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Environmental impact categories of hydrogen and ammonia driven transoceanic maritime vehicles: A comparative evaluation

Yusuf Bicer [a,*], *Ibrahim Dincer* [a,b]

[a] *Clean Energy Research Laboratory (CERL), Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4, Canada*

[b] *Faculty of Mechanical Engineering, Yildiz Technical University, Istanbul, Turkey*

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ABSTRACT

In this study, carbon-free fuels -ammonia and hydrogen-are proposed to replace heavy fuel oils in the engines of maritime transportation vehicles. Also, it is proposed to use hydrogen and ammonia as dual fuels to quantify the reduction potential of greenhouse gas emissions. An environmental impact assessment of transoceanic tanker and transoceanic freight ship is implemented to explore the impacts of fuel substituting on the environment. In the life cycle analyses, the complete transport life cycle is taken into account from manufacture of transoceanic freight ship and tanker to production, transportation and utilization of hydrogen and ammonia in the maritime vehicles. Several hydrogen and ammonia production routes ranging from municipal waste to geothermal options are considered to comparatively evaluate environmentally benign methods. Besides global warming potential, environmental impact categories of marine sediment ecotoxicity and marine aquatic ecotoxicity are also selected in order to examine the diverse effects on marine environment. Being carbon-neutral fuels, ammonia and hydrogen, yield significantly minor global warming impacts during operation. The ecotoxicity impacts on maritime environment vary based on the production route of hydrogen and ammonia. The results imply that even hydrogen and ammonia are utilized as dual fuels in the engines, the global warming potential is quite lower in comparison with heavy fuel oil driven transoceanic tankers. Geothermal energy sourced hydrogen and ammonia fuelled transoceanic tankers release about 0.98 g and 1.65 g CO_2 eq. per tonne-kilometer, respectively whereas current conventional heavy fuel oil tanker releases about 5.33 g/tonne-kilometer CO_2 eq. greenhouse gas emissions.

Introduction

The global warming potential caused by current transportation technologies and fuels can be reduced significantly by replacing alternative, clean fuels. Sea transportation vehicles mostly use heavy fuel oil or diesel fuel for power generation. Ocean tankers and freight ships require massive amount of energy for operation.

* *Corresponding author.*
E-mail addresses: yusuf.bicer@uoit.ca (Y. Bicer), ibrahim.dincer@uoit.ca (I. Dincer).

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Hydrogen and ammonia are considered as alternative fuels for power generation especially in transportation sector such as maritime. The usage of hydrogen and ammonia in the maritime applications eventually depends on the capability of producing clean, low-cost energy. One of the hydrogen carriers is ammonia which is synthesized from nitrogen and hydrogen that can be used for direct combustion in maritime vehicles. Ammonia does not contain any carbon atoms and has a high hydrogen ratio. It is a molecule which composes of three atoms of hydrogen and one atom of nitrogen. Besides having a significant advantages in storing and transporting compared to hydrogen, ammonia may also be burned directly in diesel engines. Ammonia can be easily transferred through pipelines, railway, and ships by delivering to consumption area where it may be utilized as a source of hydrogen, chemical substance, and fertilizer for agriculture, fuel for transportation such as maritime applications. Being a sustainable energy carrier that can be generated from any primary energy source, hydrogen and ammonia can subsidize to a broadening of vehicle fuel resources and may offer the long term option of being generated from renewable resources. Since ammonia produces mainly water and nitrogen on combustion, replacing a part of conventional fuel with ammonia will have a large effect in reducing carbon dioxide emissions [1]. Ammonia (NH_3) is colorless, pungent gas composed of nitrogen and hydrogen. It is the simplest stable compound of these elements and serves as a starting material for the production of many commercially important nitrogen compounds. Ammonia is majorly used as fertilizer in the world. It is most commonly applied directly to the soil from tanks containing the liquefied gas. Since the improvement potentials of renewable technologies are most likely greater than fossil fuels, it is significant to implement renewable-based alternative fuel production options from environmental point of view [2]. There have been lots of studies related to combustion characteristics of ammonia in the literature [3–9]. Moreover, hydrogen and ammonia can also be utilized in fuel cells which can be integrated to maritime applications [10].

Gilbert et al. [11] studied the manufacture process of the ships in terms of life cycle assessment. They tried to reveal material sourced emissions during manufacture. They resulted that co locating resources, ship construction and breaking is desired to lower transportation emissions but with a drawback of socio-economic impacts because current breaking regions are dependent on this industry. Singh and Pedersen [12] reviewed possible waste heat recovery options in the maritime vehicles by considering the properties of shipboard waste heat and achievable recovery efficiencies. They considered Rankine cycle, organic Rankine cycle, supercritical Rankine cycle, Kalina cycle, exhaust gas turbine systems and thermo-electric generator for heat recovery in the ships. Laumann Kjaer et al. [13] incorporated life cycle cost study into life cycle assessment by implementing a case study for medium range tankers carrying fuels. They resulted for the case study that fuel for operation of the tanker can account for 89% of total CO_2 emissions but it represents only 36% of the operation cost. Blanco-Davis and Zhou [14] emphasized the importance of LCA studies in maritime applications and decision makers. Their results showed that aside from the environmental score of CO_2 emissions per unit of work, LCA can also offer NO_x and SO_x scores, along with other hazardous releases. LCA is able to show material and energy utilization throughout different stages within the vessel's lifetime. Mosgaard and Kerndrup [15] evaluated the technologies for energy efficient retrofit solutions for the maritime sector. Demonstration projects in the maritime sector fulfill the standard goals by facilitating the entrance of technologies into the market. At the end, they will change the practices in the industry. Hence, introduction of alternative clean fuels in marine sector can make significant positive changes for the environment.

The current emission values of air pollution from ships were previously reported by International Maritime Organization (IMO) [16,17]. It was shown that for 1 crude oil tanker, the total CO_2 emission ranges between 2.9 and 33.3 g CO_2/tkm depending on the size of the tanker. On the other hand, for some type of tankers such as Ro-Ro, the emissions can go up to 65 g CO_2/tkm. In addition, Styhre et al. [18] investigated the emissions caused by the sea ports in different cities. For instance, they showed that CO_2 eq. emission from a single ship in Gothenburg port is about 25 tonnes per year. Gibbs et al. [19] and Bouman et al. [20] also studied the CO_2 reduction potentials in sea transportation by proposing alternative fuels and various policies. Burel et al. [21] assessed the GHG and cost reduction when liquefied natural gas is used for the merchant ships. Their results revealed that utilization of LNG in the ship yields to a reduction of 35% of operational costs and 25% of CO_2 emissions compared to heavy fuel oil.

In addition to the operational stage, the marine vehicles also consume power during port facilities such as loading and unloading. Most of the cases, they use their own engines for the energy requirements which eventually increases the environmental pollution. Recently, cold ironing has become an important alternative for substituting on-board energy usage. In cold ironing, when the ships and tankers are being loaded or unloaded in a port or dock, alternate marine power is supplied. Hydrogen and ammonia are clean chemical fuels for power production at ports. Especially, clean energy production (via renewable sources) using hydrogen and ammonia at the port facilities can be a very appealing solution for cold ironing in which there will be reduced environmental impact.

In this study, maritime vehicles, ocean tanker and freight ship, are driven with hydrogen and ammonia instead of heavy fuel oils in the power engines. Additionally, dual fuel options, heavy fuel oil and hydrogen/ammonia, are investigated. A comparative life cycle assessment of transoceanic fright ship and transoceanic tanker, is performed to examine the effects of clean fuel driven maritime vehicles on the environment. The complete transport life cycle is evaluated in the life cycle analyses comprising of manufacture of tanker/freight ship; operation of tanker/freight ship; construction and land use of seaport; operation, maintenance and disposal of seaport; production and transportation of hydrogen and ammonia. Hydrogen and ammonia are produced using renewable resources namely; biomass, municipal waste and geothermal energy.