Energy Policy 44 (2012) 451–463

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Environmental assessment of two pathways towards the use of biofuels in shipping

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ARTICLE INFO

Article history:
Received 21 November 2011
Accepted 11 February 2012
Available online 28 February 2012

Keywords:
Biofuels
Shipping
Life cycle assessment

ABSTRACT

The goal of this study is to evaluate the life cycle performance of two alternative pathways to biofuels in the shipping industry: the 'diesel route' and the 'gas route'. The diesel route comprises of a shift from heavy fuel oil to marine gas oil and then a gradual shift to biodiesel, whereas the gas route comprises of a shift to liquefied natural gas and then a gradual shift to liquefied biogas. The two routes are assessed in a case study for the ferry traffic between the Swedish mainland and the island Gotland. Life cycle assessment (LCA) is used to evaluate the environmental performance with the functional unit chosen to be one year of ro-pax ferry service, including both passenger and goods transportation. The gas route is indicated to have better overall environmental performance than the diesel route. Furthermore, use of biofuels is illustrated as one possible measure to decrease the global warming impact from shipping, but to the expense of greater environmental impact for some other impact categories. As an example, the global warming potential (GWP_{100}) was shown to decrease with the use of biofuels in this study, while the eutrophication potential and the primary energy use increased.

1. Introduction

To address environmental concerns and comply with stricter emission regulations, alternatives are needed for the presently used heavy fuel oils in maritime transport. The shipping industry has traditionally used fuels of low quality with high sulphur content, purchased at a price lower than the price of crude oil (Corbett, 2004). This could, however, change in the near future as stricter regulations will enter into force concerning the sulphur content of marine fuels and the emissions of nitrogen oxides (NO_x) (IMO, 2006). There has also been pressure on the International Maritime Organisation (IMO) to implement policies that will lead to reduction in emissions of greenhouse gases from shipping (Miola et al., 2011). Measures to reduce fuel consumption and thereby indirectly greenhouse gas emissions were adopted by the IMO in July 2011, in the form of the Energy Efficiency Design Index for new ships and the Ship Energy Efficiency Management Plan for all ships. In addition, the European Commission's white paper *Roadmap to a Single European Transport Area* in 2011 stresses 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 (European-Commission, 2011).

To change fuels may involve engine technology changes, e.g. to gas or dual-fuel engines, but can also be performed with new fuels that can be used in old engines with small modifications and adjustments. The fuel alternatives most discussed for a short time perspective are two fossil fuels: distillate fuels or liquefied natural gas (LNG) (Banawan et al., 2010; Bengtsson et al., 2011). It has been shown that neither of these fuels will decrease the emissions of greenhouse gases substantially in a life cycle perspective (Bengtsson et al., 2011). It was argued by Bengtsson et al. (2011) that alternative fuels and/or increased energy efficiency are needed in order to significantly reduce the contribution to global warming from the shipping industry. However, it is of interest to assess if the proposed fuels can bridge over to biofuels. ECOFYS have in a report for the European Maritime Safety Agency (EMSA), suggested that the European Renewable Energy Directive could be actively prolonged towards the shipping industry as a way to accelerate the introduction of biofuels. They also recommended a separate fuel standard for biofuels to use in ship engines (Florentinus et al., 2012).

Two promising renewable alternatives to distillate fuels and LNG are biodiesel and biogas respectively; both can be blended with fossil fuels (diesel and natural gas, respectively) (Karavalakis et al., 2008). Biodiesel is a fuel tested for marine propulsion by Maersk (Gallagher, 2010) and the US Navy (Bruckner-Menchelli, 2011).

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doi:10.1016/j.enpol.2012.02.030

It is also promoted as a fuel suitable for marine propulsion (Lin and Huang, 2012; Mihic et al., 2011). The possibility to switch from LNG to liquefied biogas (LBG) is one advantage put forward in the marketing of LNG.[1]

Biofuels are usually categorised as first or second generation. First generation biofuels are produced primarily from agricultural crops such as grains and oil seeds while second generation biofuels are produced from lingo-cellulosic materials such as forest residues. Issues concerning first generation biofuels have been raised since they can create competition for land with food production, they have limited production potential and their environmental performance is questioned (Sims et al., 2008). It is argued that second generation biofuels can avoid many of the concerns facing first generation biofuels, but they still face economical and technical challenges (Carriquiry et al., 2011; Havlík et al., 2011; Naik et al., 2010). Biodiesel and biogas can be produced with both first and second generation technologies. Biodiesel can be produced through transesterification from vegetable oils (Fatty Acid Methyl Esters, first generation biofuel) and through gasification followed by Fischer–Tropsch synthesis (synthetic biodiesel or biomass-to-liquid (BTL), second generation biofuel). Biogas can be produced through anaerobic digestion of biomass (biogas, first generation biofuel) or from gasification of biomass followed by methanation (here called bio-methane, second generation biofuel).

A limited number of studies have assessed the environmental life cycle performance of fossil marine fuels (Bengtsson et al., 2011; Corbett and Winebrake, 2008; Winebrake et al., 2007). Winebrake et al. (2007) also included biofuels, but only soybean based biodiesel. Numerous studies have, on the other hand, explored alternative fuel chains for road fuels and much data from these studies can be used to evaluate alternative shipping fuels (e.g., Edwards et al., 2007a; Strömman et al., 2006). However, there are some aspects that differ. Firstly, the basis for comparison differs, as the fuels used at present in shipping (mainly heavy fuel oils) are different from those used for road vehicles (gasoline and diesel). The infrastructure need and the storage requirements also differ as do the engines. It is therefore possible that fuels not well adjusted for road transport may be advantageous as marine fuels and vice versa.

The goal of this study is to evaluate the life cycle performance of two alternative routes toward biofuels in the shipping industry: the diesel route and the gas route. The transitions are assessed by a case study on the ferry traffic between the Swedish mainland and the island Gotland and life cycle assessment (LCA) is used to evaluate the environmental performance. The functional unit is one year of ro-pax ferry[2] service between the island Gotland and the Swedish mainland, including passenger and goods transportation.

The ferry traffic to Gotland has the opportunity to be an early mover with environmentally sustainable shipping solutions. Today, the passenger ferries use heavy fuel oil (HFO), with 0.5% sulphur, in the main engines and ultra-low sulphur HFO ($<0.05\%$ sulphur) in the auxiliary engines. All engines are equipped with selective catalytic reduction units which reduces the NO_x emissions to below 2 g NO_x per kWh. The ferries thus already fulfil MARPOL NO_x Tier III requirements,[3] but need to reduce the sulphur content to below 0.1 wt% in 2015 to fulfil the requirements for SO_2 emissions in Sulphur Emission Control Areas. The ferry traffic is procured by a Swedish authority and an investigation regarding the future ferry traffic has been made (Rikstrafiken, 2010), which stresses long term economic, social and environmental sustainability as conditions for the future ferry traffic.

This paper starts by introducing the previous experience and practical limitations of biofuels in shipping. The next section describes the methodology and case study in more detail. The last part of the paper includes result from the case study, followed by discussion and conclusions.

2. Biofuels in shipping

The shipping industry has limited experience of biofuels so far, and most biofuel studies have been directed toward road based transportation. The reason to consider biofuels for shipping is that combustion of biomass use is considered 'carbon neutral' over its life cycle because combustion of biomass releases the same amount of CO_2 as was captured by the plant during its growth.[4] By contrast, fossil fuels release CO_2 that has been locked up for millions of years.

Nearly all of the few studies found regarding biofuels in shipping concerns biodiesel or vegetable oils; benefits and problems are summarised in Table 1. The following section presents factors of importance for the use of biofuels in shipping, such as the availability and exhaust gas emissions, starting with a description of fuel distribution and engines.

2.1. Fuel distribution and engines

Today, two-stroke and four-stroke diesel engines fuelled with HFO are dominant in ship propulsion (Buhaug et al., 2009). Biodiesels, according to the standard EN 14214:2008 (CEN, 2008), can replace low sulphur fuel oils in marine diesel engines and be blended with distillate fuels according to Haraldsson (2010). Pure vegetable oils can also be used if they fulfil the engine specifications. Biodiesel can utilise the same infrastructure as HFO and marine gas oil (MGO) as it is a liquid fuel. Jiménez Espadafor et al. (2009) further states that pure vegetable oils can be used in large ships propelled by slow speed two-stroke engines as the current methods for storage and distribution is compatible.

Since LNG is a liquid only at low temperatures, it requires new fuel infrastructure in the form of terminals, bunker possibilities, new storage facilities and engines on board (Gullberg and Gahnström, 2011). LNG has previously been used as a fuel for LNG carriers, by utilisation off the boil-off gas in steam turbines, but gas or dual-fuel engines can also be used for LNG propulsion. Dual-fuel engines can run in either gas mode or diesel fuel mode. The engine works according to the Otto principle in gas mode, and the lean gas and air mixture is ignited by injection of a small amount of diesel fuel into the combustion chamber. The injected diesel fuel normally corresponds to about 1% of the total amount of energy supplied to the engine at full load (Haraldsson, 2011). The gas engine operates according to the Otto cycle and combustion is trigged by spark plug ignition (Doug, 2010). LBG and liquefied bio-methane (LB-CH_4) contain more than 97% methane and can therefore be used to replace LNG in both dual-fuel and gas engines.

2.2. Emission tests

Six articles and one report have been found that evaluate emissions from combustion of biodiesel for marine applications;

[1] See for example the report SMTF (2010).

[2] A ro-pax ferry is a roll-on-roll-off (ro–ro) ship designed to load and unload rolling cargo over ramps with high freight capacity and limited passenger facilities.

[3] According to MARPOL, a maximum of 2.6 g NO_x per kWh at 500 rpm are allowed in 2016 in Emission Control Areas for new buildings.

[4] There is a debate if biomass combustion can actually be regarded as 'carbon neutral' and how emissions of CO_2 from biomass should be treated, for more information on this see for example Whitman and Lehmann (2011), Johnson (2009) and Rabl et al. (2007).