronietis et al, 2014). Moreover, the market conditions, for instance, over-supply, volatility of oil price, and stringent regulations make a shipowner more cautious to invest in new ships. Therefore, a study of technology investment behavior towards the ship revenue is highly needed to understand the effectiveness of methanol technology investment on main engine and which ship is possible to be retrofitted.

5.1.1 Case study of PELNI passenger ship

The case study of the possibility of retrofitting a passenger ship with methanol as fuel is performed on two PELNI passenger ships; MV. Labobar and MV. Gunung Dempo (see Figure 11). MV. Labobar is a T-3000 type that is capable of loading up to 3000 passengers, while MV. Gunung Dempo is a T-2000 type (see Table 8). Both of them are 2-in-1 ships which are capable of loading both passengers and cargo. PELNI also employs T-1000. However, this type is excluded from the case study since the estimated conversion cost is based on a passenger ship with 10-25 MW main engine.

Figure 11. MV. Labobar and MV. Gunung Dempo (https://www.marinetraffic.com)

Table 8. Ship particular of MV. Labobar and MV. Gunung Dempo

No	Parameter	Labobar	Gunung Dempo
1	Type	T-3000 (2-in-1)	T-2000 (2-in-1)
2	Passenger	up to 3000	up to 2000
3	Container cargo	up to 28 TEUS	up to 98 TEUS
4	DWT	4238	3482
5	GT	15136	14017
6	LOA	146.3	147
7	Year of Built	2004	2008

Source: (Santoso, 2017; BKI database, 2017)

5.1.2 Input data and variables

The data considered in the calculation includes, but is not limited to, ship age, ship economic lifetime, opportunity loss, and ship's revenue. The initial information used for the case study was gathered from various sources as shown in Table 9:

Table 9. Input data for shipowner perspective analysis

No	Parameter	Method	Sources
1	Revenue	Interview and Correspondence	PT. PELNI
2	Total Fuel Cost		PT. PELNI
3	Ship O & M Cost		PT. PELNI
4	Average number of voyages (yearly)		PT. PELNI
5	Average distance per voyage		PT. PELNI
6	Average days of operation (yearly)		PT. PELNI
7	Remaining economic life of ship		PT. PELNI
8	Docking and Maintenance Time (yearly)		PT. PELNI
9	Docking time for conversion	Literature study	(Stojcevski, T.2014), Remontowa Shipyard Website
10	Main Engine Data		BKI (Classification Society) Database
11	Auxiliary Engine Data		
12	Engine Conversion Cost		(Andersson,K & Salazar, CM.2015)
13	MDO-Singapore Bunker Price History		Bunkerindex and Clarksons Database
14	Methanol Price History		Methanex Database
15	Discount Rate		(IMO.2016)
16	Indonesia Tax		PPh 23 of Directorate General of Taxes
17	Exchange Rate 2016		Bank of Indonesia database
18	Inflation 2016		Regulation of the Indonesian ministry of finance no.93/PMK.011/2014

There are three major cost variables and one benefit variable in this economic study, namely capital cost, opportunity cost, and operational cost for cost variables (as shown in Appendix B) and earning as benefit.

- Capital costs are the investment or fixed costs incurred in the engine conversion activity including the shipyard cost, procurement of equipment, and retrofitting cost. In this study, all parameters in capital costs were incorporated into a single cost as the function of cost/kW.

- Opportunity cost is the loss of revenue due to retrofitting activity. The retrofitting activity conducted in a shipyard results in loss of revenue for a certain trip. However, the opportunity cost is reduced due to idle fuel cost (which is unused during the retrofitting period). Moreover, in this study this cost is incorporated to the Capital expenditure (Capex), which is represented by the following formula:

  Capex = Capital cost + Opportunity cost – Total idle fuel cost

- Operational cost is the cost that arises during main engine operation, including operation-maintenance costs and fuel costs. The operational cost increases year by year because it goes hand in hand with the inflation. For main engine fuel cost, it is calculated as follows:

$$\text{Fuel Cost}_{\text{methanol}} = \text{Price}_{\text{methanol}} \text{ x \% of methanol x Fuel Consumption}_{\text{MDO}} \text{ x } \frac{\text{LHVMDO}}{\text{LHVMethanol}}$$

$$\text{Fuel Cost}_{\text{MDO}} = \text{Price}_{\text{MDO}} \text{ x \% of MDO x Fuel Consumption}_{\text{MDO}}$$

$$\text{Total Fuel Cost} = \text{Fuel Cost}_{\text{MDO}} + \text{Fuel Cost}_{\text{Methanol}}$$

- The benefit is the saving for the shipowner due to operating with methanol. It is represented by the difference in fuel cost that included in the earning before taxation and depreciation (EBTD) as the following formula:

  EBTD = Revenue – Operational Cost

5.1.3 Scenario and assumption

In order to identify investment behavior of methanol technology, two scenarios have been considered:

1. The composition of methanol as main fuel and MDO as pilot fuel

Referring to previous research, Srivastava (2016) used M-85 (85% methanol - 15% distillate fuel) for scenario calculation. According to Laakso (2017), the use of oil fuel as pilot fuel was lower compared to the methanol as main fuel, but the difference might be related to methanol properties used in the specific ship. Since the technology of methanol as marine fuel is relatively novel, it might improve in the future. In this study, the scenario of the composition of methanol as main fuel and

MDO as pilot fuel will be M-80, M-85, M-90, and M-95. Moreover, as a comparison, the scenario of 100% MDO will also be calculated.

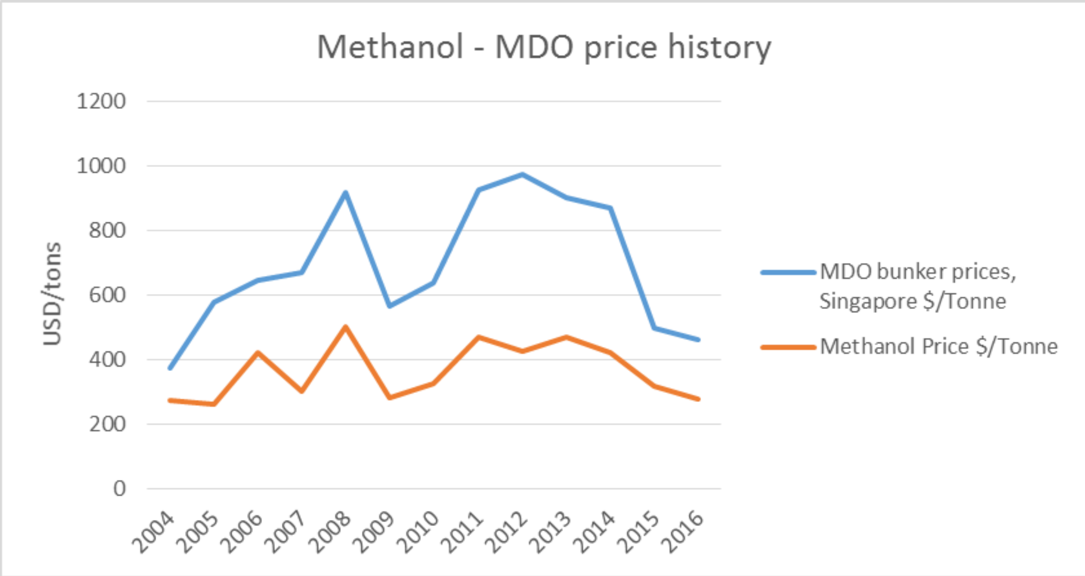
2. The percentage of methanol price compared to MDO

It is difficult to determine the pattern of fuel price since it is volatile and unpredictable. However, price history can be used to estimate the future behavior of methanol and MDO price. According to the methanol-MDO price history from 2004-2016 (see Figure 12 and Table 10), the highest percentage was 73,02% in 2004, and the lowest was 43,69%. Almost the percentage of methanol over MDO was in 40-60%, hence those percentage range with interval 2% is used as the basis of the scenario. Furthermore, the MDO price in 2016, USD 460,74/tons or Rp 6.136.596,06/tons, is used as the basis of the techno-economic calculation (see Appendices C and D) and combinatorial scenario analysis.

Table 10. percentage of methanol-MDO price history from 2004-2016

Tahun	MDO bunker prices, Singapore ($/tons)	Methanol Price ($/tons)	% Methanol : MDO Price
2004	372.50	272	73.02%
2005	576.00	260	45.14%
2006	645.00	420	65.12%
2007	670.63	300	44.73%
2008	919.50	500	54.38%
2009	566.25	280	49.45%
2010	638.25	325	50.92%
2011	926.00	470	50.76%
2012	972.75	425	43.69%
2013	902.94	470	52.05%
2014	869.06	420	48.33%
2015	498.69	315	63.17%
2016	460.74	275	59.69%

Source: Bunkerindex, Methanex, and Clarkson's Database



Source: Bunkerindex, Methanex, and Clarkson's Database

Figure 12. Methanol-MDO price trend from 2004-2016

In addition, there are some assumptions required to perform the calculations:

1. The ship maintenance cost remains similar between, before and after conversion. As methanol is considered as a clean fuel compared to fossil oil fuel, the lifetime of lubricating oil and major spare parts remains equivalent at the same energy efficiency and output as of a diesel engine (Stojcevski, 2014).
2. The cost for methanol conversion is taken as 300 EUR/kW as an assumption. According to Stefenson (2014), the cost for methanol conversion was around 300 EUR/kW for Stena Germanica. Moreover, retrofitting costs from diesel into methanol-diesel fuel have been evaluated to be 250-350 EUR/kW for large engines around 10-25 MW (Andersson & Salazar, 2015).
3. The average exchange rate used is Rp.13319/USD and Rp.14630/EUR (Bank of Indonesia database, 2017).
4. The conversion started in the year-end of 2016.
5. Depreciation was taken as straight line. This means that the invested methanol technology cost is uniformly reduced through the remaining lifecycle of the ship.

5.1.1 Combinatorial scenario analysis of NPV calculation

Net Present Value (NPV) represents to what extent a project will increase a company's value. NPV calculated based on the following formula:

$$NPV = \sum_{t=0}^{n} \frac{CFt}{(1+r)^t} - \text{Capital cost}$$

Where r is the project's risk-adjusted of capital cost or discount rate, n is remaining economic life, and CFt is the net cash flow at time t that is calculated as EBTD – (Tax x EBT). NPV is considered as one of the best criteria for investment decisions from a company perspective. When the positive NPV is obtained in a project calculation, it will add value to the company and vice versa (Brigham & Ehrhardt, 2011).

Below is one of the example NPV calculations of MV. Labobar with combinatorial scenario of 40% methanol price to MDO and 95-5% composition methanol-MDO (see also Appendix C) :

$NPV_{(40\%;95\text{-}5)}$ = $NPV_{year\ 1}$ +.....$NPV_{year\ t}$ – Capital Cost

Where,

$CF_{year\ 1}$ = EBTD – 15% EBT

= Rp26,135,414,969.409 – 15% x Rp21,649,080,001.65

= Rp22,888,052,969.161

$NPV_{year\ 1}$ = $CF_{year\ 1}/ (1+ 0.08)^1$

= Rp22,888,052,969.161/ (1.08)

= Rp21,192,641,638.112

The other NPV is calculated as above untill the end of economic life of ship

$NPV_{(40\%;95\text{-}5)}$ = Rp21,192,641,638.112+.....+Rp10,997,383,736.250 – Rp80,754,029,420

$NPV_{(40\%;95\text{-}5)}$ = Rp199,376,909,066.557

Another NPV calculation with combinatorial scenario is calculated based on the above steps both MV. Labobar and MV. Gunung Dempo.

Figure 13 shows the scenario analysis of NPV of MV. Labobar in specific criteria. The investment needed for retrofitting a ship is feasible at any composition of methanol-MDO when the percentage of the methanol price toward MDO does not exceed 52%. On the other hand, investment in methanol technology in MV. Gunung Dempo is feasible at any scenario given as shown in Figure 14, as all of the NPVs at any scenario in MV. Gunung Dempo are positive.

From both figures, the changing behavior of NPV towards the percentage of the methanol price can be seen that the improvement of the payback period is directly proportional to the increment of methanol composition as main fuel up to 46% of the methanol price to MDO. However, from 48% above the trend will be the opposite way.

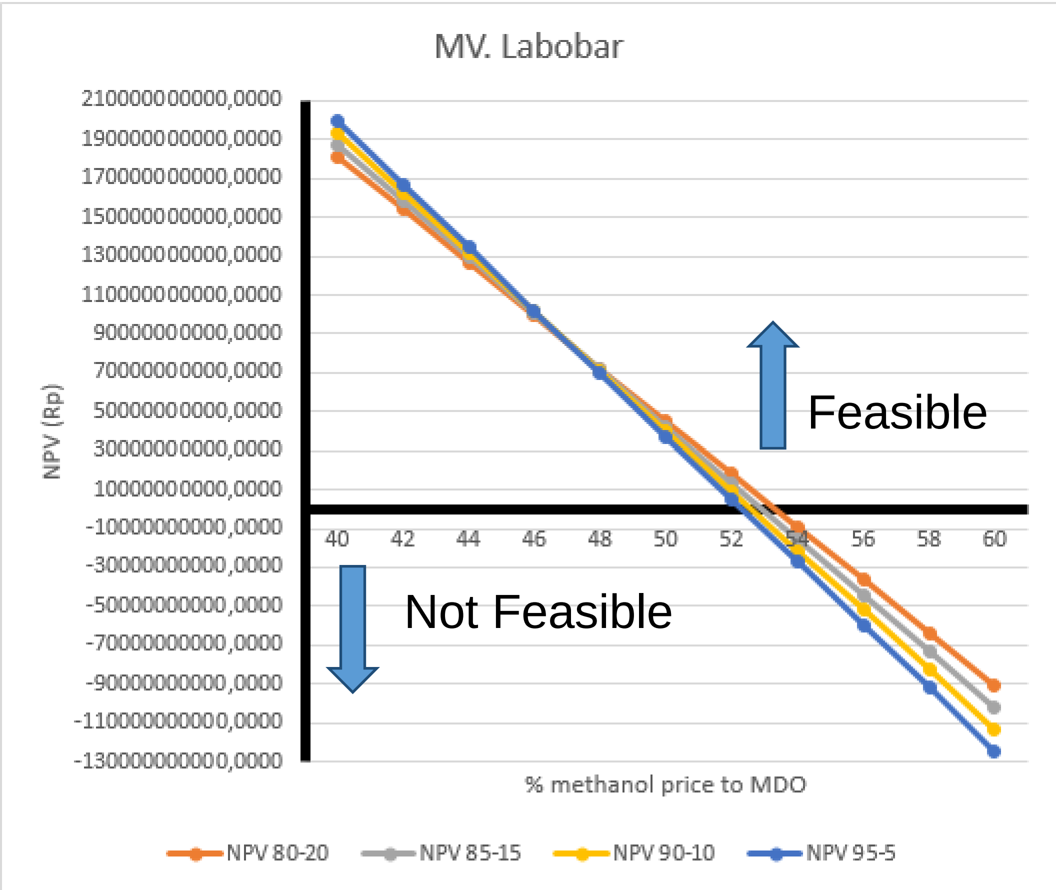


Figure 13. Scenario analysis of NPV-percentage of methanol composition-percentage of methanol price on MV. Labobar case

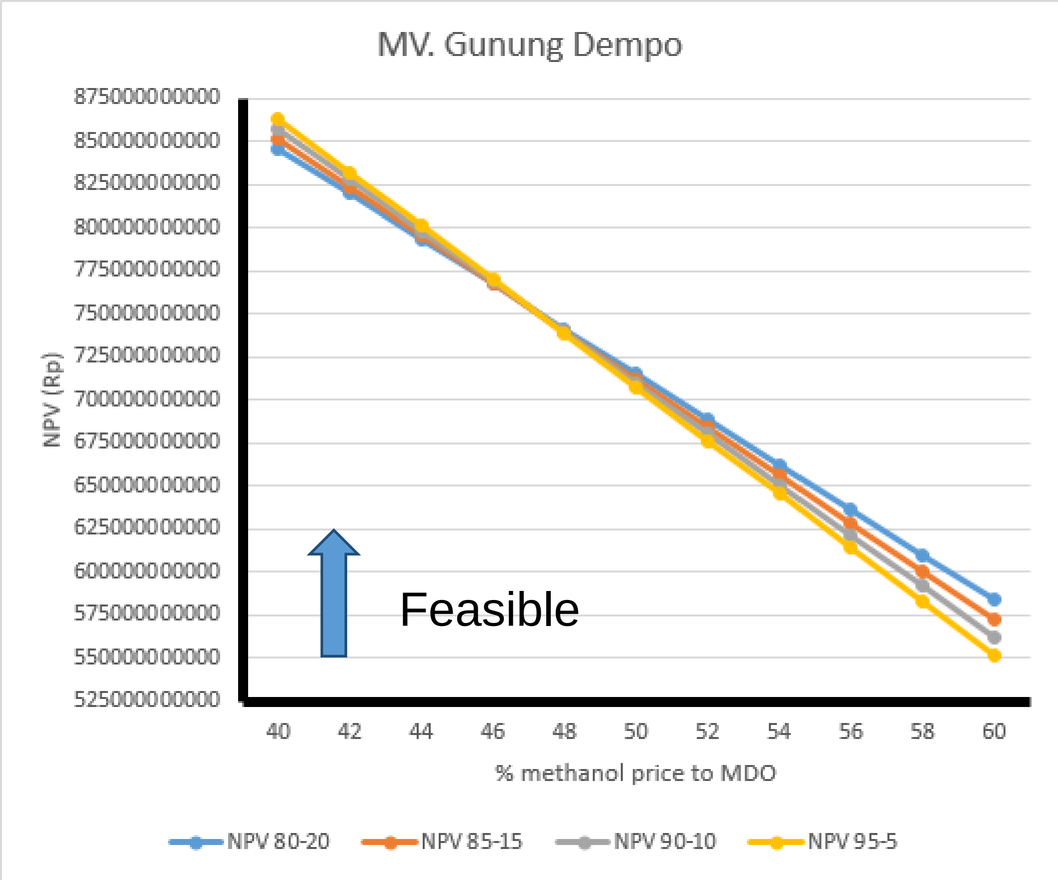


Figure 14. Scenario analysis of NPV-percentage of methanol composition-percentage of methanol price on MV. Gunung Dempo case

5.1.2 Combinatorial scenario analysis of Payback Period calculation

Together with NPV, the payback period is one of the best criteria that has to be considered in an investment analysis. The payback period is the time required when an investment or capital cost is recovered from the operating cashflow and indicated with a positive payback rate. In this study, the payback rate is calculated from discounted cash flow or present value (PV) toward capital cost. The payback period position is in between positive and negative cumulative discounted cash flow (Brigham & Ehrhardt, 2011). For the remaining period after the last negative payback rate, it is calculated as Present value of the first positive payback rate divided by 12, then multiplied with the number of months, which gives the first positive value when added to the last negative payback rate.

Below is one of the example NPV calculation of MV. Labobar with a combinatorial scenario of 40% of the methanol price to MDO and 95-5% composition methanol-MDO (see also Appendix C) :

Fisrt positive Payback rate = year of last negative payback rate (**in year 4**) + $PV_{positive}$/12 x **1 month**

= (-Rp706,164,030.81) + (Rp18,145,354,158.192/12 x 1)

= Rp805,948,815.70

So the payback period for these specific scenarios is 4.1 or 4 year and 1 month. Another determination of the payback period with the combinatorial scenario is calculated based on the above steps, both MV. Labobar and MV. Gunung Dempo.

Recently, PELNI does not use a corporate maximum payback time limit in technology investments for ships in decision-making processes (Santoso, 2017). Therefore, Table 11 in this study employed as analysis tools to determine how feasible methanol conversion is for a shipowner, where the colour also represents the payback time.

Table 11. Colour level of payback period of investment

No	Colour Level	Description
1	Highly Recommended	The payback time is ≤ 1/4 of remaining life cycle of the ship, **and** NPV is ≥ 3/2 of capital cost
2	Recommended	The payback time is 1/4<x≤1/2 of remaining life cycle of the ship, **and** NPV is 1≤x<3/2 of capital cost
3	Not Recommended	The payback time is 1/2<x≤3/4 of remaining life cycle of the ship, **and** NPV is 1/2≤x<1 of capital cost
4	Not Feasible	The payback time is > 3/4 of remaining life cycle of the ship, **and** NPV is < 1/2 of capital cost

Source: (Author, 2017)

Table 12 represents the combinatorial scenario analysis of the payback period of MV. Labobar in the applied scenarios. When looking at the results, retrofitting of MV. Labobar is highly recommended at any methanol composition when the percentage of the methanol price compared to MDO is 40%. Moreover, it is also advisable to retrofit at instances when the methanol price is up to 46% compared to MDO. However, when looking back to 2016 conditions, when the percentage of methanol over MDO was 59.69% and also based the revenue condition of MV. Labobar, shows that converting the ship into methanol as fuel is not feasible in any scenario from a shipowner's perspective. The condition might be changed if the shipowner can improve the revenue, for instance by improving container cargo capacity (MV. Labobar is a 2-in-1 ship, passenger and container cargo), or getting subsidies from the government for willing to implement green technology (this will be discussed in the government perspective below). In addition, the payback period changed with the percentage of methanol price. Up to 46%, the improvement of the payback period is directly proportional to the increment of methanol composition as main fuel. However, from 48% the trend will be the opposite way.

Table 12. Combinatorial scenario analysis of payback period-percentage of methanol-percentage of methanol price on MV. Labobar case

Methanol %	Methanol (USD/ton)	80-20	85-15	90-10	95-5
40	184	4.5	4.3	4.2	4.1
42	194	4.11	4.10	4.9	4.8
44	203	5.8	5.7	5.6	5.5
46	212	6.7	6.7	6.6	6.6
48	221	7.11	8	8.1	8.1
50	230	10	10.4	10.7	10.10
52	240	13.8	14.6	15.5	16.7
54	249				
56	258				
58	267				
60	276				

Table 13 represents the combinatorial scenario analysis of the payback period of MV. Gunung Dempo in the stated scenarios. Retrofitting of MV. Gunung Dempo is possible in all applied scenarios. Eventhough MV. Gunung Dempo is smaller than MV. Labobar in terms of size and passenger capacity, MV. Gunung Dempo can gain higher revenues from cargo than MV. Labobar, as shown in Appendix B. It can be concluded, from a shipowner's perspective, the decision of retrofitting a ship to running on methanol also depends on how productive the specific ship is.

Table 13. Combinatorial scenario analysis of payback period-percentage of methanol-percentage of methanol price on MV. Gunung Dempo case

Methanol %	Methanol (USD/ton)	80-20	85-15	90-10	95-5
40	184	1.1	1.1	1.1	1
42	194	1.1	1.1	1.1	1.1
44	203	1.1	1.1	1.1	1.1
46	212	1.2	1.2	1.2	1.2
48	221	1.2	1.2	1.2	1.2
50	230	1.3	1.3	1.3	1.3
52	240	1.3	1.3	1.4	1.4
54	249	1.4	1.4	1.4	1.4
56	258	1.4	1.5	1.5	1.5
58	267	1.5	1.5	1.6	1.6
60	276	1.6	1.6	1.6	1.7

5.2 Government perspective

Ensuring the welfare and regulation compliance for all maritime stakeholders is some of the government's considerations while developing business in the maritime sector. In the first attachment of the Presidential Regulation No. 16 of 2017 on Indonesian Maritime Policy, it is stated that the challenge in developing maritime countries is to build inter-regional connectivity and to optimize sea transportation to eliminate social and economic disparities and to facilitate the movement of people, goods, services, and capital. On the other hand, the efforts to increase maritime activities will have negative environmental impacts. Therefore, the government needs to make an effort through robust measures and policy, such as market-based intervention and regulations, to help stakeholders in improving their capability to comply with “green regulations”. One form of market-based intervention is providing subsidies when applying green technology in the maritime sector (UNEP, 2008).

In this section, the impact of methanol technology implementation on improvement of environmental protection and policy compliance will be evaluated. Further, an optimization and sensitivity analysis will be conducted to measure to what extent the government can provide subsidies to support green technology and welfare of shipping companies.

5.2.1 Environmental analysis and compliance

An environmental benefit analysis was conducted for the MV. Labobar and MV. Gunung Dempo in order to understand to what extent the application of methanol can reduce emissions generated during the operation of the ships annually. Moreover, a compliance analysis was also performed to understand to what extent the implementation of methanol as marine fuel can satisfy future environmental regulations. The parameters in the Table 14 are required for the analysis in addition to the data that has been obtained from the economic feasibility calculation in chapter 5.1.

Table 14. Input data for government perspective analysis

No	Parameter	Method	Sources
1	Methanol emission factor references	Literature review	(Brynolf et al, 2014)
2	MDO emission factor references		IMO 3rd GHG Study

There are six emission types to be analyzed, namely NOx, SOx, CO_2, CH_4, N_2O, and Particulate Matter (PM). The emission calculation is based on a one-year operation of the main engine and auxiliary engine in sailing and berthing conditions (see also Appendices E and F). For the case study, the basic formula to calculate the emission factor and total emission is used from IMO 3rd GHG Study (Smith et al, 2014) and expanded as per fuel characteristics and ship operations, as follows:

$$TE = ES + EP$$
$$ES \text{ or } EP = E_{M/E} + E_{A/E}$$
$$E_{M/E} = ((\%\ Methanol \times EF_{Methanol}) + (\%\ MDO \times EF_{MDO\ M/E})) \times P \times t \times T \times LF$$
$$E_{A/E} = EF_{MDO\ A/E} \times P \times t \times T \times n \times LF$$
$$EF_{MDO} = EF_{reference} \times SFOC_{M/E\ or\ A/E}$$
$$EF_{Methanol} = EF_{reference} \times LHV \times SFOC_{M/E}$$

Where:

TE = Total emission (tons/year)
ES = Emission during sailing (tons/year)
EP = Emission during berthing (tons/year)
EF = Emission factor (g pollutant/kWh)
P = Total operated engine power (kW)

t	= Average time of sailing or berthing (hours/trip)
T	= Number of trips annually
LF	= Average load factor
LHV	= Lower heating value (MJ/kg fuel)
SFOC	= Specific fuel oil consumption (g fuel/kWh*)*
M/E	= Main engine
A/E	= Auxiliary engine

Below is one of the examples of NOx emission calculations of the main engine MV. Labobar with 80-20 fuel composition scenario (see also Appendix E) :

$P_{M/E}$	= 9000 x 2 kW
$t_{sailing}$	= 198 hours/trip
$t_{berthing}$	= 0 (Main engine is off during berthing)
T	= 24
LF	= 0.8
LHV	= 20.1 MJ/kg fuel
SFOC	= 175 g fuel/kWh

EF_{MDO} = $EF_{reference}$ x $SFOC_{M/E}$
= 0.05684 g/gfuel x 175 gfuel/kWh
= 9.947 g/kWh

$EF_{Methanol}$ = $EF_{reference}$ x LHV x $SFOC_{M/E}$
= 0.28 g/MJ x 20.1 MJ/1000 gfuel x 175 gfuel/kWh
= 0.9849 g/kWh

$E_{M/E\ sailing}$ = ((% Methanol x $EF_{Methanol}$) + (% MDO x $EF_{MDO\ M/E}$)) x P x t x T x LF
= ((80%x0.9849) + (20%x9.947) tons/kWh) x 18000 kW x 198 h/trip x 24 trip/year x 0.8/1000000 g
= 190.0486 tons/year

$TE_{NOx\ M/E}$ = 190.0486 tons/year + 0
= 190.0486 tons/year

Another emission calculation is calculated based on the above formula; both MV. Labobar and MV. Gunung Dempo depend on the parameter, operational, and scenario required.

Table 15 shows that methanol has a clear advantage in terms of less fuel emission content compared to MDO. Even SOx, CH_4, and N_2O have zero value. Unlike the auxiliary engine of the two passenger ships, the emission factors for the main engine of MV. Labobar and MV. Gunung Dempo remains similiar since they have the same type of engine with the same SFOC but with a different number of cylinders.

Table 15. The result of emission factor of MV. Labobar and MV. Gunung Dempo

Emission	Methanol (g/kWh)	MDO (g/kWh)		
		M/E	A/E Labobar	A/E Gunung Dempo
NOx	0.9849	9.947	10.7996	10.5154
SOx	0	0.462	0.5016	0.4884
CO_2	242.7075	561.05	609.14	593.11
CH_4	0	0.0105	0.0114	0.0111
N_2O	0	0.02625	0.0285	0.02775
PM	0.01512525	0.1785	0.1938	0.1887

There are four (4) significant pollutants in the internal combustion engine, particularly in a diesel engine; CO_2, NOx, SOx, and PM. The other pollutants, CH_4, and N_2O are combined with SOx and PM in Figure 15 since their value is relatively low. CO_2 and NOx are separated to bring a clear picture since their value is much higher compared to the other pollutants.

5.2.1.1 N_2O, CH_4, SOx and PM analysis

According to Figure 15, N_2O and CH_4 have the lowest emissions compared to the other pollutants. The application of 80% methanol as main fuel in the main engine of MV Labobar and MV Gunung Dempo can reduce total emissions to become 59.65% compared to 100% MDO in the main engine (see Table 16). Subsequently, by increasing the composition of methanol by 5%, 4.5-4.7% of the emission reduction compared to the previous methanol percentage will be acquired. The reduction of SOx and PM followed the same trend. However, the reduction of

PM was slightly lower since methanol as fuel emits some PM despite that the SOx emission factor is zero. This is because the source of particulate matter not only comes from the sulfur conversion during the combustion process (IMO, 2016e).

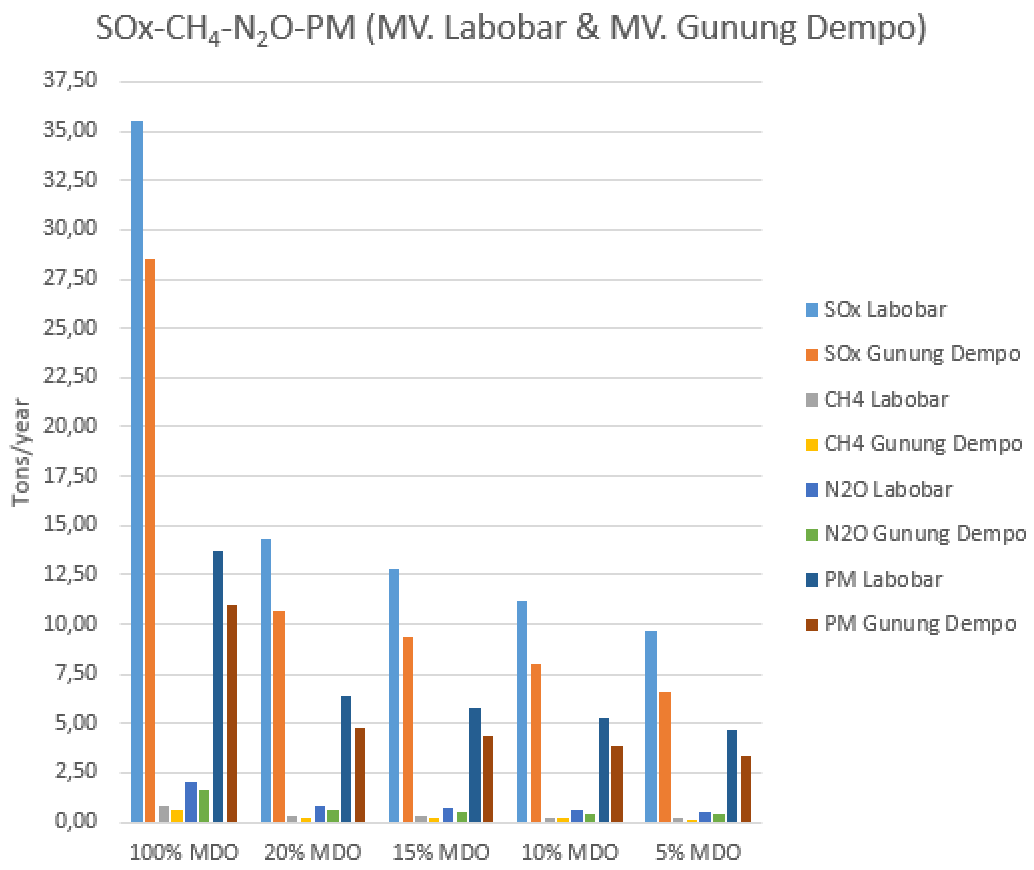


Figure 15. Total emission value of SOx-CH_4-N_2O-PM for MV. Labobar and MV. G. Dempo

Table 16. The percentage of total emission reduction of SOx-CH_4-N_2O-PM for MV. Labobar and MV. Gunung Dempo.

	% reduction SOx, N_2O, CH_4		% reduction PM	
	Labobar	G.Dempo	Labobar	G.Dempo
100% MDO	-	-	-	-
M-80	59.65%	62.66%	53.62%	56.33%
M-85	64.09%	67.33%	57.69%	60.61%
M-90	68.54%	72.00%	61.76%	64.88%
M-95	72.98%	76.68%	65.83%	69.16%

Currently, Pertamina's MDO products, which were marketed in Indonesia, have complied with national and IMO regulations with a maximum sulfur content of 1.5% m/m (Pertamina, 2009). This means that by using 100% MDO on board MV. Labobar and MV. Gunung Dempo, the ships still comply with the 3.5% m/m limit required in MARPOL Annex VI (chapter III-regulation 14). However, according to the new regulation of SOx and PM set-up by IMO, at the beginning of January 2020 the SOx and PM limit will be 0.5% m/m. Based on Figure 16, by using 100% MDO, neither of the ships will comply with this limit. Interestingly, by using methanol as marine fuel in all scenarios will help to satisfy the maximum limit of SOx and PM.

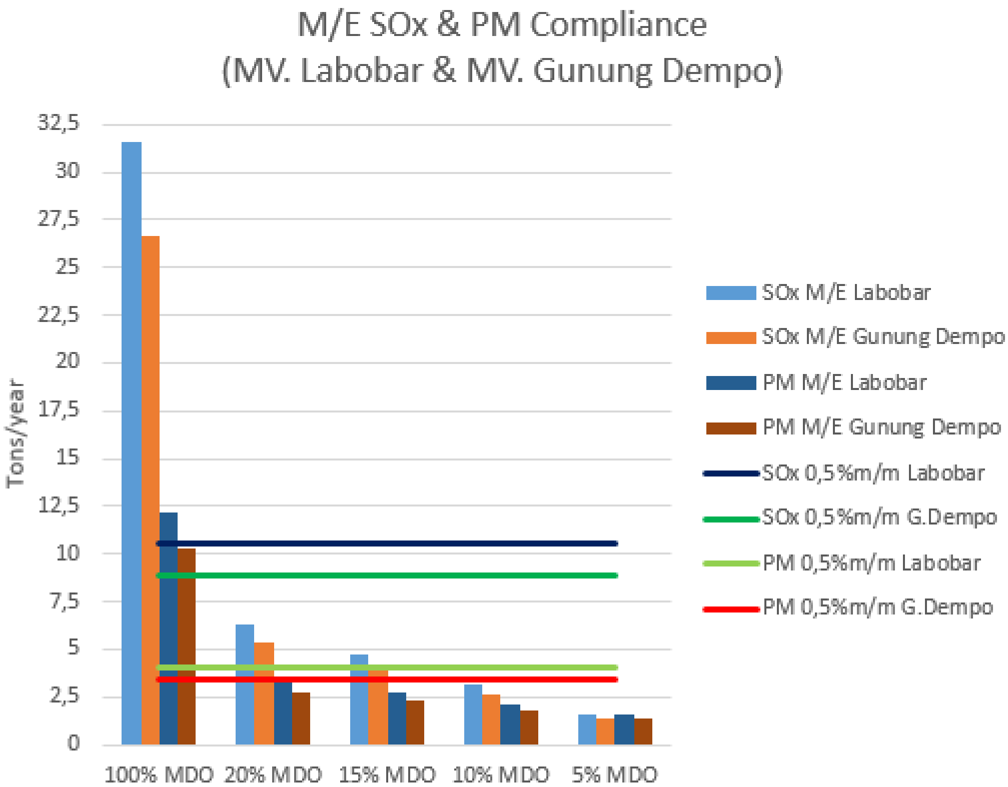


Figure 16. M/E SOx and PM value for MV. Labobar and MV. G. Dempo.

In addition to assisting in the compliance to the IMO regulations, the application of methanol as marine fuel will help the government commitment to protect the domestic environment from acidification, acid rain, and human health problem caused by SOx and PM pollution.

5.2.1.2 NOx analysis

Table 17 shows the improvement of total NOx reduction due to methanol fuel application compared to 100% MDO application on MV. Labobar and MV. Gunung Dempo. The 50-60% reduction can be achieved just using 80% of methanol as main fuel, the reduction will gradually increase with more methanol in the fuel composition.

Table 17. The percentage of total NOx reduction for MV. Labobar and MV. Gunung Dempo

	% reduction NOx	
	Labobar	G.Dempo
100% MDO	-	-
M-80	57.5%	60.08%
M-85	61.1%	63.84%
M-90	64.7%	67.59%
M-95	68.3%	71.35%

From the Figure 17, it can be seen that both main engines of MV. Labobar and MV. Gunung Dempo fulfill the IMO NOx code Tier I that applied for ships constructed after 1 January 2000, as they were built in 2004 and 2008. Eventhough the Tier II and III will not be imposed on these ships, an analysis for future regulation compliance can be done out of interest. For Tier II, the NOx emission value of the main engine is below the threshold for both MV. Labobar and MV. Gunung Dempo. Moreover, it will be difficult for ships of the same type and characteristic as MV. Labobar and MV. Gunung Dempo to comply with Tier III without applying measures to reduce NOx content. One way could be to implement methanol technology as methanol reduces NOx emission. However, not all of the scenarios resulted in NOx emissions below the Tier III threshold (see Figure 17). The possible scenarios for the ships were M-85, M-90, and M-95.

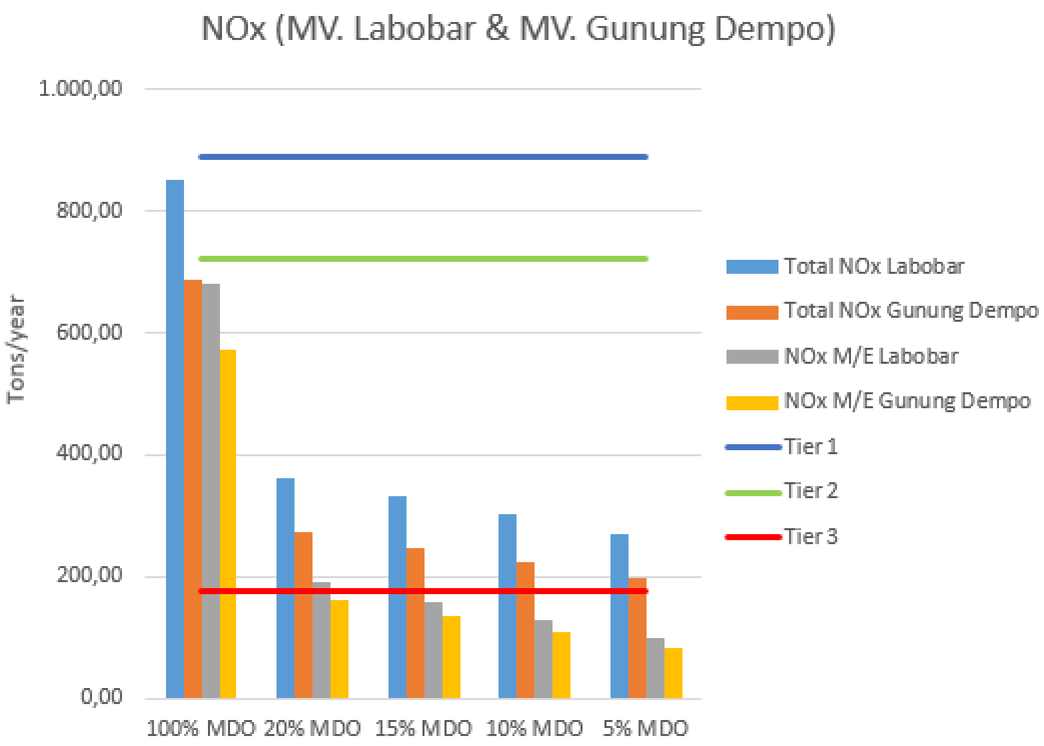


Figure 17. Emission value of NOx for MV. Labobar and MV. G.Dempo.

5.2.1.3 CO_2 analysis

Total emission value of CO_2 from MV. Labobar and MV. G. Dempo can be reduced by at least 28-30%, or 12,477 tons, annually by applying M-80. The reduction will gradually increase with a higher methanol composition (see Figure 18). This reduction is possible because methanol has a lower carbon factor compared to other fuels, even LNG.

Both of the ships are existing ships; hence, EEOI will be used to evaluate and quantify the energy efficiency improvement in the ship operations. Since PELNI does not have or implemented SEEMP, the EEOI used is the average EEOI on an annual basis (multiplying the annual fuel consumption with the carbon factor then divided by the gross tonnage of the passenger ship and the average of the voyage annually). Table 18 shows that applying M-95 can achieve 1.54925×10^{-05} $tonsCO_2/tonsNmiles$ or 36.45% of CO_2 reduction for MV. Labobar and 1.09174×10^{-05} $tonsCO_2/tonsNmiles$ or 38.28% of CO_2 reduction for MV. Gunung Dempo.

Table 18. The percentage of total CO_2 reduction and EEOI for MV. Labobar and MV. Gunung Dempo.

	% reduction CO_2		EEOI (tons CO_2/tons.Nmiles)	
	Labobar	G.Dempo	Labobar	G.Dempo
100% MDO	-	-	2.43796E-05	1.769E-05
M-80	28.89%	30.33%	1.73368E-05	1.23239E-05
M-85	31.41%	32.98%	1.6722E-05	1.18551E-05
M-90	33.93%	35.63%	1.61072E-05	1.13863E-05
M-95	36.45%	38.28%	1.54925E-05	1.09174E-05

Unlike EEDI, EEOI is not mandatory but only recommended by the IMO. Nonetheless, the result of EEOI per individual ship will give the general picture to the maritime stakeholder, especially the government, on how well the CO_2 reduction effectiveness of the applied technology is functioning. As shown in Figure 18 and Table 18, methanol as marine fuel is effectively reducing CO_2 and could be one of the government strategies to support the implementation of MARPOL annex VI chapter 4 that is already ratified by Indonesia.

5.2.2 Market-based intervention

Prior to establishing and stipulating a subsidy policy for methanol as marine fuel, the government need to have figures that show how a shipping company can improve its market when the government interferes with subsidies. Also, the government needs to know to what extent the subsidies, in terms of quantity and condition, can be given to the market. By a model optimization approach, the government may acquire such figures. Moreover, they can identify which variable has most influence on the policy-making on alternative fuel selection.

In this study, an optimization is conducted by using the OptQuest-Crystal Ball in the techno-economic model of MV. Labobar to achieve the above objectives. MV. Labobar model is selected as the basis of the optimization model because of the result gap between each payback time and NPV is wider than MV. Gunung Dempo. Hence, it will be easier to recognize the trend.

5.2.2.1 Optimization model

There are four (4) important components that have to be identified in the optimization model: assumptions, decision variables, optimization objectives, and constraints. The explanation of these components are as follows:

a. Assumptions containt an unpredicted value or are beyond internal control (Oracle, 2013). In this model the assumption variable was set as follows:
   - Total Revenue is set as normal distribution with mean value according to the total revenue in 2016.
   - Engine conversion cost is set as triangular distribution with minimum cost at 250 EUR/kWh and maximum cost at 350 EUR/kWh according to the Methanol Institute report (Andersson & Salazar, 2015). The likeliest is set up at 300 EUR/kWh based on the assumption in the techno-economy calculation.
   - The MDO price is set as normal distribution with a mean value according to the price in 2016.
   - The inflation is set as triangular distribution with minimum inflation of 4% and maximum 6% according to the regulation of the Ministry of Finance.
   - The exchange rate is set as normal distribution with a mean value at Rp. 13.319/USD.
b. Decision variables are the variables that can be controlled internally (Ora cle, 2013).
   - Percentage of methanol price compared with MDO price as the function of government subsidies. The variable is set at 43.49 as lower bounds and 73.02 as higher bounds. This value comes from the highest and lowest of the price percentage of methanol over MDO from 2004 to 2016.
   - Percentage of methanol composition is set based on the scenario in the techno-economy calculation; between 80 to 95% with interval 5%.
c. Optimization objectives are the target goal of the optimization (Oracle, 2013). Based on Table 12, it can clearly be seen that the boundary between recommended (light green) and not recommended (yellow) payback period is around 6-8 years. Therefore, the objective set year eight (8) as maximizing

mean of payback/return rate. By maximizing mean of payback rate will minimize the payback period.

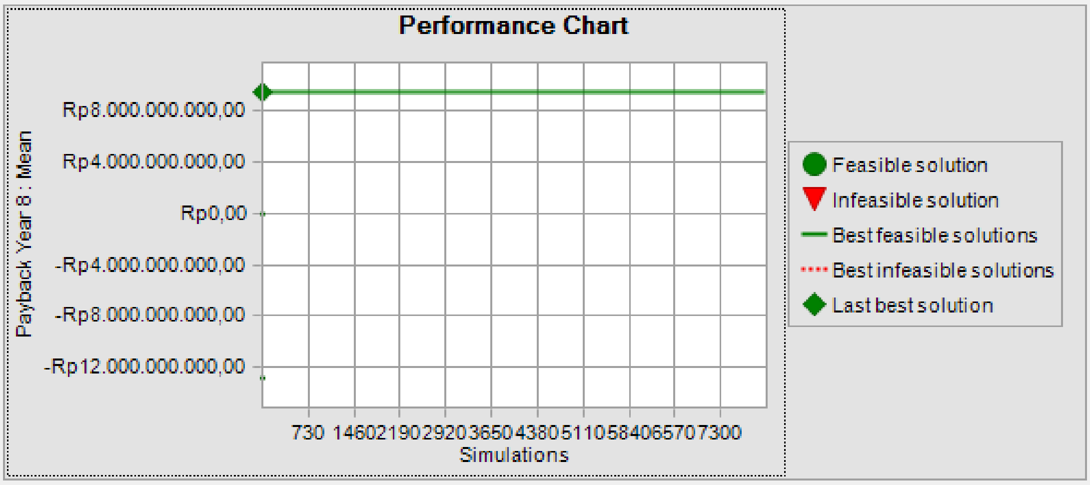
d. Constraints are the restrictions of the decision variables (Oracle, 2013).
   - The main engine dual fuel (methanol-MDO) will be determined as close as to when using 100% MDO. This means that the fuel cost is close to the business-as-usual cost of the shipping company, as the minimum standard.
   - The payback/ return rate after year 7 (seven) must be positive.

5.2.2.2 Optimization and sensitivity analysis

From Figure 19 it is shown that the optimum decision from the government's perspective is to maintain the price of methanol to 47% or less to MDO. According to Table 10, the percentage of methanol price compared to MDO for 2016 was 59.69%. Therefore, in order to support the introduction of methanol as a green technology and a sustainable marine fuel into the market, the government needs to subsidize the methanol by 12.6%, or USD 58/tons of methanol, or Rp 610.28/liter.

Moreover, from this study, it can be suggested that the government should support M-85 technology in the first introduction when the market condition is as in 2016. In addition, since the methanol technology in the maritime business is relatively novel, there are opportunities to improve the technology and advancing the product. Further, with time and a massive implementation, the price will be dropped and the government subsides can be reduced.

8000 Simulations Best Solution View



Best Solution:

Objectives	Value
Maximize the Mean of Payback Year 8	Rp9.358.244.849,12

Requirements	Value

Constraints	Left Side		Right Side
'Labobar (conversion economy)'!G7 >= 'Labobar (conversion economy)'!C7	66397860083,3...	>=	66352964545,1...
'Labobar (conversion economy)'!K28 >= 0	55960821266,523	>=	0

Decision Variables	Value
% methanol composition	0,85
% methanol price	47,00

Figure 18. OptQuest-Cristal Ball optimization result

There are also several external factors influencing a government decision to give subsidies based on the assumptions that have been made. Therefore, a sensitivity analysis was also conducted during the optimization. From figure 20, it can be concluded that the most influential external variable on government decision-making is the condition of the economic market uptake, represented in the total revenue by 52.7%. The exchange rate and the MDO price had almost the same influence, 25.2%, and 21.9% respectively. However, the engine conversion cost and the inflation had a smaller effect.

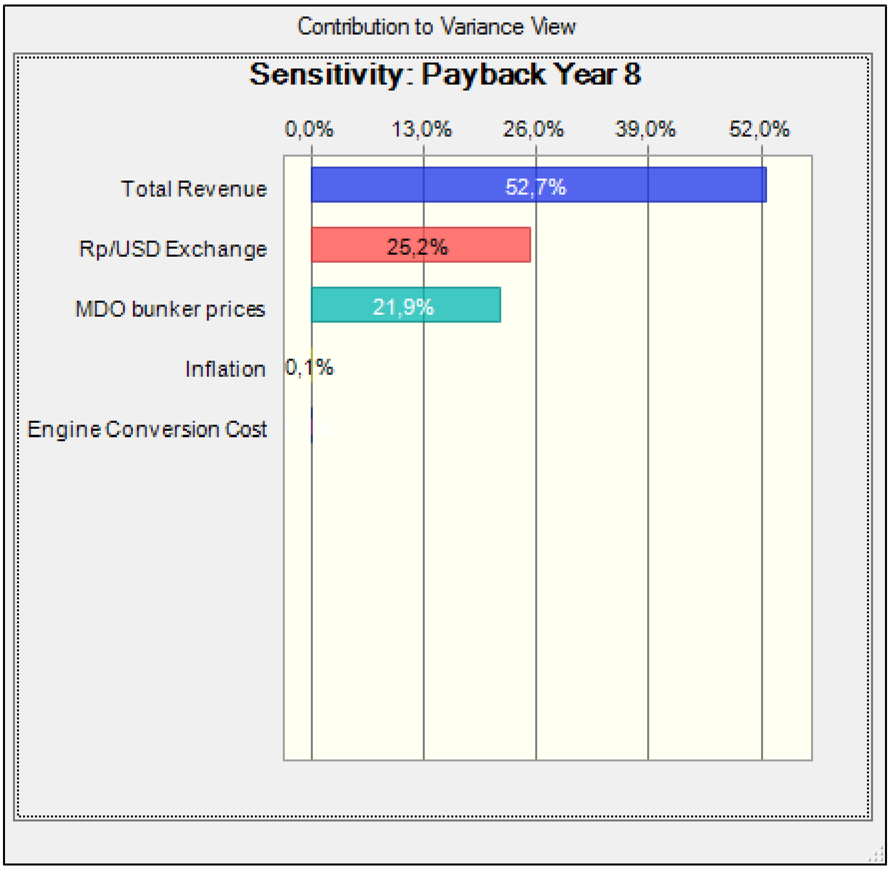


Figure 19. Sensitivity analysis of external factor for payback year-8

Generally, the result of the sensitivity analysis is logically acceptable since the government does not want to impose any new technology that can disrupt the maritime industry, for instance an exorbitant price of technology or a sluggish maritime business market. The MDO price is also considered as an external factor that can change the government decision. For instance, when the price of MDO becomes higher, the government will try to find a solution to maintain its maritime business such as introducing alternative fuels or subsidizing the fuel.

5.2.2.3 Verification

Moreover, verification of the optimization result is important. Simple verification was made by manually calculating the fuel cost of the main engine of MV. Labobar for each methanol composition scenario. Figure 21 shows that the position of the 47% line was the same as the 100% MDO line, which means that the fuel cost of the methanol as main fuel with various compositions will be close to the fuel cost of a business-as-usual condition of a shipping company. For the government perspectives, 47% was the optimum price of methanol where the optimum subsidies can maintain the market and keep the shipping company making profits as usual.

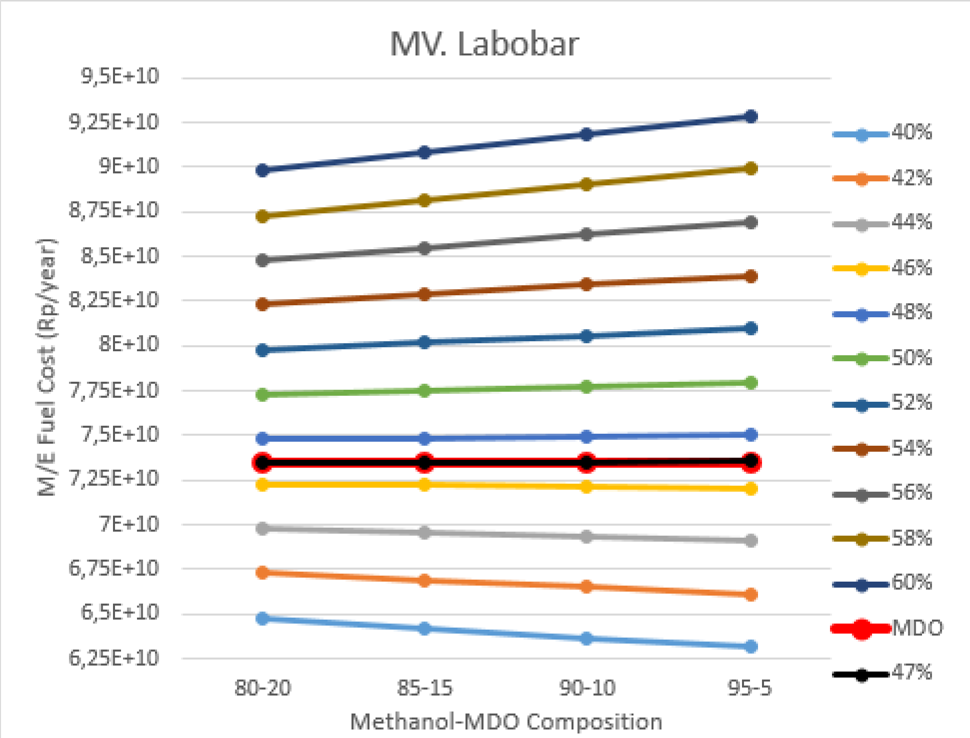


Figure 20. Verification of the optimization result based on fuel cost

From the shipowner's perspectives, the percentage was the minimum price of methanol to decide on investment of methanol technology on their fleet with favorable payback period. By inputting the scenario in methanol price to 47% with a composition of 85-15 in the techno-economic calculation, some economic criteria could be defined. Namely the payback period can be achieved by 7 year and 3 month with the positive NPV Rp86,057,237,977.600. When the criteria is plotted to Table 12, then the position will be between the light green and yellow area, which means that the criteria is the minimum criteria for the shipping companies to maintain their profit as business-as-usual if they want to apply methanol technology.

5.3 Discussion

The competitiveness of methanol as marine fuel generally depends on ship productivity and the price differences between methanol and MDO. Considering the different results of techno-economic calculations in the feasibility investment of MV. Labobar and MV. Gunung Dempo, it means the model should be applied to the individual ship. The result can not be generalized as the reference for other passenger ships, since it may vary depending on the revenue gained, engine size, maintenance cost, cargo capacity, and remaining economic life of each passenger ship.

However, the trend of the combinatorial scenario analysis can be considered for both ships as the reference for other passenger ships, since there are similiar trends and an interesting relationship between NPV, payback period, percentage of price, and percentage of methanol price to MDO. The payback period and NPV for each percentage of methanol composition are sensitive to the percentage of the methanol price. Up to 46% of the methanol price to MDO, the improvement of payback period and NPV are directly proportional to the increment of methanol composition as main fuel. While around 48% above the trend will be the opposite. These results can be considered as the indicative strategy for shipowners to select the operational option when dealing with the current market situation. When the price of methanol is close to or above 48% of the MDO price, then the lowest set-up methanol composition (80% methanol-20% MDO) can be operated to maintain the profit and payback time.

In terms of regulation compliance, running with dual-fuel methanol propulsion significantly reduces the emission. Generally, as seen from Tables 16-18, the higher methanol composition as main fuel, the higher performance of emission reduction is gained. Further, most of the scenario can comply with the recent and upcoming regulations, particularly MARPOL Annex VI. Therefore, in the policy compliance point of view, the application of methanol as marine fuel is feasible to get government support since it will help the government commitment to protect the domestic environment from negative impacts to the environment and human health caused by pollution from ships.

Decision-making and policy analysis using optimization can be performed as one of the government approaches in determining the optimum point and condition to introduce and establish methanol as marine fuel. The optimum point that the government should maintain is the methanol price at 47%. The MDO price has a similiar trend of combinatorial scenario analysis from the shipowner’s perspective. Moreover, from the sensitivity analysis result shown there are three main external variables that have to be taken into account in the policy-making, ie market situation, methanol price and exchange rate.

6. Conclusion

The aims of this study are to provide insight and to explore the future potential of methanol as an alternative marine fuel for domestic passenger ships in Indonesia. In order to fulfill the main objectives, the study focused on relevant specific goals to identify the current status of global methanol-fuelled passenger ships, including the technology and regulation development, and the potential application in Indonesia. For the Indonesian case, a thorough analysis, including economic, environmental, and technological aspects of methanol-fuelled passenger ships, compared with resource availability and stakeholder readiness, has been performed.

To date, two main projects of methanol fuelled internal combustion engine in passenger ships have been executed, ie Pilot Methanol and Methasip. Both of them were initiated by governments who collaborated with industrial stakeholders and research institutions. Safety, environmental, and technological maturity assessments were performed during these projects. Furthermore, since the application of methanol is relatively novel, the results of the assessments were also used by international institutions, like the IMO and classification societies, as the basis to develop supporting regulations on methanol as marine fuel.

Passenger ships are one of the best means of transport to connect islands in an archipelagic country like Indonesia. Some of the passenger ships are assigned to deliver services in uncompetitive commercial areas, but still also have to compete with air transportation. In addition, most of the present passenger ships are heavily dependent on fossil fuel, and therefore, vulnerable to fluctuations of fuel oil prices. In order to bring a sustainable passenger shipping market, methanol fuel can be one of the best options to be introduced in passenger ships in Indonesia. Abundant potential feedstock with availability of methanol producers and some of infrastructure in Indonesia has been identified. In addition, apart from domestic feedstock, running with dual-fuel methanol propulsion significantly reduces air emissions. From the emission calculations performed, most of the scenarios can comply with the recent and upcoming regulations, particularly of MARPOL Annex VI.

Subsequently, an economic analysis was performed using a techno-economic model based on case studies of two passenger ships owned by PELNI, ie MV. Labobar and MV. Gunung Dempo. The combinatorial scenario approach has been developed in this study, which is the combination of economic measures of merit (NPV and payback period) with the technical solution scenario (main-pilot fuel set up), which effectively provides a broader overview for shipowners not only to determine the feasibility of the investment of methanol technologies, but also to determine which ships are eligible for retrofitting and what scenarios of engine set-up to be operated onboard the ship based on ship age, ship productivity, and current and long-term market conditions.

It was found that the competitiveness of methanol application is mainly dependent on ship productivity and the price differences between methanol and MDO. Productivity of passenger ships, represented with revenue, can be improved by modifying and improving container cargo capacity (MV, Labobar is a 2-in-1 ship, passenger and container cargo), or by acquiring “green technology” subsidies as a market-based intervention from the government.

However, there is a trade-off situation in the market-based intervention. Ship-owners tend to get high income by having as many incentives as possible, while the government needs to provide subsidies that are as optimum as possible due to a limited state budget but still maintaining the market. Therefore, an optimization approach was developed and performed by utilizing the combinatorial scenario model; hence, the optimum methanol price was evaluated. The optimization result revealed that the optimum price of methanol was when the percentage of methanol price compared to MDO was 47%. That is the optimum percentage where both fuels costs are at the same value. Moreover, it could be the reference for the government to keep the percentage by giving subsidies for the market to be maintained and to keep the shipping company making profits as if they had been operating fully with MDO.

Giving support for methanol as marine fuel will improve and increase domestic methanol production and encourage other industrial sectors. Methanol hopefully can fulfill the energy transition needed since the oil reserves in Indonesia are decreasing. However, there are several issues that must be addressed and considered:

- In the short term, an initiative should come first from the government with a national policy including financial support, such as subsidies to the stakeholders to develop sustainable energy strategies ranging from model to full-scale experiment. This is important for gaining the trust from shipping companies that do not want to take the risk. The government also needs to stimulate academic and research institutions, engine manufacturers, methanol producers, and other parties involved in developing the market for methanol as marine fuel. Moreover, in order to bring clarity regarding the legal basis, the government should work together with classification societies to develop safety regulations for domestic passenger ships running on methanol.
- In the medium term, the government should develop a strong energy policy and a national strategic roadmap that includes methanol as one of the alternative fuels in transportation, particularly in marine transportation. The policy and strategic roadmap need to consider an incentives scheme, allocation of methanol fuel supplies, an inter-ministerial coordination framework, and explicit responsibilities for each party involved. In addition, Indonesia still has abundant resources of coal and natural gas that have not yet been absorbed by the domestic and international market. Therefore, it would be favourable to increase methanol production using coal and natural gas in the medium term of the energy transition.
- In the long term, considering Indonesia has ample waste as renewable feedstock resources, such as plantation waste and municipal waste, it would be favourable to shift the methanol feedstock from natural gas and coal into sustainable feedstock. Further, utilization of sustainable feedstock can help

the environment by reducing air emissions and by creating a circular economy. Moreover, volatility and uncertainty of future fuel price can be avoided. Unlike sustainable feedstock-based methanol, methanol production from natural gas highly depends on the natural gas price which is also volatile and uncertain.

This study gives broader insight to provide capacity building information for related stakeholders intending to develop strategic adaptation, planning, and implementation of methanol fuel for passenger ships in developing countries, particularly in Indonesia since this study area is relatively novel. Eventhough this study is concentrated on the possible application of a methanol fuelled internal combustion engine of passenger ships in Indonesia, the methodology approach using techno-economic calculation with the combinatorial scenario, which was developed to determine the feasibility of methanol technology application toward the market condition, can be utilized for other specific ships and not only passenger ship. Moreover, the optimization using the techno-economic model to identify the optimum condition for both shipowners and the government can be applied not only to the Indonesian market but also to other countries' markets by considering the relevant policy and economic conditions.

6.1 Further study

This study mainly focused on technical, environmental, economic, and policy-making perspectives of the potential implementation of methanol on board ships. It would be worth to further study the human element aspect, in terms of seafarer behaviour and perspectives towards new technology introduction with special attention on hazard risks, for example by conducting a survey and interview staff onshore and onboard ships. In addition, it is also important to conduct further assessment on the bunkering readiness of methanol as fuel of the existing infrastructure in Indonesia. Moreover, this assessment can be expanded to include potential ports that can install bunkering systems, by considering supply chain and logistics availability in the nearest area of the port being assessed.

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Appendix A. Synergy and coordination framework among stakeholder

Coordinating Level	Coordinating Ministry for Maritime Affairs	Coordinating Ministry for Economic Affair	Coordinating Ministry for Human Development	Ministry of National Development Planning	Establishing national energy roadmap in transportation sector
Feedstock	ESDM	Ministry of Agriculture	Ministry of Research and Technology		- Planning of feedstock allocation for Methanol Plant - Standardizing the economic price of methanol feedstock - Researh of methanol feedstock from renewable and sustainable materials
	SKK MIGAS	Ministry of Environtment and Forestry	BPPT		
	Oil and Gas Company	Ministry of Finance	LIPI		
Production	ESDM	Ministry of Industry	Ministry of Research and Technology		- Strategic Planning of methanol production using biomass feedstock - Determining of methanol allocation for marine transportation - Planning of technology R & D and improvement of production efficiency of methanol - Developing alternative fuel standard for marine transportation
		Petrochemical Industry	BPPT		
		Ministry of Finance	LIPI		
Distribution	Ministry of ESDM	Ministry of Trade	BPPT		- Standardizing of economic price of feedstock - Establishing DCS system and fuel availability in accordance with IMO - Development of methanol distribution system for marine fuel
	Ministry of Transportation	Ministry of Finance			
		Bunker Company			
Marine Transportation	Ministry of Transportation	Ministry of Finance	Ministry of Research and Technology		- Developing the safety regulation of methanol-fuelled ships - Establishing tax holiday policy for methanol-fueled vessels - Improving R & D for methanol technology and system in ships
	Classification Society (BKI)		BPPT		
			LIPI		

Appendix B. Revenue and cost related data

No	Parameter	Unit	KM. LABOBAR	KM. G. DEMPO
			2016	**2016**
1	Revenue (x Rp. 1,000,000)	Rp.		
	- Passenger	Rp.	87,656	77,339
	- Cargo	Rp.	17,782	61,922
	- Others	Rp.	726	1,020
	Total Revenue		**106,164**	**140,281**
2	Cost (x Rp. 1,000,000)			
	- M/E Fuel Cost	Rp.	73,486	61,857
	- Operation and Maintenance	Rp.	17,898	13,347

No	Parameters	**Labobar**	**Gunung Dempo**	**Unit**
1	Engine Conversion (Capital Cost) 300 EUR/kW	79,002,000,000	52,668,000,000	Rp
2	Opportunity Cost	13,270,500,000	16,833,720,000	Rp
	- Revenue/trip	4,423,500,000	5,611,240,000	Rp/days
	- No of days/1 trip	15	14	days
	- Day loss	43	40	days
	- No of trip loss	3	3	trip
3	Total Fuel unused	11,518,470,580	8,992,224,217	Rp
	- F.C/trip	626	488	T/trip
4	Total	**80,754,029,420**	**60,509,495,783**	Rp

Appendix C. Techno-economic calculation of MV. Labobar

Below is a calculation using combinatorial scenario of 40% methanol price to MDO and 95-5% composition methanol-MDO, another combinatorial scenario is calculated in the same way.

No	Fuel	Methanol	MDO	Methanol	MDO
		0	100%	80%	20%
1	Consumption	0	11975.04	20399.27212	2395.008
2	Price/t (usd)	$0	$5,517,380	$3,759,504	$1,103,476
3	Price/t (Rp)	Rp0	Rp73,485,983,282	Rp50,072,837,166	Rp14,697,196,656
4	Fuel Cost (usd)	$5,517,380		$4,862,980	
5	Fuel Cost (Rp)	Rp73,485,983,282		Rp64,770,033,822	

MDO Price	460.74	$/t
Methanol Price	184	$/t
% of methanol-MDO	40%	

Inflation	0.04
Discount Rate	0.08

No			1	2	3
		2016	**2017**	**2018**	**2019**
1	**Revenue**	Rp106,164,000,000	Rp110,410,560,000.00	Rp114,826,982,400.00	Rp119,420,061,696.00
2	**O & M Cost**	Rp17,898,000,000	Rp18,613,920,000.00	Rp19,358,476,800.00	Rp20,132,815,872.00
3	**M/E Fuel Cost**				
	- Methanol	Rp59,461,494,135	Rp61,839,953,899.91	Rp64,313,552,055.91	Rp66,886,094,138.14
	- MDO	Rp3,674,299,164	Rp3,821,271,130.68	Rp3,974,121,975.91	Rp4,133,086,854.95
4	**EBITDA**		Rp26,135,414,969.409	Rp27,180,831,568.185	Rp28,268,064,830.913
5	**Depreciation**		Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757
6	**EBIT**		Rp21,649,080,001.65	Rp22,694,496,600.43	Rp23,781,729,863.16
7	**Tax**		Rp3,247,362,000.25	Rp3,404,174,490.06	Rp3,567,259,479.47
8	**Net Income**		Rp18,401,718,001.404	Rp19,290,322,110.364	Rp20,214,470,383.682
9	**Net Cashflow**		Rp22,888,052,969.161	Rp23,776,657,078.121	Rp24,700,805,351.439
10	**NPV**	Rp199,376,909,066.557	Rp21,192,641,638.112	Rp20,384,651,130.076	Rp19,608,295,667.136
11	**Payback rate**	-Rp80,754,029,420	-Rp59,561,387,781.52	-Rp39,176,736,651.44	-Rp19,568,440,984.31
			1	2	3

Methanol	MDO	Methanol	MDO	Methanol	MDO
85%	15%	90%	10%	95%	5%
21674.22663	1796.256	22949.18113	1197.504	24224.13564	598.752
$3,994,473	$827,607	$4,229,442	$551,738	$4,464,411	$275,869
Rp53,202,389,489	Rp11,022,897,492	Rp56,331,941,812	Rp7,348,598,328	Rp59,461,494,135	Rp3,674,299,164
$4,822,080		$4,781,180		$4,740,280	
Rp64,225,286,981		Rp63,680,540,140		Rp9,580,106,484	

Rp/USD 13319

4	5	6	7	8	9
2020	**2021**	**2022**	**2023**	**2024**	**2025**
Rp124,196,864,163.84	Rp129,164,738,730.39	Rp134,331,328,279.61	Rp139,704,581,410.79	Rp145,292,764,667.23	Rp151,104,475,253.92
Rp20,938,128,506.88	Rp21,775,653,647.16	Rp22,646,679,793.04	Rp23,552,546,984.76	Rp24,494,648,864.15	Rp25,474,434,818.72
Rp69,561,537,903.67	Rp72,343,999,419.81	Rp75,237,759,396.61	Rp78,247,269,772.47	Rp81,377,160,563.37	Rp84,632,246,985.90
Rp4,298,410,329.14	Rp4,470,346,742.31	Rp4,649,160,612.00	Rp4,835,127,036.48	Rp5,028,532,117.94	Rp5,229,673,402.66
Rp29,398,787,424.149	Rp30,574,738,921.115	Rp31,797,728,477.960	Rp33,069,637,617.078	Rp34,392,423,121.761	Rp35,768,120,046.632
Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757
Rp24,912,452,456.39	Rp26,088,403,953.36	Rp27,311,393,510.20	Rp28,583,302,649.32	Rp29,906,088,154.00	Rp31,281,785,078.87
Rp3,736,867,868.46	Rp3,913,260,593.00	Rp4,096,709,026.53	Rp4,287,495,397.40	Rp4,485,913,223.10	Rp4,692,267,761.83
Rp21,175,584,587.933	Rp22,175,143,360.354	Rp23,214,684,483.672	Rp24,295,807,251.923	Rp25,420,174,930.903	Rp26,589,517,317.043
Rp25,661,919,555.690	Rp26,661,478,328.112	Rp27,701,019,451.429	Rp28,782,142,219.680	Rp29,906,509,898.661	Rp31,075,852,284.801
Rp18,862,276,953.494	Rp18,145,354,158.192	Rp17,456,341,091.989	Rp16,794,103,540.252	Rp16,157,556,742.297	Rp15,545,663,008.201
-Rp706,164,030.81	Rp17,439,190,127.38	Rp34,895,531,219.37	Rp51,689,634,759.62	Rp67,847,191,501.92	Rp83,392,854,510.12
4	5	6	7	8	9

10	11	12	13	14	15
2026	**2027**	**2028**	**2029**	**2030**	**2031**
Rp157,148,654,264.07	Rp163,434,600,434.63	Rp169,971,984,452.02	Rp176,770,863,830.10	Rp183,841,698,383.30	Rp191,195,366,318.64
Rp26,493,412,211.47	Rp27,553,148,699.93	Rp28,655,274,647.92	Rp29,801,485,633.84	Rp30,993,545,059.20	Rp32,233,286,861.56
Rp88,017,536,865.34	Rp91,538,238,339.95	Rp95,199,767,873.55	Rp99,007,758,588.49	Rp102,968,068,932.04	Rp107,086,791,689.32
Rp5,438,860,338.76	Rp5,656,414,752.32	Rp5,882,671,342.41	Rp6,117,978,196.10	Rp6,362,697,323.95	Rp6,617,205,216.91
Rp37,198,844,848.497	Rp38,686,798,642.437	Rp40,234,270,588.134	Rp41,843,641,411.660	Rp43,517,387,068.126	Rp45,258,082,550.851
Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757
Rp32,712,509,880.74	Rp34,200,463,674.68	Rp35,747,935,620.38	Rp37,357,306,443.90	Rp39,031,052,100.37	Rp40,771,747,583.09
Rp4,906,876,482.11	Rp5,130,069,551.20	Rp5,362,190,343.06	Rp5,603,595,966.59	Rp5,854,657,815.06	Rp6,115,762,137.46
Rp27,805,633,398.629	Rp29,070,394,123.478	Rp30,385,745,277.321	Rp31,753,710,477.317	Rp33,176,394,285.314	Rp34,655,985,445.630
Rp32,291,968,366.386	Rp33,556,729,091.235	Rp34,872,080,245.078	Rp36,240,045,445.074	Rp37,662,729,253.071	Rp39,142,320,413.387
Rp14,957,429,464.747	Rp14,391,905,922.668	Rp13,848,182,857.928	Rp13,325,389,500.181	Rp12,822,692,022.079	Rp12,339,291,823.437
Rp98,350,283,974.86	Rp112,742,189,897.53	Rp126,590,372,755.46	Rp139,915,762,255.64	Rp152,738,454,277.72	Rp165,077,746,101.16
10	11	12	13	14	15

16	17	18
2032	**2033**	**2034**
Rp198,843,180,971.38	Rp206,796,908,210.24	Rp215,068,784,538.65
Rp33,522,618,336.03	Rp34,863,523,069.47	Rp36,258,063,992.25
Rp111,370,263,356.89	Rp115,825,073,891.16	Rp120,458,076,846.81
Rp6,881,893,425.58	Rp7,157,169,162.61	Rp7,443,455,929.11
Rp47,068,405,852.885	Rp48,951,142,087.001	Rp50,909,187,770.481
Rp4,486,334,967.757	Rp4,486,334,967.757	Rp4,486,334,967.757
Rp42,582,070,885.13	Rp44,464,807,119.24	Rp46,422,852,802.72
Rp6,387,310,632.77	Rp6,669,721,067.89	Rp6,963,427,920.41
Rp36,194,760,252.359	Rp37,795,086,051.357	Rp39,459,424,882.315
Rp40,681,095,220.116	Rp42,281,421,019.114	Rp43,945,759,850.072
Rp11,874,423,904.694	Rp11,427,355,324.457	Rp10,997,383,736.250
Rp176,952,170,005.85	Rp188,379,525,330.31	Rp199,376,909,066.56
16	17	18

Appendix D. Techno-economic calculation of MV. Gunung Dempo

Below is a calculation using combinatorial scenario of 40% methanol price to MDO and 95-5% composition methanol-MDO, another combinatorial scenario is calculated in the same way.

		Methanol	MDO	Methanol	MDO
No	Fuel	0	100%	80%	20%
1	Consumption	0	10080	17171.10448	2016
2	Price/t (usd)	$0	$4,644,259	$3,639,251	$928,852
3	Price/t (Rp)	Rp0	Rp61,856,888,285	Rp48,471,180,758	Rp12,371,377,657
4	Fuel Cost (usd)	$4,644,259		$4,568,103	
5	Fuel Cost (Rp)	Rp61,856,888,285		Rp60,842,558,415	

460.74 $/t

212 $/t

46%

Inflation 4

Discount Rate 0.08

No			1	2	3
		2016	2017	2018	2019
		1	1.04	1.0816	1.124864
1	**Revenue**	Rp140,281,000,000	Rp145,892,240,000.00	Rp151,727,929,600.00	Rp157,797,046,784.00
2	**O & M Cost**	Rp13,347,000,000	Rp13,880,880,000.00	Rp14,436,115,200.00	Rp15,013,559,808.00
3	**M/E Fuel Cost**				
	- Methanol	Rp57,559,527,150	Rp59,861,908,236.44	Rp62,256,384,565.90	Rp64,746,639,948.54
	- MDO	Rp3,092,844,414	Rp3,216,558,190.81	Rp3,345,220,518.44	Rp3,479,029,339.18
4	**EBITDA**		Rp68,932,893,572.746	Rp71,690,209,315.656	Rp74,557,817,688.282
5	**Depreciation**		Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503
6	**EBIT**		Rp66,182,461,946.24	Rp68,939,777,689.15	Rp71,807,386,061.78
7	**Tax**		Rp9,927,369,291.94	Rp10,340,966,653.37	Rp10,771,107,909.27
8	**Net Income**		Rp56,255,092,654.307	Rp58,598,811,035.781	Rp61,036,278,152.513
9	**Net Cashflow**		Rp59,005,524,280.810	Rp61,349,242,662.283	Rp63,786,709,779.015
10	**NPV**	Rp769,970,933,555.836	Rp54,634,744,704.453	Rp52,597,087,330.490	Rp50,635,946,771.179
11	**Payback Year**	-Rp60,509,495,783	-Rp5,874,751,078.60	Rp46,722,336,251.888	Rp97,358,283,023.066
			1	2	3

Methanol	MDO	Methanol	MDO	Methanol	MDO
0.85	0.15	90%	10%	95%	5%
18244.29851	1512	19317.49254	1008	20390.68657	504
$3,866,704	$696,639	$4,094,157	$464,426	$4,321,610	$232,213
Rp51,500,629,556	Rp9,278,533,243	Rp54,530,078,353	Rp6,185,688,828	Rp57,559,527,150	Rp3,092,844,414
$4,563,343		$4,558,583		$4,553,823	
Rp60,779,162,798		Rp60,715,767,182		Rp9,203,276,742	

Rp/USD 13319

4	5	6	7	8	9
2020	**2021**	**2022**	**2023**	**2024**	**2025**
1.16985856	1.216652902	1.265319018	1.315931779	1.36856905	1.423311812
Rp164,108,928,655.36	Rp170,673,285,801.57	Rp177,500,217,233.64	Rp184,600,225,922.98	Rp191,984,234,959.90	Rp199,663,604,358.30
Rp15,614,102,200.32	Rp16,238,666,288.33	Rp16,888,212,939.87	Rp17,563,741,457.46	Rp18,266,291,115.76	Rp18,996,942,760.39
Rp67,336,505,546.48	Rp70,029,965,768.34	Rp72,831,164,399.07	Rp75,744,410,975.04	Rp78,774,187,414.04	Rp81,925,154,910.60
Rp3,618,190,512.75	Rp3,762,918,133.26	Rp3,913,434,858.59	Rp4,069,972,252.93	Rp4,232,771,143.05	Rp4,402,081,988.77
Rp77,540,130,395.814	Rp80,641,735,611.646	Rp83,867,405,036.112	Rp87,222,101,237.557	Rp90,710,985,287.059	Rp94,339,424,698.541
Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503
Rp74,789,698,769.31	Rp77,891,303,985.14	Rp81,116,973,409.61	Rp84,471,669,611.05	Rp87,960,553,660.56	Rp91,588,993,072.04
Rp11,218,454,815.40	Rp11,683,695,597.77	Rp12,167,546,011.44	Rp12,670,750,441.66	Rp13,194,083,049.08	Rp13,738,348,960.81
Rp63,571,243,953.914	Rp66,207,608,387.372	Rp68,949,427,398.168	Rp71,800,919,169.396	Rp74,766,470,611.473	Rp77,850,644,111.233
Rp66,321,675,580.417	Rp68,958,040,013.875	Rp71,699,859,024.671	Rp74,551,350,795.898	Rp77,516,902,237.975	Rp80,601,075,737.735
Rp48,748,411,439.088	Rp46,931,683,333.824	Rp45,183,073,409.148	Rp43,499,997,143.225	Rp41,879,970,302.160	Rp40,320,604,887.487
Rp146,106,694,462.154	Rp193,038,377,795.979	Rp238,221,451,205.126	Rp281,721,448,348.351	Rp323,601,418,650.511	Rp363,922,023,537.997
4	5	6	7	8	9

10	11	12	13	14	15
2026	**2027**	**2028**	**2029**	**2030**	**2031**
1.480244285	1.539454056	1.601032219	1.665073507	1.731676448	1.800943506
Rp207,650,148,532.63	Rp215,956,154,473.94	Rp224,594,400,652.89	Rp233,578,176,679.01	Rp242,921,303,746.17	Rp252,638,155,896.02
Rp19,756,820,470.81	Rp20,547,093,289.64	Rp21,368,977,021.22	Rp22,223,736,102.07	Rp23,112,685,546.15	Rp24,037,192,968.00
Rp85,202,161,107.02	Rp88,610,247,551.30	Rp92,154,657,453.36	Rp95,840,843,751.49	Rp99,674,477,501.55	Rp103,661,456,601.61
Rp4,578,165,268.32	Rp4,761,291,879.05	Rp4,951,743,554.22	Rp5,149,813,296.38	Rp5,355,805,828.24	Rp5,570,038,061.37
Rp98,113,001,686.483	Rp102,037,521,753.942	Rp106,119,022,624.100	Rp110,363,783,529.064	Rp114,778,334,870.226	Rp119,369,468,265.035
Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503
Rp95,362,570,059.98	Rp99,287,090,127.44	Rp103,368,590,997.60	Rp107,613,351,902.56	Rp112,027,903,243.72	Rp116,619,036,638.53
Rp14,304,385,509.00	Rp14,893,063,519.12	Rp15,505,288,649.64	Rp16,142,002,785.38	Rp16,804,185,486.56	Rp17,492,855,495.78
Rp81,058,184,550.983	Rp84,394,026,608.324	Rp87,863,302,347.958	Rp91,471,349,117.177	Rp95,223,717,757.165	Rp99,126,181,142.753
Rp83,808,616,177.486	Rp87,144,458,234.826	Rp90,613,733,974.460	Rp94,221,780,743.680	Rp97,974,149,383.668	Rp101,876,612,769.255
Rp38,819,605,258.800	Rp37,374,764,423.184	Rp35,983,960,483.546	Rp34,645,153,238.371	Rp33,356,380,925.833	Rp32,115,757,105.530
Rp402,741,628,796.797	Rp440,116,393,219.982	Rp476,100,353,703.528	Rp510,745,506,941.899	Rp544,101,887,867.733	Rp576,217,644,973.262
10	11	12	13	14	15

16	17	18	19
2032	**2033**	**2034**	**2035**
1.872981246	1.947900496	2.025816515	2.106849176
Rp262,743,682,131.86	Rp273,253,429,417.13	Rp284,183,566,593.82	Rp295,550,909,257.57
Rp24,998,680,686.72	Rp25,998,627,914.19	Rp27,038,573,030.76	Rp28,120,115,951.99
Rp107,807,914,865.68	Rp112,120,231,460.30	Rp116,605,040,718.71	Rp121,269,242,347.46
Rp5,792,839,583.82	Rp6,024,553,167.18	Rp6,265,535,293.86	Rp6,516,156,705.62
Rp124,144,246,995.637	Rp129,110,016,875.462	Rp134,274,417,550.481	Rp139,645,394,252.500
Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503
Rp121,393,815,369.13	Rp126,359,585,248.96	Rp131,523,985,923.98	Rp136,894,962,626.00
Rp18,209,072,305.37	Rp18,953,937,787.34	Rp19,728,597,888.60	Rp20,534,244,393.90
Rp103,184,743,063.764	Rp107,405,647,461.616	Rp111,795,388,035.381	Rp116,360,718,232.098
Rp105,935,174,690.267	Rp110,156,079,088.118	Rp114,545,819,661.884	Rp119,111,149,858.600
Rp30,921,467,671.499	Rp29,771,767,990.480	Rp28,664,980,159.693	Rp27,599,490,378.719
Rp607,139,112,644.761	Rp636,910,880,635.241	Rp665,575,860,794.935	Rp693,175,351,173.653
16	17	18	19

20	21	22
2036	**2037**	**2038**
2.191123143	2.278768069	2.369918792
Rp307,372,945,627.87	Rp319,667,863,452.99	Rp332,454,577,991.11
Rp29,244,920,590.07	Rp30,414,717,413.67	Rp31,631,306,110.22
Rp126,120,012,041.36	Rp131,164,812,523.02	Rp136,411,405,023.94
Rp6,776,802,973.84	Rp7,047,875,092.80	Rp7,329,790,096.51
Rp145,231,210,022.600	Rp151,040,458,423.504	Rp157,082,076,760.444
Rp2,750,431,626.503	Rp2,750,431,626.503	Rp2,750,431,626.503
Rp142,480,778,396.10	Rp148,290,026,797.00	Rp154,331,645,133.94
Rp21,372,116,759.41	Rp22,243,504,019.55	Rp23,149,746,770.09
Rp121,108,661,636.683	Rp126,046,522,777.451	Rp131,181,898,363.850
Rp123,859,093,263.185	Rp128,796,954,403.954	Rp133,932,329,990.353
Rp26,573,746,430.308	Rp25,586,255,265.250	Rp24,635,580,686.624
Rp719,749,097,603.962	Rp745,335,352,869.212	Rp769,970,933,555.836
20	21	22

Appendix E. Emission calculation MV. Labobar

Sailing condition

No	Fuel	Unit	M/E		A/E	M/E		A/E	M/E		A/E	M/E		A/E	M/E		A/E
			Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO
			0	100%	100%	80%	20%	100%	85%	15%	100%	90%	10%	100%	95%	5%	100%
1	NOx	Ton/year	0	680.661274	87.7566856	53.91642	136.1322547	87.756686	57.28619635	102.099191	87.756686	60.65597261	68.0661274	87.75668563	64.02574886	34.0330637	87.756686
2	SOx	Ton/year	0	31.6141056	4.07596147	0	6.32282112	4.0759615	0	4.74211584	4.0759615	0	3.16141056	4.075961472	0	1.58070528	4.0759615
3	CO2	Ton/year	0	38391.9782	4949.82291	13286.55	7678.395648	4949.8229	14116.95553	5758.796736	4949.8229	14947.36468	3839.19782	4949.822909	15777.77383	1919.59891	4949.8229
4	CH4	Ton/year	0	0.7185024	0.09263549	0	0.14370048	0.0926355	0	0.10777536	0.0926355	0	0.07185024	0.092635488	0	0.03592512	0.0926355
5	N2O	Ton/year	0	1.796256	0.23158872	0	0.3592512	0.2315887	0	0.2694384	0.2315887	0	0.1796256	0.23158872	0	0.0898128	0.2315887
6	PM	Ton/year	0	12.2145408	1.5748033	0.828002	2.44290816	1.5748033	0.879752301	1.83218112	1.5748033	0.931502436	1.22145408	1.574803296	0.983252572	0.61072704	1.5748033

Port condition

No	Fuel	Unit	M/E		A/E	M/E		A/E	M/E		A/E
			Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO
			0	100%	100%	80%	20%	100%	85%	15%	100%
1	NOx	ton/ year	0	0	85.0973921	0	0	85.097392	0	0	85.097392
2	SOx	ton/ year	0	0	3.95244749	0	0	3.9524475	0	0	3.9524475
3	CO2	ton/ year	0	0	4799.82828	0	0	4799.8283	0	0	4799.8283
4	CH4	ton/ year	0	0	0.08982835	0	0	0.0898284	0	0	0.0898284
5	N2O	ton/ year	0	0	0.22457088	0	0	0.2245709	0	0	0.2245709
6	PM	ton/ year	0	0	1.52708198	0	0	1.527082	0	0	1.527082

M/E		A/E	M/E		A/E
Methanol	MDO	MDO	Methanol	MDO	MDO
90%	10%	100%	95%	5%	100%
0	0	85.09739213	0	0	85.097392
0	0	3.952447488	0	0	3.9524475
0	0	4799.828275	0	0	4799.8283
0	0	0.089828352	0	0	0.0898284
0	0	0.22457088	0	0	0.2245709
0	0	1.527081984	0	0	1.527082

Appendix F. Emission calculation MV. Gunung Dempo

Sailing condition

No	Fuel	Unit	M/E		A/E	M/E		A/E
			Methanol	MDO	MDO	Methanol	MDO	MDO
			0	100%	100%	80%	20%	100%
1	NOx	Ton/year	0	572.9472	74.028416	45.38419	114.58944	74.028416
2	SOx	Ton/year	0	26.6112	3.438336	0	5.32224	3.438336
3	CO2	Ton/year	0	32316.48	4175.4944	11183.96	6463.296	4175.4944
4	CH4	Ton/year	0	0.6048	0.078144	0	0.12096	0.078144
5	N2O	Ton/year	0	1.512	0.19536	0	0.3024	0.19536
6	PM	Ton/year	0	10.2816	1.328448	0.696972	2.05632	1.328448

M/E		A/E	M/E		A/E	M/E		A/E
Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO
85%	15%	100%	90%	10%	100%	95%	5%	100%
48.220704	85.94208	74.028416	51.057216	57.29472	74.028416	53.893728	28.64736	74.028416
0	3.99168	3.438336	0	2.66112	3.438336	0	1.33056	3.438336
11882.959	4847.472	4175.4944	12581.9568	3231.648	4175.4944	13280.9544	1615.824	4175.4944
0	0.09072	0.078144	0	0.06048	0.078144	0	0.03024	0.078144
0	0.2268	0.19536	0	0.1512	0.19536	0	0.0756	0.19536
0.7405322	1.54224	1.328448	0.78409296	1.02816	1.328448	0.82765368	0.51408	1.328448

Port condition

No	Fuel	Unit	M/E		A/E	M/E		A/E	M/E		A/E
			Methanol	MDO	MDO	Methanol	MDO	MDO	Methanol	MDO	MDO
			0	100%	100%	80%	20%	100%	85%	15%	100%
1	NOx	ton/year	0	0	40.379136	0	0	40.379136	0	0	40.379136
2	SOx	ton/year	0	0	1.875456	0	0	1.875456	0	0	1.875456
3	CO2	ton/year	0	0	2277.5424	0	0	2277.5424	0	0	2277.5424
4	CH4	ton/year	0	0	0.042624	0	0	0.042624	0	0	0.042624
5	N2O	ton/year	0	0	0.10656	0	0	0.10656	0	0	0.10656
6	PM	ton/year	0	0	0.724608	0	0	0.724608	0	0	0.724608

M/E		A/E	M/E		A/E
Methanol	MDO	MDO	Methanol	MDO	MDO
90%	10%	100%	95%	5%	100%
0	0	40.379136	0	0	40.379136
0	0	1.875456	0	0	1.875456
0	0	2277.5424	0	0	2277.5424
0	0	0.042624	0	0	0.042624
0	0	0.10656	0	0	0.10656
0	0	0.724608	0	0	0.724608