Chapter

# Comparative Life Cycle Assessment of Liquefied Natural Gas and Marine Fuel for Ship from Well to Hull

*Kyeonghun Jwa, Yanghwa Kim and Ocktaeck Lim*

## Abstract

In this study, well-to-hull was obtained by life cycle assessment (LCA) and GREET, which is developed by Argonne National Laboratory to evaluate the environmental impact of marine LNG and marine fuel. This study compared the environmental impact of marine LNG and marine fuels, which were caused by green house gases (GHGs) emissions and energy consumption. The effect resulted from well-to-pump (WTP) process and pump to hull (PTH). Natural gas has the potential to generate more greenhouse gases than liquid fuels due to the amounts of leaks of the gas that were sent out of the air during production and processing. Nevertheless, the results showed that the greenhouse gases produced during transportation were enough to reduce the disadvantages (pump-to-hull process). The research expects that the results will be under the environmental policy of South Korea.

**Keywords:** liquified natural gas (LNG), GREET 2018, well to hull, life cycle assessment (LCA), marine fuel, greenhouse gas

## 1. Introduction

Even though having the disadvantages from 2020.01.01, the International Maritime Organization (IMO) will strengthen a regulation to enforce the content of sulfur compounds in ship engine exhaust gas from 3.5% to 0.5%. In response, using liquified natural gas (LNG) as a fuel of transportation has emerged. To respond to IMO's environmental regulations, shipbuilders in each country are ordering eco-friendly ships in consideration of new ship construction, and the order status of ships using LNG as fuel is shown in **Figure 1** below. LNG-fueled ships are rapidly being applied and distributed in northern Europe. Since the first passenger ship 'Glutra' was built in Norway for the first time in 2000, National Steel and Shipbuilding Company (NASSCO) has recently ordered 3, 400TEU (twenty-foot equivalent unit) container ships.

The current market is still hesitant to introduce LNG fueled vessels. However, if LNG fueled vessels are ordered in earnest, the size of the market is not expected. However, the biggest obstacle to ordering LNG fueled vessels is the lack of infrastructure for fueling vessels [2]. Even though the disadvantages, The Korea government plan to introduce the LNG industry. Life Cycle Assessment for vehicles is

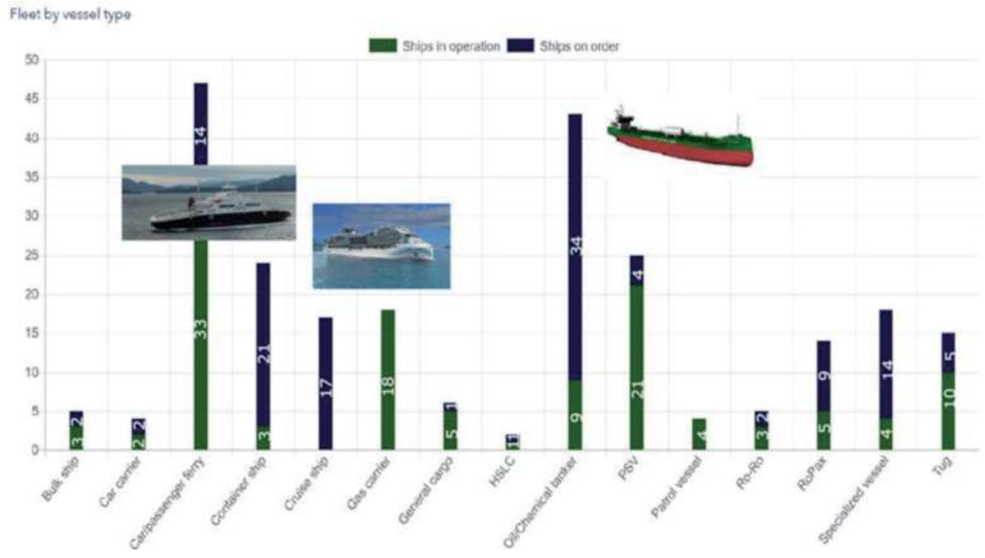


**Figure 1.**
*Order status of ships using LNG as fuel [1].*

studied in South Korea [3]. There is little research on ship emissions. Especially, emissions from return gas, boil-off-gas are hard to evaluate

In this study, we evaluated the environmental impact of the whole process for Well-to-Hull. It analyzes and evaluates the environmental problems arising from each process of the product through evaluation, including the production and transportation of fuel used for ships as well as operation and compared fossil fuels with natural gas [4]. Therefore, it is necessary to compare and analyze the WTP (Well to Pump) process using GREET. Generally, natural gas occurs greenhouse gas in the WTP than diesel due to the amounts of leakage generated during the production and treatment process. Nevertheless, the greenhouse gases produced during transportation are expected to be good enough to reduce the shortcomings because of the pump-to-hull process. A more detailed comparison of the operation part is needed through WTP analysis using GREET. The PTH result is obtained from the emission information in operating. There are many limitations to conducting experiments using large marine engines. Therefore, the PTH is calculated from an engine specification that is operated in ships (Ilshin Shipping and Incheon Port Authority).

## 2. Methods

### 2.1 LCA

LCA (life cycle Assessment) is developed and utilized by many companies, and research institutes around the world in the 1970s to compare and analyze the environmental friendliness of products [5]. The process in LCA is described in **Figure 2**. It is

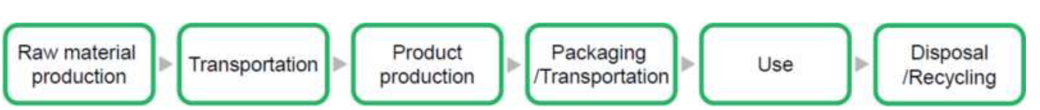


**Figure 2.**
*Process of life cycle assessment [1].*

possible to analyze and evaluate the environmental problems caused by the process of the product, and it is possible to perform a comparative analysis of the products.

### 2.2 GREET

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) was developed by Argonne under the auspices of the US Department of Energy (Energy Efficiency and Renewable Energy) [6]. It is a program that enables LCA of energy usage and emissions that occur during production and transportation of fuel as well as the driving of the vehicle. Also, it can accumulate data on a wide range of data, including moving parts in the picking and transportation production of raw materials. It is calculated based on actual measurement results rather than simulation results. In addition to gasoline and diesel, there are data on full-range fuels used in transportation such as natural gas, electricity, and bio-oil. Not only energy consumption but also exhaust gas and greenhouse gas emissions are investigated, and it is very useful for comparative analysis under the purpose of life cycle assessment. GREET includes more than 100 fuel routes, including petroleum and natural gas fuels, as well as biofuels, hydrogen, and electricity from a variety of energy sources. It is easy to compare and analyze the effects of each stage in the calculation by dividing the process from fuel production to supply. It provides the sources, usage from, contents of the data used in the GREET development process in the public domain.

### 2.3 LCA method

Well-to-hull processes of marine fuel and LNG are described in **Figures 3** and **4**. To evaluate the environmental impact of diesel compared to natural gas, we use GREET to compare the following WTP processes. In the case of natural gas, it is expected that more greenhouse gases will be generated than diesel due to the amounts of leaks generated during production and processing. However, compared to diesel, the amount of traffic generated during transport is expected to be good enough to reduce the above disadvantages. To compare and analyze this, we want to compare and analyze the operation part using GREET and WTP analysis, PTH data [7].

In the case of the WTP process, it is difficult to obtain reliable data, and there are a lack of extensive data on each process. To solve this problem, we would like to compare and analyze the results using the following GREET results.

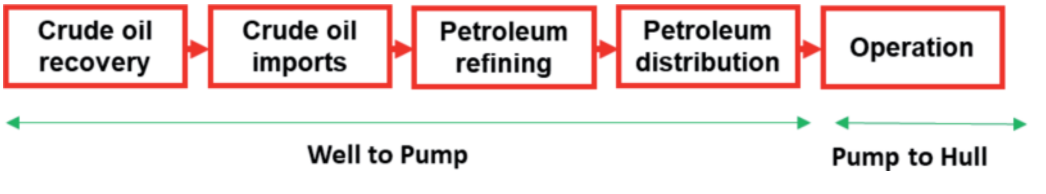


**Figure 3.**
*Well-to-hull process of marine fuel [1].*

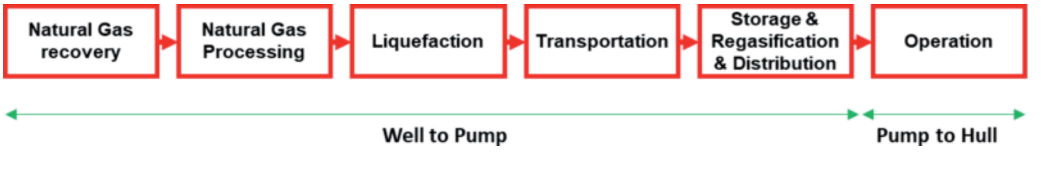


**Figure 4.**
*Well-to-hull process of LNG [1].*

## 2.4 Well to pump

### *2.4.1 Marine fuel*

GREET shows five things related to the WTP process of marine fuels. The values are 1) petroleum-based marine fuels from crude oil, 2) Fisher-Tropsch diesel fuel from natural gas, coal, and cellulosic biomass, 3) hydro-processed esters and fatty acids (HEFA) or hydro-processed renewable diesel (HRD) diesel fuel from bio-oil found in soybeans, palm, rapeseed, jatropha, camelina, and algae, 4) renewable diesel from pyrolysis of cellulosic biomass, and 5) biodiesel or fatty acid methyl esters (FAMEs) from bio-oil found in soybeans, palm, rapeseed, jatropha, camelina, and algae. Among them, crude oil-based marine fuels are chosen. The average distance from oil-importing country to the Korean refinery is 12,135 km based on Korea National Oil Corporation's data, using Voyage calculator. According to the Korea National Oil Corporation, most volume of crude oil is imported from overseas. About 76% of total crude oil imports are from the Middle East (Saudi Arabia, Kuwait, Iraq, Qatar, etc.) in 2018. Domestic data on crude oil import, preparation, and distribution for the diesel life cycle analysis were provided by the Korea Petroleum Association [8].

### *2.4.2 LNG*

The data of LNG required for well-to-pump analysis are as follows. We consider the energy efficiency of raw material extraction and processing and the ratio of process fuel in natural gas production in the NG recovery and NG processing steps. Korea Gas Corporation provides information about natural gas imports. From the information, we calculate the import distance to consider the transportation step. The information is described in **Table 1**. In the case of storage, regasification, and distribution step after importing LNG, the data were used in GREET because there were not enough data accumulated.

## 2.5 Pump to hull

Although it is necessary to find and compare diesel ships of similar specifications as LNG vessels, it is difficult to obtain information on the number of days of sailing, sailing distance, ship weight (including load weight), fuel consumption, and electricity consumption for a certain period required for calculation. There are three types of marine-fueled vessels that are bulk carriers, oil tankers, and container ships. At the time, GREET only provided specifications of these ships. We average the total energy use and greenhouse gases to calculate data in the operation step. The information related to ships using LNG as fuel is not explained. Therefore, we get data from a company that operates LNG ships in South Korea.

| Country | Distance(km) | Import volume(ton) |
|---|---|---|
| Qatar | 11,297 | 14,250,000 |
| Australia | 6,667 | 7,870,000 |
| The U.S. | 10,556 | 4,660,000 |
| Oman | 10,556 | 4,280,000 |
| Malaysia | 4,598 | 3,700,000 |

**Table 1.**
*Import distance to South Korea of natural gas (2018).*

## 3. Results

In the case of marine fuel, shows the well-to-pump result of energy use and greenhouse gas emissions are in **Table 2**. In the pump-to-hull pathway, the GHG emissions are only calculated from the specification of HYUNDAI MAN B & W TYPE: 6G50ME-GI used in Ilshin Shipping LNG propulsion vessel because of the company's secret. The GHG emissions result is 74.4 g/MJ in diesel mode.

Processes of extraction, production processing, and storage before importing LNG to Korea are included. Since NG also uses GREET, it is necessary to analyze additional information by importing the country later. Based on GREET, energy use: 59,287 kJ / GJ. GHGs emission results: 12606 $gCO_2$ / GJ. In the natural gas processing step, energy use is 4510 kJ/GJ, and GHGs emission result is 34,741$gCO_2$/GJ. In the transportation step, GREET only provides a specification of oil tankers that transport crude oil, so we use the same value as well. Because LNG carriers generate electricity and heat from vented gases, they are expected to emit fewer emissions than diesel ships. The results are 19,646 kJ/GJ and 1643.8$gCO_2$/GJ. In the storage, re-gasification, and distribution step, the data are not accumulated enough to evaluate, so we use the value in GREET. The values are 15,478 kJ/GJ and 1904$gCO_2$/GJ.

For LNG, the well-to-pump result of energy use is 194.8 kJ/MJ, and GHG emissions are 19.75 g/MJ. In the pump-to-hull step, the GHG emission result is 56.5 g/MJ in gas mode.

In **Figures 5**–7, all the results of WTP are organized to be comprehensive. In the case of well to pump (WTP), LNG has higher energy consumption and GHGs emissions due to the addition of processes such as compressed gas and re-liquefaction, as

| | Residual oil | Marine Distillate | Low suffer Marine Distillate |
|---|---|---|---|
| Energy use(kJ/MJ) | 152.1 | 202.8 | 202.8 |
| GHG emissions(g/MJ) | 13.74 | 16.77 | 16.78 |

**Table 2.**
*Well to pump results in marine fuel.*

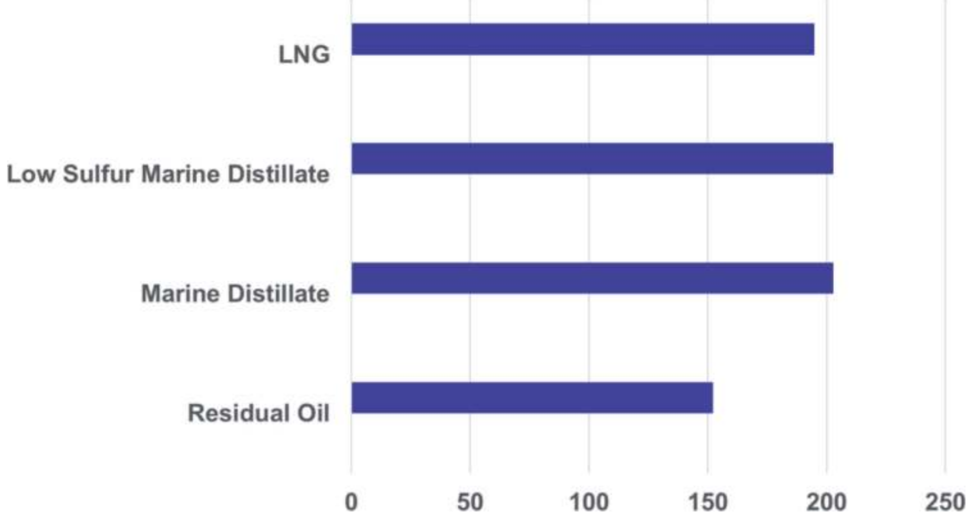


**Figure 5.**
*Marine fuel WTP energy usage results (kJ/MJ).*

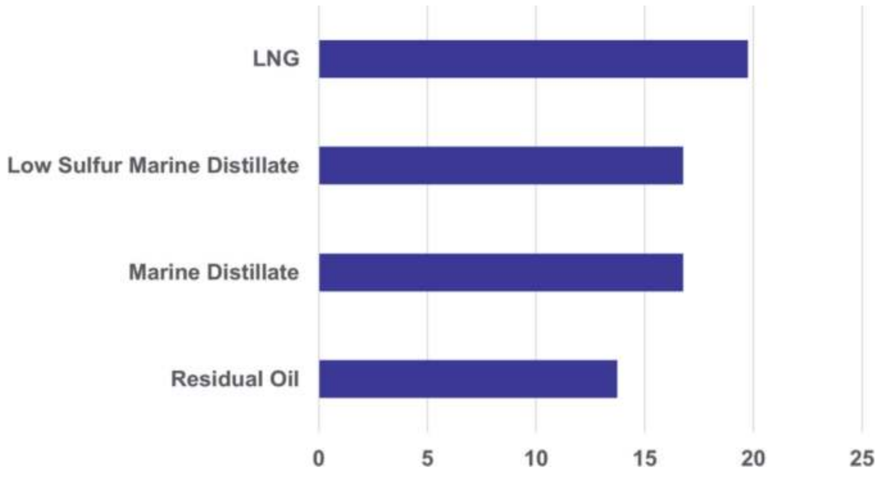


**Figure 6.**
*Marine fuel WTP GHG emissions results (g/MJ).*

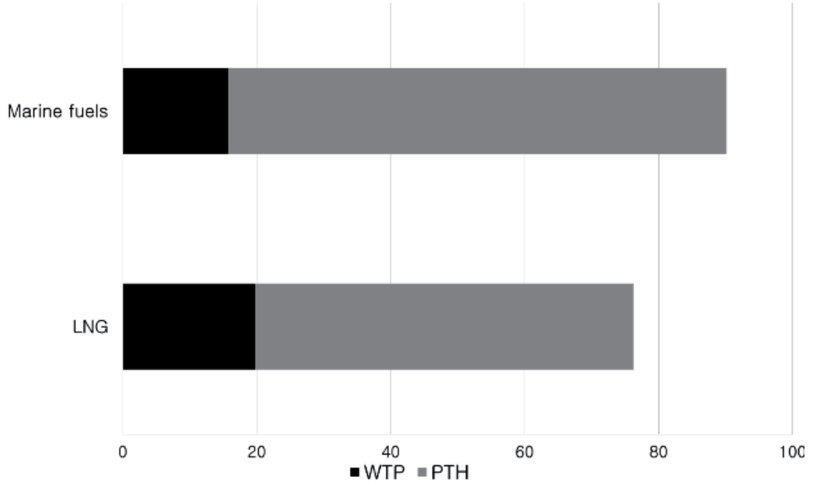


**Figure 7.**
*Marine fuel WTH GHG emissions results (g/MJ).*

well as the amount of gas discharged during production compared to marine fuels such as residual oil and marine distillate. Energy consumption data in PTH CANNOT have been obtained from Ilshin. However, it is considered that the energy consumption of LNG is higher because of use to boil-off-gas re-liquefaction. For pump to hull (PTH), GHGs emissions from operations are far above the WTP process.

## 4. Conclusions

The research was carried out to investigate the environmental impacts of LNG as fuel, comparing marine fuels. LCA analysis shows that natural gas produces more GHGs in WTP compared to liquid fuel for ships, but fewer in PTH. In the case of pump to hull (PTH), the energy consumption and GHG emissions in operation far exceed the WTP process due to the nature of ships that must cross the Pacific. Therefore, LNG, which emits less GHGs than diesel, is thought to be much better than diesel in terms of the environment but may differ from actual operating conditions, so engine experiments and additional data are needed to confirm in the future.

In South Korea, both natural gas and marine fuels depend on imports, so GHG emissions from WTP are relatively low. To satisfy the IMO regulations, the exhaust gas generated during ship operation (PTH) should be managed in a focused manner. Therefore, the amount of exhaust gas generated during operation is less than that of marine fuel, so it is considered to be suitable for satisfying environmental regulations. However, more detailed comparisons are needed between engine efficiency and operating costs (price, storage costs, safety management costs, etc.) compared to diesel. However, the emissions from WTP in LNG, which is higher than marine fuels could not be ignored.

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## References

[1] Ole Vidar Nilsen. DNV GL-LNG Fueled Vessels n.d. www.golng.eu%2Ffiles%2FMain%2F20180417%2F2.%2520Ole%2520Vidar%2520Nilsen%2520-%2520DNV%2520GL.pdf&usg=AOvVaw1Ln

[2] Ministry of Land, Infrastructure, Transport and T of J. VI. Operation Guidelines for Truck to Ship LNG Transfer [Purpose and Scope of Application] n.d

[3] Choi W, Song HH. Well-to-wheel analysis on greenhouse gas emission and energy use with natural gas in Korea. International Journal of Life Cycle Assessment. 2014;**19**:850-860. DOI: 10.1007/s11367-014-0704-7

[4] Heywood JB. Internal Combustion Engine Fundamentals. New York: McGraw-Hill Education; 1988

[5] NETL. Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels. Pittsburgh: National Energy Technology Laboratory; 2008. https://doi.org/DOE/NETL-2009/1346

[6] Laboratory AN. Argonne National Laboratory, GREET1 (Greenhouse gases, Regulated Emissions, and Energy use in transportation) transportation fuel cycle analysis model Version 2018 - Google Search n.d. https://www.google.com/search?safe=strict&biw=1920&bih=880&sxsrf=ALeKk02-6QVL0geYlLoZG0Glz3znnhQAhA%3A1615897616677&ei=EKRQYKXxKIf70gSf-qfQBA&q=Argonne+National+Laboratory%2C+GREET1+%28Greenhouse+gases%2C+Regulated+Emissions%2C+and+Energy+use+in+transport (accessed March 17, 2021)

[7] Jwa K, Lim O. Comparative life cycle assessment of lithium-ion battery electric bus and Diesel bus from well to wheel. Energy Procedia. 2018;**145**: 223-227. DOI: 10.1016/j.egypro.2018.04.039

[8] KEMCO. No Title n.d. http://www.petronet.co.kr/main2.j.