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Environmental assessment of marine fuels: liquefied natural gas, liquefied biogas, methanol and bio-methanol

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ABSTRACT

The combined effort of reducing the emissions of sulphur dioxide, nitrogen oxides and greenhouse gases to comply with future regulations and reduce impact on climate change will require a significant change in ship propulsion. One alternative is to change fuels. In this study we compare the life cycle environmental performance of liquefied natural gas (LNG), liquefied biogas (LBG), methanol and bio-methanol. We also highlight a number of important aspects to consider when selecting marine fuels. A transition to use of LNG or methanol produced from natural gas would significantly improve the overall environmental performance. However, the impact on climate change is of the same order of magnitude as with use of heavy fuel oil. It is only the use of LBG and bio-methanol that has the potential to reduce the climate impact. The analysis did not show any significant differences in environmental performance between methane and methanol when produced from the same raw materials, but the performance of the methanol engines are yet to be validated.

1. Introduction

Sea-transport of cargo has grown with about 4% or more per year during the last decades (Buhaug et al., 2009; Eyring et al., 2010). This together with a lack of strict emission regulation has resulted in constantly increasing emissions to air from shipping (Buhaug et al., 2009; Endresen et al., 2003; Eyring et al., 2005). However, there is now a focus on reducing these emissions.

The International Maritime Organisation (IMO) has adopted stricter regulations regarding the sulphur content in fuels and the emissions of nitrogen oxides (NO_X), especially in certain emission control areas (ECAs). Recently, there have also been efforts made by the IMO to control emissions of greenhouse gases by introducing the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for existing ships (Miola et al., 2011). Furthermore, the European Commission's white paper "Roadmap to a Single European Transport Area" in 2011 states that the carbon dioxide (CO_2) emissions from maritime transport should be reduced with 40% in 2050 compared to 2005 levels in the European Union but also that 50% of road freight should be moved to rail and sea (European Commission, 2011).

The paradox is that shipping is an efficient transport mode on a t km basis consuming less fuel compared to other transport modes (Buhaug et al., 2009), but in the same time a large contributor to emissions of air pollutants due to high sulphur content in the fuels and higher NO_X and particle emissions compared to for example road transportation.

The combined effort of reducing the emissions of sulphur dioxide (SO_2), NO_X and greenhouse gases (GHGs) will require a significant change in ship propulsion. Increased energy efficiency as well as a change of fuel and/or the use of exhaust gas abatement equipment will be necessary. New regulations may now push the shipping industry from the existing use of fossil fuels with high sulphur content, i.e. heavy fuel oil (HFO), to use cleaner fossil fuels. This raises the question of which fuel that is the preferable future marine fuel.

There is a large interest in the use of liquefied natural gas (LNG) in shipping (Burel et al., 2013; Danish Maritime Authority, 2012). LNG consists mainly of methane and is favoured since it has lower sulphur and carbon content and causes lower NO_X emissions from the engines compared to the traditionally used HFOs. The significantly lower NO_X emissions compared to HFO is mainly a result of reduced peak temperatures during combustion (Doug, 2010). LNG

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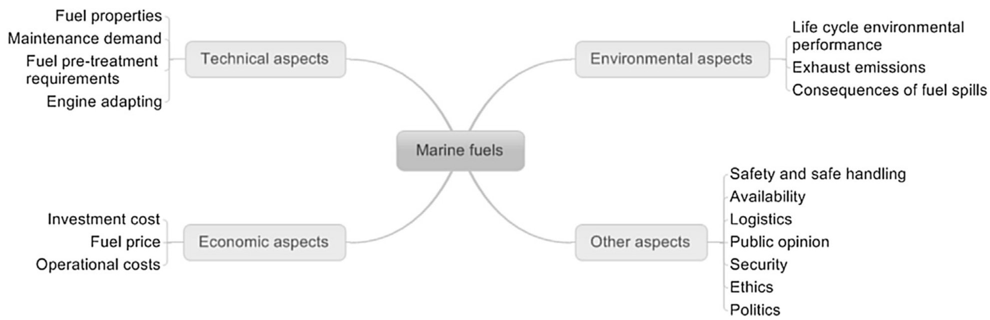

Fig. 1. Aspects to consider when selecting future marine fuels.

is already tested, as there are about 20 ships operating on LNG in Norwegian waters (IMO, 2013b).

Methanol is also a potential fuel for shipping and comparable to LNG in some aspects. Methanol is produced from synthesis gas, which can be produced from e.g. natural gas or biomass, in a methanol synthesis reactor (Riaz et al., 2013). It has very low sulphur content and could possibly comply with the strictest NO_X regulation. It is, in contrast to LNG, liquid at standard temperature and pressure and therefore much easier to handle. Liquefaction of natural gas into LNG is one way of taking remote natural gas resources to the market; production of methanol from natural gas is another possibility (Riaz et al., 2013). The interest in methanol as a shipping fuel started in the Swedish research and development project Effship (www.effship.com). As a consequence of this, Stena Line, a large ferry operator mainly operating in northern Europe, is now investigating the option to convert vessels to run on methanol (Einemo, 2013).

In order for a fuel to be environmentally sustainable, it must not only be associated with low emissions during the combustion of the fuel, but also in the whole fuel life cycle starting from raw material extraction, followed by fuel production, distribution and finally combustion in marine engines for ship propulsion. The life cycle environmental performance of LNG as a marine fuel has earlier been evaluated by Bengtsson et al. (2011a) and Lowell et al. (2013) and compressed natural gas (CNG) by Winebrake et al. (2007). LNG was shown to reduce emissions of SO_2 and NO_X and thereby the acidification and eutrophication potentials substantially in the life cycle compared to HFO (Bengtsson et al., 2011a). While the impact on climate change was shown to be in the range of −20% to +5% compared to HFO (Bengtsson et al., 2011a; Lowell et al., 2013).

There are so far no life cycle assessments evaluating the use of methanol in ships. However, there are studies evaluating the environmental performance of methanol production and use in road transportation, e.g. Börjesson and Tufvesson (2011a), Strömman et al. (2006) and Edwards et al. (2011a). Methanol has been considered for road transport since the oil shocks in the 1970s in the US and in Europe, but never in larger scale. Today, methanol, mainly produced from coal, is used in cars in China. The development in China have been driven by the favourable cost of methanol and the possibility of domestic production (Bromberg and Cheng, 2010).

As methanol has some advantageous aspects compared to LNG regarding, e.g. fuel distribution and retrofit costs (Fagerlund and Ramne, 2013), and as there are plans to run vessels on methanol it is interesting to compare the use of LNG and methanol. The aim of this study is, therefore, to compare the life cycle environmental performance in terms of methane, the energy carrier in LNG, and methanol as marine fuels, considering both natural gas and biomass as raw materials.

2. Methane and methanol as marine fuels

There are many aspects that are important to consider when selecting a new marine fuel, some are summarised in Fig. 1. The following section highlights some of these aspects for methane and methanol.

2.1. Technical aspects

The technical system in the fuel chain includes the systems on board the ships which deal with the fuel, e.g. engines, storage tanks, pumps, pipes, exhaust funnel, etc., the bunkering ships and the fuel storage terminal. All these systems need to be technically feasible and it is a prerequisite that it must be possible to construct and operate such systems.

Several types of prime movers are possible for methane and methanol, e.g. two-stroke and four-stroke diesel engines, Otto engines, fuel cells, making the fuels rather flexible from a technological perspective. The energy efficiency and exhaust emissions are dependent on which concept that is used. One difference between methane and methanol is that the engine technology for LNG propulsion is well developed and available on the market (Gullberg and Gahnström, 2011), but methanol has not been tested at all for marine propulsion.

The LNG propelled ships in operation in Norway are either equipped with spark-ignited lean burn gas engines or dual fuel (DF) engines. DF engines can run on LNG, HFO or marine gas oil (MGO). When using LNG, a small amount of diesel pilot fuel is injected for ignition. One of the downsides with LNG is the rather complicated and costly retrofits for existing engines. The four-stroke LNG engines comply with Tier III NO_X limits (1.96–3.3 g/kWh dependent on engine speed).

Two different engine concepts for methanol have been evaluated in the EffShip project, the premixed DF concept and the methanol-diesel concept. In the DF concept the gas valve on a DF gas engine is replaced or the engine is complemented with a methanol injector. Premixed methanol and air is ignited with a small pilot fuel diesel spray. Some modifications of ignition energy/preheating of the combustion air may be necessary and the output will be limited by knocking. The NO_X emissions are expected to be in the range of a DF engine running on LNG (Fagerlund and Ramne, 2013). Concerns are possibly high concentration of formaldehyde in the exhaust gas and corrosions in the fuel inlet and on the cylinder liner surface (Fagerlund and Ramne, 2013). This concept will face the same difficulties during retrofit as the DF engines running on LNG.

In the methanol-diesel concept, the methanol is injected at high pressure and ignited with a small amount of pilot diesel. This is similar to the gas-diesel concept (see Doug (2010)), but will require modification of the fuel injection system. The NO_X emissions are

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