Energy Policy 87 (2015) 153–167

Contents lists available at ScienceDirect

Energy Policy

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

Natural gas as a marine fuel

Heather Thomson [a,*], James J. Corbett [a], James J. Winebrake [b]

[a] University of Delaware, Newark, DE, USA
[b] Rochester Institute of Technology, Rochester, NY, USA

HIGHLIGHTS

- Natural gas reduces local air pollutants compared to traditional maritime fuels.
- First application of Technology Warming Potential in a marine setting.
- LNG may exhibit lower TWP compared to diesel under certain conditions and timeframes.
- Well-designed energy policy can promote better regional low-GHG LNG infrastructure.

ARTICLE INFO

Article history:
Received 6 January 2015
Received in revised form
5 August 2015
Accepted 21 August 2015

Keywords:
Natural gas
Life-cycle analysis
Greenhouse gases
Marine transportation
Environmental policy

ABSTRACT

This paper provides new knowledge about the life-cycle emissions of natural gas compared to traditional petroleum-based fuels in the marine sector. While natural gas will reduce local air pollutants, such as sulfur oxides and particulate matter, the implications for greenhouse gases depend on how the natural gas is extracted, processed, distributed, and used. Applying a "technology warming potential" (TWP) approach, natural gas as a marine fuel achieves climate parity within 30 years for diesel ignited engines, though could take up to 190 years to reach climate parity with conventional fuels in a spark ignited engine. Movement towards natural gas as a marine fuel continues to progress, and conditions exist in some regions to make a near-term transition to natural gas feasible. Liquefied natural gas in marine transportation is likely to be incentivized where economics favoring natural gas is coupled with air emissions public policy targets. To ensure that climate neutral conversion is achieved with the least delay, TWP results highlight the important role of energy policy for infrastructure development of up-stream pathways and onboard ship systems technology innovation.

1. Introduction

1.1. Overview

The maritime industry faces three new realities that are changing marine fuel investment choices. First, regulators, environmentalists, and health officials are concerned about pollutants near major coastal population centers. Marine vessels have historically emitted large amounts of pollutants into the atmosphere (Corbett and Fischbeck, 1997). Although vessels have

Abbreviations: BTU, British Thermal Unit; CAGR, compound annual growth rate; CH_4, methane; CI, compression ignited; CO_2, carbon dioxide; EC, East Coast Case; ECA, emissions control area; EMSA, European Maritime Safety Agency; EU, European Union; GHG, greenhouse gases; GIFT, Geospatial Intermodal Freight Transportation; GREET, Greenhouse Gas and Regulated Emissions and Energy Use in Transportation; GWP, Global Warming Potential; GWP_{100}, Global Warming Potential at 100 years; HP, Horsepower; HS, high sulfur distillate marine fuel (10,000 ppm sulfur); IEA, International Energy Agency; IMO, International Maritime Organization; Import Terminal, Facility that is licensed to accept natural gas from overseas; IPCC, Intergovernmental Panel on Climate Change; LA/LB, Port of Los Angeles and Long Beach; LCA, Life-Cycle Analysis; LNG, liquefied natural gas; LS, low sulfur distillate marine fuel (1000 ppm sulfur); MARAD, U.S. Department of Transportation Maritime Administration; MARPOL, International Convention for the Prevention of Pollution from Ships; N_2O, Nitrous Oxide; NA NG, North American Natural Gas; NG, Natural Gas; NNA NG, Non-North American Natural Gas; NO_x, Oxides of Nitrogen; OECD, Organisation for Economic Cooperation and Development; OGV, Ocean-Going Vessel; PANYNJ, Port Authority of New York and New Jersey; PM_{10}, Particulate Matter (with aerodynamic diameter smaller than 10 μm); Pathway, The set of processes utilized to get the fuel from the wellhead to the fueling station in the port.; S, sulfur; SI, spark ignited; SO_x, oxides of sulfur; TEAMS, Total Energy and Environmental Analysis for Marine Systems; TEU, twenty-foot equivalent unit; TFCA, total fuel-cycle analysis, which is a life-cycle analysis of fuel production and use; TWP, Technology Warming Potential; US, United States; USCG, U.S. Coast Guard; WC, West Coast Case

* Corresponding author.
E-mail addresses: hthomson@udel.edu (H. Thomson), jcorbett@udel.edu (J.J. Corbett), jjwgpt@rit.edu (J.J. Winebrake).

http://dx.doi.org/10.1016/j.enpol.2015.08.027

become cleaner over time, international shipping still represents a large portion of local pollutant inventories, specifically along coastal areas, since 70% of the emissions are deposited within 400 km of land. Assessments for years 2007 through 2012 show that international shipping remains problematic and that these emissions may lead to significant health concerns in exposed populations (IMO, 2014b).

While the International Maritime Organization's (IMO) adoption of the International Convention for the Prevention of Pollution from Ships (MARPOL) addressed some pollutants in 1973, the response by the international maritime policy community has been aggressive of late. The IMO used the MARPOL framework to introduce regulations controlling specific pollution emissions. MARPOL's Annex VI, originally adopted in 1997, began an effort to reduce SO_x and NO_x emissions from ship smokestacks by initiating emissions standards for ships that reduce ship emissions rates by ~80% for both sulfur and nitrogen emissions, globally, and greater than 90% reduction in IMO-designated emissions control areas (ECAs) along European and United States (US) coasts (IMO, 2013; IMO, 2014a; Lauer et al., 2009). These ECAs establish stricter emissions requirements for vessels operating within coastal areas, e.g., 0.10% sulfur limits for marine fuels, Tier III NO_x controls for engine exhaust. Vessel operators, engine manufacturers, and technology providers responded with approaches to meet new standards, mainly through smokestack controls or fuel switching. Natural gas offers lower local pollution emissions compared to distillate fuels. For NO_x emissions, current engine designs equal those of distillate fuels, and proposed improvements to engine design may reduce emissions to meet Tier III levels without aftertreatment (Wärtsilä, 2012). Research indicates that the SO_x and PM_{10} emissions of natural gas meet current, pending, and proposed standards for marine vessel operations and can significantly reduce local pollutants from vessel operations.

Second, price differences between natural gas and low-sulfur fuel oil since 2002 (IEA, 2012) suggest an economic advantage may favor natural gas (see Supporting material, Fig. D.1). An increasing number of newly constructed vessels are powered either by natural gas exclusively or by a combination of conventional diesel and natural gas (MarineLink, 2013; Posplech, 2013). Market-ready reciprocating internal combustion marine engines capable of natural gas and/or dual fuel operation enabled multiple shipbuilders to install these engines (Germanischer Lloyd, 2011; Rolls Royce, 2013). In addition, natural gas infrastructure is growing (Fullenbaum et al., 2013), making it more plausible to fuel ships with natural gas. These two drivers – the need to comply with ECA regulations and the competitive market for natural gas fuel – highlight a surge in interest in the use of natural gas as a marine fuel (Germanischer Lloyd, 2011; Posplech, 2013).

However, increased use of natural gas in the marine sector may negatively affect a third important factor: climate change. Complementing the IMO's concerns about local pollutants such as SO_x, NO_x, and PM_{10}, new research regarding greenhouse gas (GHG) emissions from vessel operations has stimulated efforts to reduce GHG emissions from international shipping. Currently, international shipping is responsible for ~2–3% of total CO_2 emissions globally, and the IMO adopted mandatory measures to reduce GHGs in 2011 (Bazari and Longva, 2011; IMO, 2014b). Increased natural gas use in the marine sector may increase GHG emissions globally, due to the global warming potential (GWP) of natural gas (i.e., methane) in our atmosphere and the potential for methane leakage along the fuel production and delivery pathway (Brynolf et al., 2014a; Lowell et al., 2013; Meyer et al., 2011). When upstream emissions are considered, advantages from a GHG emissions perspective remain uncertain, because natural gas fuel production pathways can be relatively energy intensive compared to petroleum pathways, and methane leakage during natural gas extraction and distribution may have important GHG impacts (Æsoy et al., 2011; Arteconi et al., 2010; Bengtsson et al., 2011b, 2014; Brinkman et al., 2005; Brynolf et al., 2014b; Choi and Song, 2014; Elgowainy et al., 2009; Huo et al., 2008; Jayaram et al., 2010; Korakianitis et al., 2011; Lowell et al., 2013; Shen et al., 2012; TIAX LLC, 2007a; TIAX LLC, 2007b; Wu et al., 2006; Yazdanie et al., 2014).

Therefore, decision makers find it important to look at the life-cycle emissions generated by natural gas fuels compared to traditional marine bunkers (NREL, 2013). This paper expands on previous maritime life-cycle analyses by Winebrake et al. (2007) by looking at different marine case studies and applies a Technology Warming Potential (TWP) approach from Alvarez et al. (2012) to consider the implications of a fuel switch technology transition. This work evaluates whether a natural gas transition can achieve both local pollution reductions and GHG reductions in the marine sector.

We evaluate "well-to-wake" emissions for vessel operations using best available data reflecting recent research on leakage of natural gas during vessel operation and refueling. We compare multiple natural gas production and delivery pathways for three vessel case studies using natural gas with similar vessels using ECA-compliant distillate fuels meeting 2012 and 2015 standards (that is, 10,000 ppm sulfur [S] and 1000 ppm S, respectively). Specifically, a large Ocean-Going Vessel (OGV) is evaluated transiting a U.S. West Coast route, from Los Angeles/Long Beach (LA/LB) to Honolulu, HI; a coastwise OGV is evaluated transiting a U.S. East Coast route between the Port Authority of New York and New Jersey (PANYNJ) and Jacksonville, FL; and a tug/tow vessel is evaluated for typical service at a Norway natural gas terminal. These three cases represent typical transits by marine vessels and encompass long-haul cargo transport, short sea transport, and regional service vessel conditions encountered by vessels potentially fueled by liquefied natural gas (LNG). Analyzing diverse pathways examines a range of scenarios to determine the potential for benefit from a natural gas transition.

We compare emissions of NO_x, SO_x, and PM_{10}, for each of the three vessel case studies. We also quantify and compare GHG emissions (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]) for each case. Control of NO_x, SO_x, and PM_{10} from ships provides significant beneficial impacts on human health, acidification, and eutrophication (Hassellöv et al., 2013; Lauer et al., 2009; Winebrake et al., 2009), although policies to reduce short-lived aerosols from OGVs can slightly increase warming by reducing negative radiative forcing and enhancing tropospheric ozone at global scales (Capaldo et al., 1999; Lauer et al., 2009; Lawrence and Crutzen, 1999). Indirect forcing of aerosols is not considered in GWP or TWP calculations.

We apply traditional methods of quantifying GHG emissions that use the global warming potential (GWP) of the gases at a future point in time (typically either 20 or 100 years), and we also apply a TWP method that evaluates emissions across a technology's useful life. The TWP presents a warming potential value for technology conversion over time, which avoids the contentious debate over choosing an appropriate GWP base-year (Boucher and Reddy, 2008; Moura et al., 2013; Shine, 2009). This allows for an evaluation that recognizes the long lifetimes of vessel operations if traditional technologies were replaced (Alvarez et al., 2012).

Lastly, we qualitatively consider regionally variable drivers that may influence adoption of natural gas as a marine fuel using International Energy Agency (IEA) regional statistics (IEA, 2012). This regional assessment – in combination with the results of our emissions analysis – provides information necessary for policymakers assessing the potential impacts of energy and environmental policies aimed at improving air quality, reducing GHG emissions, and incentivizing a movement toward non-petroleum