# Conceptual design of a Bay Tug powered by liquefied natural gas (LNG), as a strategy for the Naval energy transition

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## Abstract

Since the Industrial Revolution, fossil fuels have played a central role in global economic and industrial development. For more than two centuries, coal, oil, and natural gas have been the energy pillars powering our societies, providing the energy needed to light our cities, propelling our machines and moving our vehicles, among many other applications. However, this extraordinary development has not occurred without adverse consequences and significant environmental impacts. In this context of growing awareness of the devastating impacts of fossil fuels on the environment and the urgent need to move towards cleaner and more sustainable energy sources, Liquefied Natural Gas (LNG) emerges as a promising alternative for the global energy transition. In this scenario, the National Navy requires the implementation of environmentally sustainable, efficient, and effective technologies to fulfil its mission. This paper presents the conceptual design of an LNG-powered bay tug intended as a logistics support vessel for National Navy units, representing a milestone in the naval energy transition.

**Key words:** Liquefied natural gas, bay tug, energy transition, environmental sustainability, conceptual design, naval.

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## Introduction

Global maritime transport dates back to around 3500 BC, when it enabled the carriage of small loads and a limited number of crew members along short coastal routes *(Ocean Container Trading SL, 2018)*. However, it was not until the mid-19th century that coal began to be used as fuel for steamships, allowing vessels equipped with coal-powered engines to cross canals, seas, and oceans *(World History Encyclopedia, 2023)*. Subsequently, in 1887 and 1897, with the invention of the explosion engine and the combustion engine, respectively, coal was replaced by petroleum derivatives as marine fuels, a practice that has continued to the present day *(Petróleo, 2020)*.

The main source of pollution from maritime transport is that ocean-going vessels use highly polluting fossil fuels for propulsion, predominantly heavy fuel oil. This fuel contains high concentrations of sulfur, ash, heavy metals, and other toxic residues, which, during combustion, , in addition to $CO_2$, give off elevated levels of sulfur oxides (SOx), nitrogen oxides (NOx), and particulate matter (PM), pollutants that are highly hazardous to human health.

The International Maritime Organization (IMO) has developed a series of policies aimed at reducing greenhouse gas emissions from ships. In 2005, the International Convention for the Prevention of Pollution from Ships (MARPOL) entered into force. Later, in 2011, amendments to Annex VI of the MARPOL Convention were adopted through Resolution MEPC 62, which legally regulated the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. These measures demonstrate a strong global commitment to reducing greenhouse gas emissions, further reinforced in 2018 with the publication by the IMO of the document "Reduce Greenhouse Gas Emissions from International Shipping", which outlines the strategy to achieve the objective of zero greenhouse gas emissions from maritime transport throughout this century *(International Maritime Organization, 2024)*.

In Colombia, concerning environmental regulations aimed at reducing greenhouse gas emissions from maritime transport and the need to transition toward alternative energy sources through an efficient energy transition, Law 2099 (2021) was recently enacted, "whereby provisions are established for energy transition, the dynamization of the energy market, and the country's economic reactivation." Likewise, Law 2169 (2021) was established, "whereby low-carbon development of the country is promoted

**Fig. 1. Greenhouse gas emissions from a merchant vessel.**

**Source: https://es.mongabay.com/2023/07/acuerdos-para-reducir-las-emisiones-del-transporte-maritimo-son-considerados-debiles-oceanos.**

through the establishment of targets and minimum measures related to carbon neutrality and climate resilience."

In response to these regulations and in the search for alternative fuel sources in the international maritime sector, liquefied natural gas (LNG) has emerged as an effective and sustainable solution to meet global and national decarbonization objectives, contributing significantly to climate change mitigation and the protection of the marine environment. Nevertheless, it should be noted that natural gas is a fossil-based substance whose main component is methane, in proportions close to 90%. In addition, it contains fractions of gaseous hydrocarbons such as ethane, propane, butane, pentane, or hexane. The data presented below are expressed in millions of m³, measured at 15 °C and 760 mm Hg, and define the quality of natural gas as follows:

- Higher heating value (HHV), expressed in terajoules (TJ), is the heat released during the complete combustion of a unit volume of gas, considering the water produced by the reaction in the liquid state. Its values typically range between 9 and 11 TJ/m³.
- Lower heating value (LHV), expressed in Mtoe (1 million tons of oil equivalent = 41.868 GJ), corresponds to the heat released during the complete combustion of a unit volume of gas, considering the water produced by the reaction in the vapor state. The difference between the LHV and the HHV is the latent heat of vaporization of the water vapor generated during gas combustion. For natural gas, the lower heating value is approximately 10% lower than the higher heating value.
- The absolute density of natural gas under standard conditions ranges between 0.6 and 0.8 kg/m³. The density of LNG is 451 kg/m³, indicating that 1 m³ of LNG is approximately equivalent to 600 m³ of natural gas.

In Colombia, use of LNG began in 2016 with the creation and commissioning of the SPEC-LNG regasification plant, located in Cartagena de Indias. Its primary purpose is to ensure thermal power generation to support the national electricity supply. However, to date, LNG bunkering is not provided to any Colombian vessels, representing a market that has been largely neglected by the country and reflecting a technological evolution that lags behind the global landscape. National environmental regulations, along with the regulations established by the IMO, set guidelines of strict global compliance, one of which is the Climate Change Management Plan for Colombian Maritime Ports *(Ministry of Environment and Sustainable Development, Ministry of Transport, INVEMAR, 2016)*.

Based on the above, and intending to ensure environmental sustainability and contribute to the energy transition of the national naval sector, this study proposes the design of an LNG-powered harbor tug for the Bay of Cartagena de Indias, with a bollard pull of 30 tons in accordance with Annex B, "Tables for determining the minimum bollard pull capacity during assistance services" *(DIMAR, 2018)*. The proposed harbor tug is designed with a maximum speed of 13 knots, an overall length of 23 m, and an operational range of 500 nautical miles.

## Development

The sizing of the proposed tugboat was carried out using linear regression analyses based on a database of 15 tugboats with a length below 30 m and equipped with Schottel-type azimuthal propulsion. Additionally, the results were verified using the formulas described in the book "The Basic Design of the Merchant Ship" *(Alvariño, 1997)*. The results obtained are shown in Table 1.

Based on the dimensional sizing, the initial modeling was carried out using the Rhinoceros

**Table 1. Main dimensions of the proposed tugboat.**

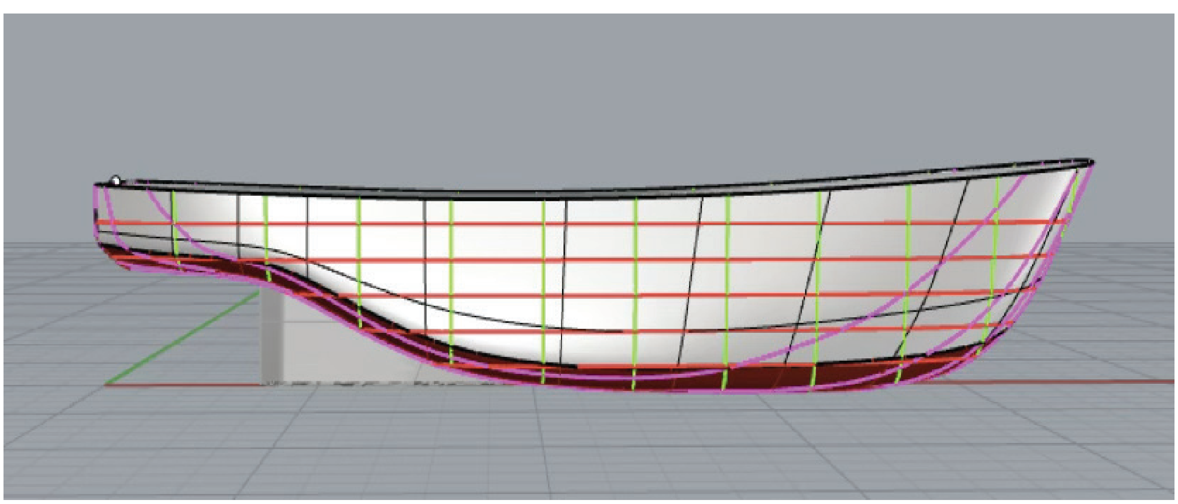
| BASIC CHARACTERISTICS OF THE TUG | |
|---|---|
| Type Of Tug | Coast and bay tug |
| Classification | Lloyd Register |
| Range | 500 Nautical miles |
| Propulsion | Azimuthal systems schottel rudder propeller |
| Machinery | 2 Dual fuel thrusters Lng/mdo |
| Main Fuel | Liquefied natural gas |
| Overall Length | 23 Meters |
| Bollard Pull | 30 Tons |
| Beam | 7.66 Meters |
| Depth | 3.83 Meters |
| Draft | 3.0 Meters |
| Installed Power | 1950 Kw |
| Displacement | 527 Tons |
| Block Coefficient | 0.508 Dimensionless |
| Maximum Speed | 13 Knots |
| Froude Number | 0.44 |

software. The model was subsequently imported into the Maxsurf software, where the resistance to forward motion was specifically evaluated, as well as the calculation of the required power as a function of speed. In the initial hull form, a keel shoe was included as a distinctive structural feature, providing protection to the aft azimuthal propulsion system and ensuring a favorable transverse righting arm.

The distinguishing aspect in the design of an LNG-propelled tugboat lies in the arrangement of the engine room. This process begins with the selection of the engines, either dual-fuel Diesel/LNG or engines dedicated exclusively to LNG, which also requires determining the volume of the liquefied natural gas storage tanks and the fuel supply system for the main machinery. DNV Rules, Part 6, “Gas installations for machinery fuel”, Chapter 13, published in January 2011, establishes the requirements and criteria to be considered in the design of a vessel’s engine room. Likewise, the IGC Code sets forth the applicable regulations for LNG storage tanks onboard ships. Additionally, according to Lloyd’s Register, the classification society applicable to this specific case, a series of regulations is available, including “Lloyd’s Register Rules for Natural Gas Fueled Ships” and “LNG as a marine bunker fuel.”

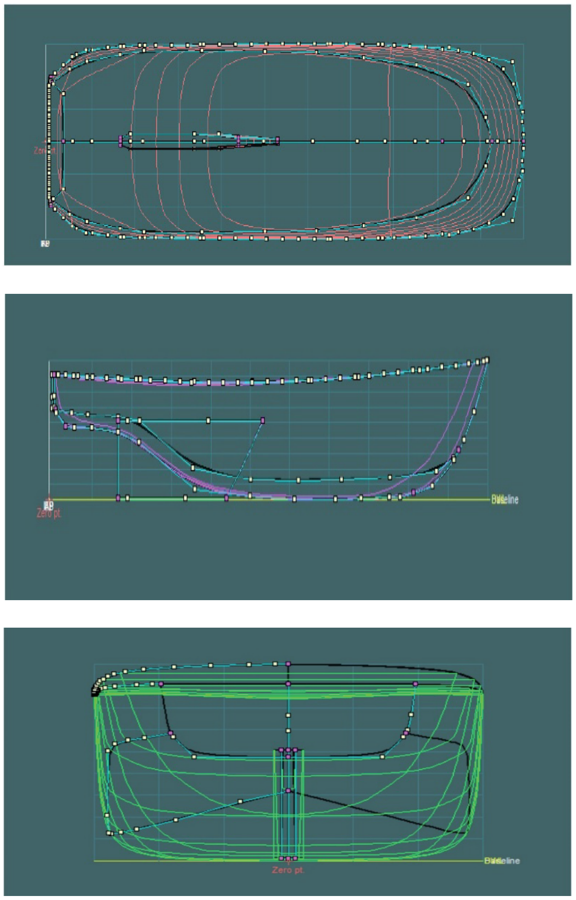
In compliance with the regulations established by both the classification society and the International Maritime Organization, the

**Fig. 2. Dimensional modeling of the proposed tugboat.**



**Source: Authors’ own work using the Rhinoceros software.**

**Fig. 3. Hull form lines modeling of the proposed tugboat.**



**Source: Authors' own work using the Maxsurf software.**

propulsion machinery for the proposed tugboat was selected based on the power calculations obtained through linear regression and the formulas described in the book "The Basic Design of the Merchant Ship" *(Alvariño, 1997)*.

For a bollard pull of 30 tons, a power of 1955 kW is obtained from the regression analysis. When calculating the preliminary power using the formula provided in the book "The Basic Design of the Merchant Ship", the following result is obtained:

$$PB\,(KW) = K1 * TPF \quad (1)$$

Where:

*PB:* Installed power
*K1:* Constant according to the type of propulsion.
*TPF:* Bollard pull

For the proposed tugboat:

$$PB = 55 * 30 = 1650\,KW$$

$$PB = 60 * 30 = 1800\,KW$$

Therefore, based on the regression analyses and the formulas applied, an analytical power range between 1800 kW and 1955 kW can be estimated. According to the calculated power requirements and after reviewing the engines available on the market, the Wärtsilä 8L20DF engine was selected, with a rated power of 1580 kW. Its main advantage is the LNGPac, defined as an integrated system that includes the bunkering station, the LNG storage tank and tank connection space, the processing and heating equipment, as well as the control and monitoring system.

Once the total installed power of 2,686 kW at an MCR of 85%, corresponding to two Wärtsilä 8L20DF engines, was defined, the operational autonomy in terms of fuel consumption hours under maximum-power towing conditions was calculated based on the LNG storage tank capacity.

$$BSEC = 7.700\,\frac{KJ}{KW}.h$$

According to the engine technical datasheet.

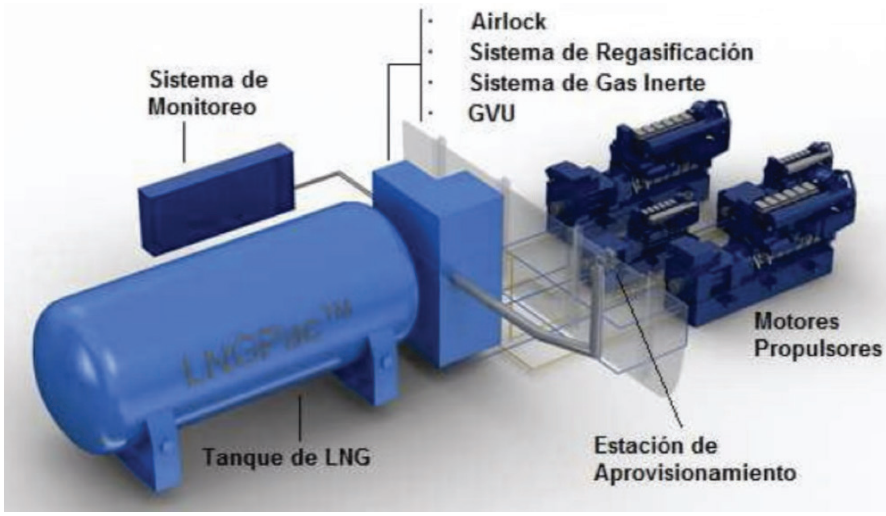
$$LHV = 49.165\,\frac{KJ}{Kg}$$

$$Hourly\ fuel\ consumption = \frac{7.700}{49.165} = 0{,}1566\,\frac{kg}{kw}.h$$

$$Hourly\ fuel\ consumption = 0{,}1566\,\frac{kg}{kw}.$$

$$h * 2.686\,kw = 420{,}6\,kg/h$$

**Fig. 4. Schematic of the Wärtsilä LNGPac system.**




For a storage capacity of 40 m³, according to the onboard tank capacity and an LNG density of 451 kg/m³ (once natural gas is liquefied at an approximate temperature of −160 °C, its volume is reduced by a factor of about 600).

$$LNG\ Mass = 451\ \frac{kg}{m3} * 40\,m3$$

$$LNG\ Mass = 18.040\ Kg$$

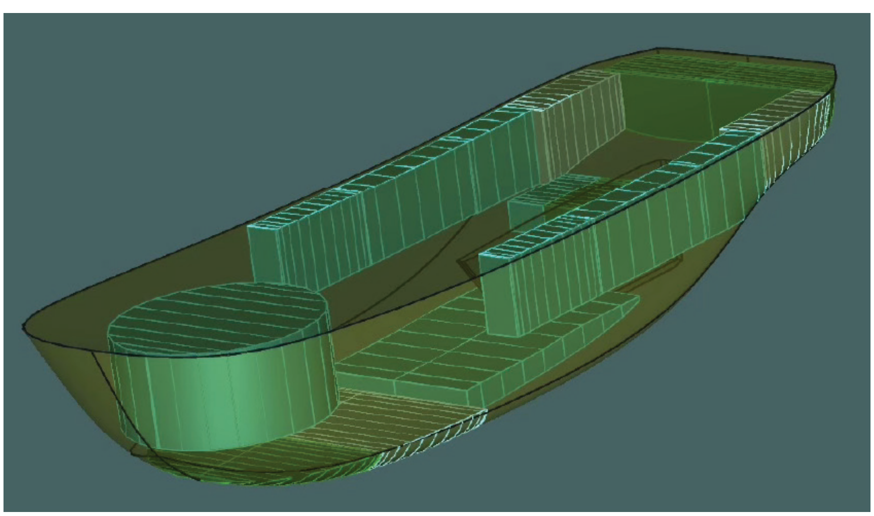
Which, when divided by the previously calculated fuel consumption, yields the following operational autonomy in hours of navigation:

$$LNG - based\ \ operational\ \ autonomy = 18040 / 420{,}6$$

$$LNG - based\ \ operational\ \ autonomy = 42{,}9\ \ horas$$

This value was calculated based on the maximum towing power according to the propulsion machinery installed onboard the proposed tugboat, thus satisfactorily complying with all previously established requirements.

**Fig. 5. Tank arrangement of the proposed tugboat.**



**Source: Authors' own work using the Maxsurf software.**

## Conclusions

The commissioning and implementation of an LNG-powered harbor tug in the Port of Cartagena offers a series of significant benefits. First, it represents an effective and sustainable solution for meeting national decarbonization objectives. By using LNG as fuel, vessels can drastically reduce carbon emissions, thereby contributing significantly to climate change mitigation and the protection of the marine environment.

Additionally, the transition to LNG provides an immediate reduction in $CO_2$ emissions of up to 30% compared to conventional fuels. This decrease has a positive impact on both local and global levels, as it helps improve air quality in urban areas and reduce the country's carbon footprint. The adoption of LNG on national port tugboats allows Colombia to take a first step toward fulfilling its environmental commitments and positions the country in the search for innovative and sustainable solutions for maritime transport. The energy efficiency of LNG and its availability in the international market will help reduce vessel operating costs, increase competitiveness, and improve long-term profitability. Likewise, by promoting LNG demand, the country will foster the development of a robust and diversified local supply chain, while generating employment and promoting economic growth.

Despite the benefits offered by LNG, its implementation in harbor tugboats poses significant challenges, particularly regarding the availability of adequate infrastructure for the safe and efficient storage, handling, and distribution of LNG. This requires substantial investments in terminals, storage tanks, regasification systems, and cargo-handling equipment, as well as in training and capacity building for specialized personnel, the implementation of strict safety standards, and the establishment of emergency response protocols. In conclusion, LNG should be thoroughly studied, analyzed, and implemented in port tugboats, prioritizing projects aimed at their adaptation as marine fuel and thereby promoting the country's energy transition within the Colombian maritime transport sector.

## Contributions

- Ricardo Navarro Rodríguez: Contribution (Conceptualization, methodology, manuscript writing, data analysis)
- José Rengifo Dávila: Contribution (Validation, manuscript review)
- José María Riola: Contribution (Supervision, final editing)

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